LUMBOSACRAL TRANSITIONAL VERTEBRAE:



FROM DEVELOPMENT TO CLINICAL PRACTICE AND DIAGNOSTIC PRECISION

DRS. B.J.F. LIEBRAND

RADBOUD UNIVERSITY PRESS

Lumbosacral Transitional Vertebrae: From Development to Clinical Practice and Diagnostic Precision

drs. B.J.F. Liebrand

drs. B.J.F. Liebrand
Lumbosacral Transitional Vertebrae: From Development to Clinical Practice and Diagnostic Precision

Radboud Dissertation Series
ISSN: 2950-2772 (Online); 2950-2780 (Print)

Published by RADBOUD UNIVERSITY PRESS
Postbus 9100, 6500 HA Nijmegen, The Netherlands
www.radbouduniversitypress.nl

Design: ProefschriftOntwerp.nl
Cover image: ProefschriftOntwerp.nl
Printing: ProefschriftMaken/Pumbo

ISBN: 9789465153292
DOI: 10.54195/9789465153292
Free download at: https://doi.org/10.54195/9789465153292

© 2026 drs. B.J.F. Liebrand

RADBOUD
UNIVERSITY
PRESS

This is an Open Access book published under the terms of Creative Commons Attribution-Noncommercial-NoDerivatives International license (CC BY-NC-ND 4.0). This license allows reusers to copy and distribute the material in any medium or format in unadapted form only, for noncommercial purposes only, and only so long as attribution is given to the creator, see http://creativecommons.org/licenses/by-nc-nd/4.0/.

Lumbosacral Transitional Vertebrae: From Development to Clinical Practice and Diagnostic Precision

Dissertation to obtain the degree of doctor
from Radboud University Nijmegen
on the authority of the Rector Magnificus prof. dr. J.M. Sanders,
according to the decision of the Doctoral Board
to be defended in public on

Thursday, December 3, 2026
at 10:30 a.m.

by

Bart Johan Frederik Liebrand
born on June 23, 1970
in Haaksbergen (the Netherlands)

Supervisors:

Prof. dr. K.C.P. Vissers

Prof. dr. J.H.M. Van Zundert (Maastricht University)

Co-supervisors:

Dr. S.E.I. van der Wal

Dr. W. van der Weegen (Anna Hospital)

Manuscript Committee:

Prof. dr. J.J. Fütterer

Prof. dr. P.C. Willems (Maastricht University)

Dr. M.B. Berrevoets-Aerts (Anna Hospital)

Lumbosacral Transitional Vertebrae: From Development to Clinical Practice and Diagnostic Precision

Proefschrift ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. dr. J.M. Sanders,
volgens besluit van het college voor promoties
in het openbaar te verdedigen op

donderdag 3 december 2026
om 10.30 uur precies

door

Bart Johan Frederik Liebrand
geboren op 23 juni 1970
te Haaksbergen

Promotoren:

Prof. dr. K.C.P. Vissers

Prof. dr. J.H.M. Van Zundert (Universiteit Maastricht)

Copromotoren:

Dr. S.E.I. van der Wal

Dr. W. van der Weegen (Anna Ziekenhuis)

Manuscriptcommissie:

Prof. dr. J.J. Fütterer

Prof. dr. P.C. Willems (Universiteit Maastricht)

Dr. M.B. Berrevoets-Aerts (Anna Ziekenhuis)

Table of contents

Chapter 1	General Introduction	11
Chapter 2	Diagnostic and Treatment Pitfalls in a Patient with Lumbosacral Transitional Vertebrae: A Real-life Case Based Review.	31
Chapter 3	Diagnostic treatment level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies.	45
Chapter 4	Diagnostic Precision in Lumbar Radiculopathy: Impact of Transitional Vertebrae on Treatment Level Selection and Outcomes	61
Chapter 5	Accuracy in Spinal Level Determination, Including Transitional Vertebrae: An ASReview supported Systematic Review.	79
Chapter 6	Real-Life level Identification accuracy study in patients with lumbosacral transitional vertebrae.	111
Chapter 7	Transitional Vertebrae and Numerical Variations: Two Distinct Embryological Mechanisms with Radiological Implications for Vertebral Level Identification.	129
Chapter 8	General Discussion	147
Chapter 9	Summary in English and Dutch of the thesis	165
Chapter 10	Research data management	175
Chapter 11	Acknowledgements / Dankwoord	181
Chapter 12	Curriculum Vitae	187
Chapter 13	Portfolio	191
Abbreviations		197



Chapter 1

General Introduction

§1.1 General introduction

Low back pain is a highly prevalent disease and leading cause of disability worldwide (1, 2). The lifetime prevalence estimates reaching up to 70–80% in the general population. In the Netherlands, the prevalence lies around 17.2 per 1,000 person-years and incidence of 9.4 per 1,000 person-years. About half of these cases are clinically classified as radiculopathy, underscoring that true nerve root involvement constitutes a significant proportion of presentations in Dutch primary care (3).

Patients with lumbosacral radicular pain typically first present to primary care, where a majority of patients improve with conservative management in accordance with the guidelines of the Dutch College of General Practitioners and National Institute for Health and Care Excellence (4). However, about 40% of these patients present with persistent symptoms despite first-line therapy and will be referred to specialized neurological centers for further diagnostics and, when indicated, interventional treatment within a Pain Management Department (PMD) (3). In these referrals, often a request for diagnosis and treatment at a specific spinal level is made based on the patient's clinical neurological presentation and the findings described in the MRI report.

The human spine typically consists of seven cervical, twelve thoracic, and five lumbar vertebrae. However, some patients exhibit transitional anatomy—a congenital variant where a vertebra displays characteristics of two distinct spinal regions. Present in approximately 10% of individuals with lumboradicular pain, these variations can lead to ambiguous or incorrect level identification during clinical assessment and incorrect treatment in spine procedures for back and radicular pain (5-11) . To emphasize the extent of the wrong level treatment, half of American neurosurgeons have reported performing at least one wrong-level surgery during their careers (6). The interventional pain medicine literature addressing this problem is however very limited until now.

Standardized MRI protocols for patients with lumboradicular pain generally include only limited sagittal and transverse sequences and often assume that the lowest lumbar vertebra represents L5. As a result, lumbosacral transitional vertebrae (LSTV) are frequently not identified and therefore not mentioned in the initial radiological assessment report. Consequently, the presence of an LSTV is often only identified during fluoroscopic procedures performed in the PMD. If this LSTV is recognized during this interventional procedure, uncertainty about the correct vertebral level arises and a complicated process of accurately targeting the intended treatment level start

§1.2 Introduction to transitional vertebrae

Thoracolumbar transitional vertebrae (TLTV) have a prevalence of 3.5-10.9 % in the population and may result in eleven or thirteen thoracic vertebrae (12-16). These patients also have a greater chance of a lumbosacral transitional vertebrae (LSTV) (17). LSTV may result in four or six lumbar vertebrae (15, 17). The average prevalence of an LSTV is even higher, namely 12.3-15.3% (range in different research populations 4.0-35.9) (18, 19). The Castellvi classification is used to determine the type of LSTV displayed in Figure 1 (20).

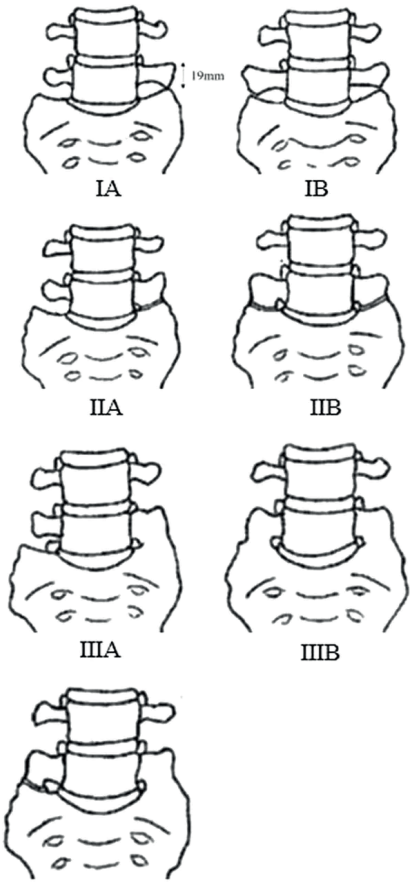


Figure 1 (20)**:** Castellvi classification: (1) Type Ia (unilateral) and Ib (bilateral): dysplastic, triangular-shape transverse processes measuring at least 19 mm. (2) Type IIa (unilateral) and IIb (bilateral): incomplete lumbarization/sacralization due to diarthrodial joint between the enlarged transverse process(es) and sacrum. (3) Type IIIa (unilateral) and IIIb (bilateral) with complete lumbarization/sacralization due to the total bony union of transverse processes to the sacrum. (4) Type IV: mixed unilateral type II and contralateral type III. (Permission asked from the publisher)

The transverse processes and corpus of the lowest lumbar vertebra may be fused with the sacrum (sacralization), or the upper sacral segment may be defused from the sacrum (lumbarization) (21). Due to transitional vertebrae, a total of 23, 24 or 25 mobile vertebrae and seven combinations of thoracic and lumbar vertebra can exist (14-17). Variations at the sacrococcygeal border do exist as well and border shifts are more commonly observed in the lower regions of the spine, particularly at the lumbosacral and sacrococcygeal junctions (21). In their research on segmentation anomalies in the human sacrum, Krenn et al. found that sacralizations of the coccyx frequently occurred in conjunction with lumbarizations (21). The anatomical variations are displayed in figure 2. The consequence of all these segmentation anomalies is the challenge of correct numbering of the vertebrae.

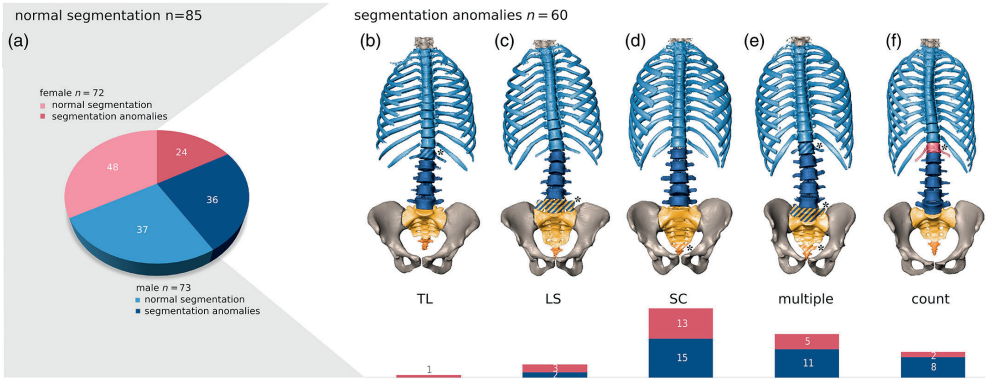


Figure 2: Typical segmentation anomalies. (a) Frequencies of various types of segmentation anomalies at different levels of the spine are shown as pie charts differentiated by sexes (blue, male; red, female). Typical configurations of the spine associated with segmentation anomalies at the (b) thoracolumbar (TL), (c) lumbosacral (LS), (d) sacrococcygeal (SC) level, (e) Multiple border shifts, and (f) true numerical (i.e., meristic) aberrations (count). Corresponding frequency bar charts are shown at the bottom. Out of 145 individuals, 85 possessed the typical spinal count of 12 thoracic (T), 5 lumbar (L), and 5 sacral (S) vertebrae and 60 expressed some type of segmentation anomaly (11–13 T, 4–6 L, and 4–6 S). Transitional vertebrae are marked by a diagonal patterning and an asterisk (American Journal of Biological Anthropology, Volume: 177, Issue: 4, Pages: 690-707, First published: 29 December 2021, DOI: (10.1002/ajpa.24466) (Figure published with approval of the author (21), published under CC BY-NC 4.0, no changes applied)

Embryology and the origin of transitional vertebrae

Although not investigated in this thesis, understanding the origin of transitional vertebrae and insight in the development of the vertebral column, a process called somitogenesis in the early embryonal period (22), can be helpful. Spinal embryonic development occurs in six stages (23). It begins with gastrulation (week 2), forming the three germ layers- ectoderm, mesoderm, and endoderm- and the notochord (precursor for the intervertebral discs) (24). Subsequently, the segmentation clock regulates the formation of 42–44 pairs of somites along the craniocaudal axis by week 5 (24, 25). Fig. 3 presents an electron micrograph of the three germ layers (26).

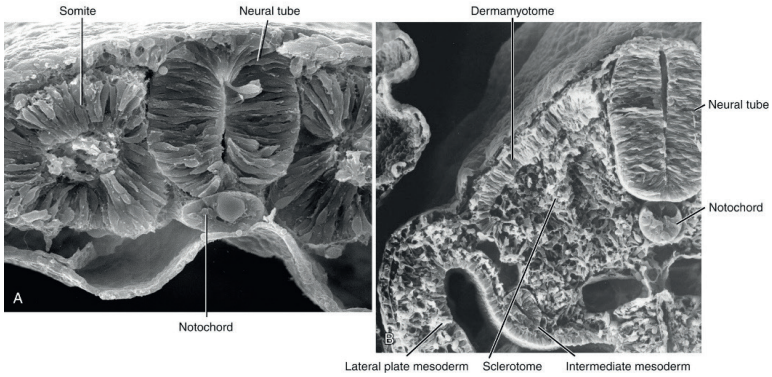


Figure 3: fig 4.25 chp 4 page 101. With permission of the publisher.

There are 4 occipital, 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 8 to 10 coccygeal pairs. The first occipital and five to seven coccygeal somites will disappear. The number of somites that are formed in a given species are highly constrained but not fixed (27). In the third stage, somites reorganize into the dermomyotome and sclerotome, providing the basis for the axial skeleton (26). This is followed by resegmentation (stage 4), where sclerotomal cells recombine around the neural tube to form definitive vertebrae (23-25, 28), see Fig. 4. (25). Finally, chondrification (stage 5) and ossification (stage 6) begin, with primary centers appearing in week 8 and secondary centers fusing by adolescence (24, 25).

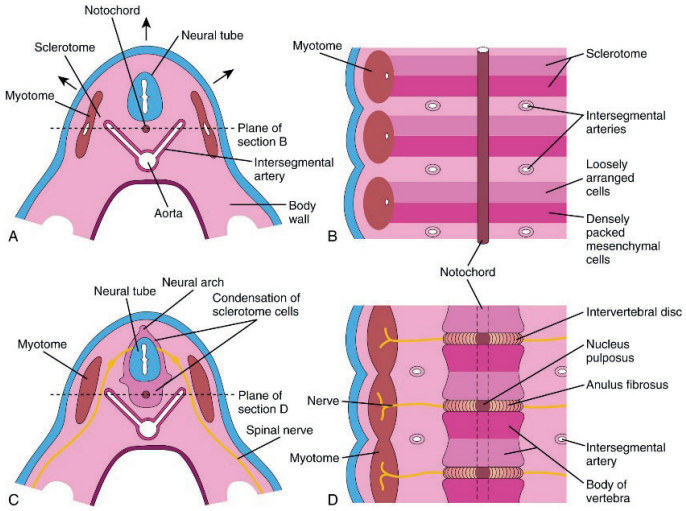


Figure 4. Page 321 fig 14.6. With permission of the publisher.

Genetics and the origin of transitional vertebrae

The subdivision into cervical, thoracic, lumbar, and caudal regions is controlled by a set of transcription factors located on the so-called Hox genes (22). The 39 hox genes are distributed in four clusters A-D, subdivided in 13 groups (figure 5) and located on chromosomes 7, 17, 12, and 2, respectively (29).

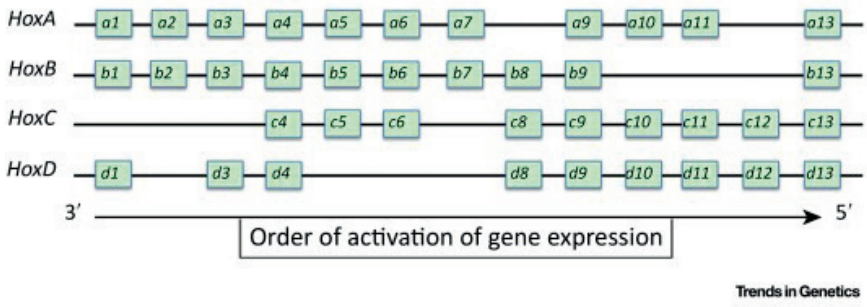


Figure 5: Basic Structure of the Mammalian *Hox* Clusters (30).
(Permission asked form the publisher)

Hox genes, activated during gastrulation, dictate vertebral identity and segmentation, with specific Hox10 and Hox11 expression patterns regulating the thoracolumbar and lumbosacral transitions respectively (22, 31-33). Disruptions in this hierarchical, colinear system can result in transitional vertebrae or variations in vertebral number (22, 23). The expression of Hox 10 genes controls the transition between the thoracic and lumbar regions and inhibits the development of thoracic ribs in the lumbar to sacral regions (31-33) The Hox 11 genes control the lumbosacral transition (31-33). While studies in mice have confirmed these mechanisms, a direct genetic link to human transitional vertebrae remains unconfirmed (31-33).

§1.3 History of anatomical level determination in patients with transitional vertebrae

One of the earliest studies highlighting challenges with level determination at transitional spinal junctions was conducted by Wigh et al. (34). Since the first documented mention of wrong-level surgery in 1976 (35), numerous studies have addressed this problem. A literature search (March 2026) for “accurate level determination of the spine” yielded 1,252 studies, while “wrong level surgery spine” returned to 187 results (Appendix 1). This growing body of literature underscores the ongoing challenges associated with accurate level identification and the prevention of wrong-level surgery.

Four systematic reviews, published between 2010 and 2024, provide valuable insights on this topic. Longo et al (2012) focused on the incidence, prevalence and prevention strategies of wrong-level surgery, identifying 12 relevant publications for full review (7). They concluded that no clear estimate of the incidence of wrong-level or wrong-site spinal surgery could be determined due to heterogeneity of the included studies, preventing an analysis of pooled data. Furthermore, the analyzed protocols did not fully prevent wrong-level determination, highlighting the need for improved prevention strategies.

Devine et al. (2010) reported a wrong-site surgery rate ranging from 0.09 to 4.5 per 10,000 surgeries (36). This review evaluated The Joint Commission Universal Protocol but found insufficient evidence in the literature supporting its effectiveness in reducing wrong-level or wrong-site spinal surgeries. They recommended intraoperative imaging after exposure and marking of fixed anatomical landmarks as a necessary step to minimize the risk of these errors. In a subsequent update (2020), Devine et al. reaffirmed that although the rate of wrong-level surgery remained low, it continuous to pose a potentially devastating problem (37).

Strong et al. (2022) reviewed various techniques for level determination in spine surgery, including preoperative percutaneous fiducial metallic marker-, metallic coil-, marking wire- and polymethylmethacrylate placement, preoperative injecting methylene blue, intraoperative spinal navigation and intraoperative devices (38). No single technique was found to be superior. Instead, they recommended using these techniques or combinations, to minimize the risk of wrong-level surgery, especially in cases where fluoroscopy may be unreliable.

Albano et al (2024) specifically examined surgical considerations for lumbar spine cases involving LSTV (5). They found that 1.3% of patients had wrong level surgery, requiring adaption of the current procedure or repeated surgery. When cases involving bony resection of a variant lumbar vertebra, pseudoarthrosis or transverse process were excluded, the rate of wrong site surgery increased to 8.5%. This may result from inaccurate localization preoperatively during the

planning stage. The findings emphasize the importance of thorough preoperative assessment of LSTV to mitigate surgical risks, including wrong-level procedures (5).

In summary, wrong-level spine procedures continue to occur, and transitional vertebrae represent a significant risk factor. A golden standard approach was presented by Lian et all. (39), recommending that sagittal whole-spine imaging should be included when performing a lumbar MRI. This method enables accurate numbering of transitional vertebral segments by counting caudally from C2, as no other reliable technique currently exists. This is supported in the recent literature by Sabri et al. (2025) who analyzed full spine radiographs in 3147 patients (40). Systematic reviews provide substantial insight, but they have mainly been conducted within the field of spinal surgery. In pain medicine, the number of spinal interventions is likely far higher compared to spinal surgeries, yet we have virtually no understanding of the role or prevalence of LSTV in this domain. Since most references were from the surgical field, it is imperative to understand what happens in percutaneous pain interventional procedures.

§1.4 Factors influencing level determination in patients with transitional vertebrae

Correct level determination in patients with transitional vertebrae is a clinical and anatomical challenge in daily practice of interventional procedures. Specific factors of influence are the clinical decision making process (41), altered anatomy (42-46), standard MRI protocols diagnosing neurologic lumbosacral radicular pain with limited sagittal and axial images (47, 48), different nomenclature and approaches between involved physicians (41) and counting processes between MRI and fluoroscopy during procedures (48) (49).

1.4.1 Clinical findings vs. diagnostic image studies

Nakagawa were the first (2017) to evaluate how LSTV affects the diagnosis in lumbar spine disorders and included 71 LSTV cases out of 550 patients (12.9%) (50). The number of vertebrae was miscounted in 38 cases (54%). Possible influencing factors discussed were the hypoplastic or absent 12^{th} rib, the unreliability of common landmarks used for level determination at the lower lumbar spine and lumbosacral transition and, the ambiguous correspondence between neurological findings and imaging studies due to the functional anomaly of the nerve root in these patients.

1.4.2 Altered spine anatomy

As discussed in paragraph 1.2 TV might change the standard spine anatomy. The seven possible combinations of the number of mobile vertebrae leads to miscounting when whole spine images are unavailable. Within the transitional anatomical variants, cervical ribs, supra-nummary ribs of the seventh cervical vertebra with a prevalence of 1.1% in the population, should be included

(51). In the literature a broad accepted consensus exists however about the attachment of the cervical rib to the seventh cervical vertebrae in the human spine (52), therefore non-influencing the counting and level determination process. Therefore, the cervicothoracic transition was not studied in this thesis.

1.4.3 Limited MRI protocols

Standardized MRI protocols for patients with lumboradicular pain typically assume the lowest lumbar vertebra to be L5, which can lead to inaccuracies in spinal level identification within this patient population (53, 54). A similar protocol is followed in Dutch hospitals, where radiologists begin vertebral counting at the presumed fifth lumbar vertebra. This is done with patients in the supine position, using the mid-sagittal MRI image for reference (47).

1.4.4 Differences in level determination during treatment procedures

Treatment approach between the involved physicians, but also differences in used terminology cause inconsistencies (41). Berger et al. analyzed the process of ordering lumbar transforaminal epidural steroid injections. Multiple inconsistencies were identified at various phases such as differences between the levels written on the injection order form and seen during intra-operative fluoroscopy. This suggests a significantly higher incidence of wrong-site and near-miss procedures than previously reported.

1.4.5 Differences in counting between specialties

Interventional pain specialists perform lumbar level determination using fluoroscopic guidance in a posterior-anterior view and start counting from T12 with the lowest rib bearing vertebrae, caudally (55). Radiologists count form L5 cranially in the mid-sagittal image of the MRI (47). Berger et al. stated that the idea behind standardization of certain medical practices is the foundation to preventing medical errors. (41).

Several surveys in the literature support these various factors contributing to the risk of wrong-level treatment (6, 56-58). It is important to note that wrong-level exposure refers to the exposure of a spinal level other than the intended pathological level; however, this does not necessarily imply that the actual treatment was performed at the incorrect level (36). A term that more accurately reflects clinical reality in pain medicine is ‘inappropriate level.’

§1.5 Outline of the thesis

The aim of this thesis was to analyze inconsistencies in level determination across referral documentation, MRI reports, and interventional procedures, as well as to assess the clinical implications of these discrepancies in pain medicine. We sought to find scientific support for these inconsistencies. Could they also be systematically identified with our colleagues

of our national, or international pain societies? Furthermore, we aimed to examine how interventionalists determine spinal levels during procedures and which methods they employ.

Therefore, we formulated the following research questions:

1. How are patients with a lumbosacral transitional vertebra identified?
   This question was addressed through a case-based review of the literature focusing on clinical decision-making and the diagnostic process in patients with LSTV and lumboradicular pain. Key clinical and radiological considerations relevant to patient identification are discussed, providing insights into daily clinical practice. This study is presented in Chapter 2.

2. What is currently known about invasive pain management in patients with lumbosacral transitional vertebrae?
   This question is addressed through an overview of the current state of knowledge on the management and treatment of patients with LSTV in the general introduction of this thesis, as well as in the introductions to Chapters 2, 3, and 4, and the discussion of Chapter 5. Furthermore, Chapters 3 and 4 offer new insights about level diagnosis and clinical consequences.

3. What are the accuracies of spine level determination methods, given the variability of transitional vertebrae?
   This question was investigated through a comprehensive systematic review conducted using PubMed, Web of Science, and Embase. The review evaluates the accuracy of both conventional and advanced methods of spinal level determination, including fluoroscopy, X-ray, ultrasound, CT, MRI, intraoperative navigation, 3D–2D algorithms, and deep learning models. The results are presented in Chapter 5.

4. Do the identified level inconsistencies found during interventional treatments occur locally, nationally, or internationally?
   This question was explored by comparing existing MRI protocols and diagnostic approaches at a regular second line accredited pain center in the Netherlands with the guidelines of the Dutch Society of Radiology, as well as with international practices in interventional pain management. The findings are discussed throughout the introductions and discussions of Chapters 2, 3, and 4. In addition, the systematic review in Chapter 5 includes an analysis of the countries represented in the literature, with a broader perspective provided in the discussion section. Chapter 6 displays a level accuracy study amongst Belgium and Dutch certified pain specialists.

5. Is it possible to improve the accuracy of spinal level identification in patients with lumbosacral transitional vertebrae?

This question is examined in the systematic review presented in Chapter 5. Potential improvements in diagnostic accuracy, including novel methodologies and recommendations for clinical practice, are discussed in detail in the discussion section of this chapter and the overall thesis.

To better understand the clinical consequences of an LSTV and to increase awareness among radiologists and interventionalists, the embryological origin of LSTVs is correlated with their possible radiological appearance in Chapter 7.

§1.6 References

1. Organisaion WH. World Health Organisation 2026 [Available from: https://www.who.int/.
2. Hartvigsen J, Hancock MJ, Kongsted A, Louw Q, Ferreira ML, Genevay S, et al. What low back pain is and why we need to pay attention. Lancet. 2018;391(10137):2356-67.
3. Spijker-Huiges A, Groenhof F, Winters JC, van Wijhe M, Groenier KH, van der Meer K. Radiating low back pain in general practice: incidence, prevalence, diagnosis, and long-term clinical course of illness. Scand J Prim Health Care. 2015;33(1):27-32.
4. Het Nederlands Huisartsen Genootschap 2026 [Available from: https://www.nhg.org.
5. Albano S, Brown NJ, Pennington Z, Nguyen A, Hsu TI, Pham MH, et al. Risks Associated with Surgical Management of Lumbosacral Transitional Vertebrae: Systematic Review of Surgical Considerations and Illustrative Case. World Neurosurg. 2024.
6. Mody MG, Nourbakhsh A, Stahl DL, Gibbs M, Alfawareh M, Garges KJ. The prevalence of wrong level surgery among spine surgeons. Spine. 2008;33(2):194-8.
7. Longo UG, Loppini M, Romeo G, Maffulli N, Denaro V. Errors of level in spinal surgery: an evidence-based systematic review. J Bone Joint Surg Br. 2012;94(11):1546-50.
8. Malanga GA, Cooke PM. Segmental anomaly leading to wrong level disc surgery in cauda equina syndrome. Pain physician. 2004;7(1):107-10.
9. Nakajima A, Usui A, Hosokai Y, Kawasumi Y, Abiko K, Funayama M, et al. The prevalence of morphological changes in the thoracolumbar spine on whole-spine computed tomographic images. Insights into imaging. 2013;5(1):77-83.
10. Yun S, Park S, Park JG, Huh JD, Shin YG, Yun JH. Spinal Enumeration by Morphologic Analysis of Spinal Variants: Comparison to Counting in a Cranial-To-Caudal Manner. Korean journal of radiology. 2018;19(6):1140-6.
11. Konin GP, Walz DM. Lumbosacral Transitional Vertebrae: Classification, Imaging Findings, and Clinical Relevance. American Journal of Neuroradiology. 2010;31(10):1778-86.
12. Carrino J, Campbell P, Lin D, Morrison W, Schweitzer M, Flanders A, et al. Effect of Spinal Segment Variants on Numbering Vertebral Levels at Lumbar MR Imaging. RADIOLOGY. 2011;259(1):196-202.
13. Hu Z, Zhang Z, Zhao Z, Zhu Z, Liu Z, Qiu Y. A neglected point in surgical treatment of adolescent idiopathic scoliosis: Variations in the number of vertebrae. Medicine (Baltimore). 2016;95(34):e4682.
14. Chiu CK, Chin TF, Chung WH, Chan CYW, Kwan MK. Variations in the Number of Vertebrae, Prevalence of Lumbosacral Transitional Vertebra and Prevalence of Cervical Rib Among Surgical Patients With Adolescent Idiopathic Scoliosis: An Analysis of 998 Radiographs. Spine. 2024;49(1):64-70.
15. Tatara Y, Niimura T, Sekiya T, Mihara H. Changes in Lumbosacral Anatomy and Vertebral Numbering in Patients with Thoracolumbar and/or Lumbosacral Transitional Vertebrae. JB JS Open Access. 2021;6(3).
16. Gonzales-Portillo GS, Rizvi O, Avila MJ, Dumont TM. The prevalence of 11 ribs and its potential implications in spine surgery. Clin Neurol Neurosurg. 2021;203:106544.
17. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, et al. The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul). 2020;15(1):103-10.

18. Jancuska JM, Spivak JM, Bendo JA. A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. International Journal of Spine Surgery. 2015;9:42.
19. Fang H, Wang J, Kiwale JC, Cui M, Zeng X, Yang C, et al. Prevalence, diagnosis, and clinical significance of lumbosacral transitional vertebrae: A systematic review and narrative analysis. Brain Spine. 2025;5:105628.
20. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine. 1984;9(5):493-5.
21. Krenn VA, Fornai C, Webb NM, Woodert MA, Prosch H, Haeusler M. The morphological consequences of segmentation anomalies in the human sacrum. Am J Biol Anthropol. 2022;177(4):690-707.
22. Iimura T, Denans N, Pourquié O. Establishment of Hox vertebral identities in the embryonic spine precursors. Curr Top Dev Biol. 2009;88:201-34.
23. Dias MS. Normal and abnormal development of the spine. Neurosurg Clin N Am. 2007;18(3):415-29.
24. Sadler TW. Langman's Medial Embryology. Fifteenth Edition ed: Wolters Kluwer; 2024.
25. KL Moore TP, MG Torchia. The Developing Human, Cl,inically Oriented Embryology. 11th ed: Elsevier; 2020.
26. GC Schoenwolf SB, PR Brauer, PH Franscis-West. Larsen's Human Embryology. Sixth ed: Elsevier; 2021.
27. Asher RJ, Lin KH, Kardjilov N, Hautier L. Variability and constraint in the mammalian vertebral column. J Evol Biol. 2011;24(5):1080-90.
28. Scaal M. Early development of the vertebral column. Semin Cell Dev Biol. 2016;49:83-91.
29. Lappin TR, Grier DG, Thompson A, Halliday HL. HOX genes: seductive science, mysterious mechanisms. Ulster Med J. 2006;75(1):23-31.
30. Mallo M. Reassessing the Role of Hox Genes during Vertebrate Development and Evolution. Trends Genet. 2018;34(3):209-17.
31. Carapuço M, Nóvoa A, Bobola N, Mallo M. Hox genes specify vertebral types in the presomitic mesoderm. Genes Dev. 2005;19(18):2116-21.
32. Guerreiro I, Casaca A, Nunes A, Monteiro S, Nóvoa A, Ferreira RB, et al. Regulatory role for a conserved motif adjacent to the homeodomain of Hox10 proteins. Development. 2012;139(15):2703-10.
33. Wellik DM, Capecchi MR. Hox10 and Hox11 genes are required to globally pattern the mammalian skeleton. Science. 2003;301(5631):363-7.
34. Wigh RE. The thoracolumbar and lumbosacral transitional junctions. Spine. 1980;5(3):215-22.
35. Pheasant H. Sources of failure in laminectomies. Orthop Clin North Am. 1975;6(1):319-29.
36. Devine J, Chutkan N, Norvell DC, Dettori JR. Avoiding wrong site surgery: a systematic review. Spine. 2010;35(9 Suppl):S28-36.
37. DeVine JG, Chutkan N, Gloystein D, Jackson K. An Update on Wrong-Site Spine Surgery. Global Spine J. 2020;10(1 Suppl):41s-4s.
38. Strong MJ, Santarosa J, Sullivan TP, Kazemi N, Joseph JR, Kashlan ON, et al. Pre- and intraoperative thoracic spine localization techniques: a systematic review. J Neurosurg Spine. 2022;36(5):792-9.
39. Lian J, Levine N, Cho W. A review of lumbosacral transitional vertebrae and associated vertebral numeration. Eur Spine J. 2018;27(5):995-1004.
40. Sabri SA, Laynes RA, Hoffman CJ, Chavarria JC, Prusick PJ, Weesner RE, et al. Implications of lumbosacral transitional anatomy on vertebral numbering: evaluation of 3147 adult full-length spine radiographs. Neurosurg Focus. 2025;58(6):E13.

41. Berger R, Bulloch L, Hysong A, Huggins B, Horan N, Van Der Noord R, et al. Establishing a common language for lumbar transforaminal epidural steroid injections. J Spine Surg. 2021;7(4):467-74.
42. Thawait GK, Chhabra A, Carrino JA. Spine segmentation and enumeration and normal variants. Radiol Clin North Am. 2012;50(4):587-98.
43. Neelakantan S, Anandarajan R, Shyam K, Philip B. Multimodality imaging in Bertolotti's syndrome: an important cause of low back pain in young adults. BMJ Case Rep. 2016;2016.
44. Chang HS, Nakagawa H. Altered function of lumbar nerve roots in patients with transitional lumbosacral vertebrae. Spine. 2004;29(15):1632-5; discussion 5.
45. Hinterdorfer P, Parsaei B, Stieglbauer K, Sonnberger M, Fischer J, Wurm G. Segmental innervation in lumbosacral transitional vertebrae (LSTV): a comparative clinical and intraoperative EMG study. Journal of Neurology, Neurosurgery & Psychiatry. 2010;81(7):734-41.
46. Kim YH, Lee PB, Lee CJ, Lee SC, Kim YC, Huh J. Dermatome variation of lumbosacral nerve roots in patients with transitional lumbosacral vertebrae. Anesthesia and analgesia. 2008;106(4):1279-83.
47. Robin Smithuis RdotRhiL, the Netherlands. . Lumbar Disc Herniation and other causes of nerve compression: Educational site of the Radiological Society of the Netherlands; 2014 [updated 2014-12-14. Available from: https://radiologyassistant.nl/neuroradiology/spine/lumbar-disc-herniation#mri-protocol.
48. Farshad-Amacker NA, Farshad M, Winklehner A, Andreisek G. MR imaging of degenerative disc disease. Eur J Radiol. 2015;84(9):1768-76.
49. Grimm BD, Laxer EB, Blessinger BJ, Rhyne AL, Darden BV. Wrong-Level Spine Surgery. JBJS reviews. 2014;2(3).
50. Nakagawa T, Hashimoto K, Tsubakino T, Hoshikawa T, Inawashiro T, Tanaka Y. Lumbosacral Transitional Vertebrae Cause Spinal Level Misconception in Surgeries for Degenerative Lumbar Spine Disorders. TOHOKU JOURNAL OF EXPERIMENTAL MEDICINE. 2017;242(3):223-8.
51. Henry BM, Vikse J, Sanna B, Taterra D, Gomulska M, Pękala PA, et al. Cervical Rib Prevalence and its Association with Thoracic Outlet Syndrome: A Meta-Analysis of 141 Studies with Surgical Considerations. World Neurosurg. 2018;110:e965-e78.
52. Brewin J, Hill M, Ellis H. The prevalence of cervical ribs in a London population. Clin Anat. 2009;22(3):331-6.
53. van der Windt DA, Simons E, Riphagen, II, Ammendolia C, Verhagen AP, Laslett M, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. The Cochrane database of systematic reviews. 2010(2):CD007431.
54. Liebrand B, Brakel K, Boon A, van der Weegen W, van der Wal S, Vissers KCP. Diagnostic treatment-level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies. Regional Anesthesia and Pain Medicine. 2022;47(3):177-82.
55. Fellow of Interventional Pain Practice (FIPP)® Examinations, provided by the World Institute of Pain [Available from: https://www.worldinstituteofpain.org/fipp-examination/.
56. Groff MW, Heller JE, Potts EA, Mummaneni PV, Shaffrey CI, Smith JS. A survey-based study of wrong-level lumbar spine surgery: the scope of the problem and current practices in place to help avoid these errors. World Neurosurg. 2013;79(3-4):585-92.
57. Mayer JE, Dang RP, Duarte Prieto GF, Cho SK, Qureshi SA, Hecht AC. Analysis of the techniques for thoracic- and lumbar-level localization during posterior spine surgery and the occurrence of wrong-level surgery: results from a national survey. Spine J. 2014;14(5):741-8.

58. Naqvi AZ, Magill H, Anjarwalla N. Intraoperative practices to prevent wrong-level spine surgery: a survey among 105 spine surgeons in the United Kingdom. Patient Saf Surg. 2022;16(1):6.

§1.7 Appendix 1: Search Strategies for Medline:

Accurate level determination spine.

Search	String	Hits
#1	("accurate"[All Fields] OR "accurately"[All Fields] OR "accurates"[All Fields]) AND ("level"[All Fields] OR "levels"[All Fields]) AND ("analysis"[MeSH Subheading] OR "analysis"[All Fields] OR "determination"[All Fields] OR "determinant"[All Fields] OR "determinants"[All Fields] OR "determinate"[All Fields] OR "determinated"[All Fields] OR "determinates"[All Fields] OR "determinating"[All Fields] OR "determinations"[All Fields] OR "determine"[All Fields] OR "determined"[All Fields] OR "determines"[All Fields] OR "determining"[All Fields]) AND ("spine"[MeSH Terms] OR "spine"[All Fields] OR "spines"[All Fields] OR "spine s"[All Fields]).	1252

Wrong level surgery spine.

Search	String	Hits
#2	("wrong"[All Fields] OR "wronged"[All Fields] OR "wrongful"[All Fields] OR "wrongfulness"[All Fields] OR "wronging"[All Fields] OR "wrongness"[All Fields] OR "wrongs"[All Fields]) AND ("level"[All Fields] OR "levels"[All Fields]) AND ("surgery"[MeSH Subheading] OR "surgery"[All Fields] OR "surgical procedures, operative"[MeSH Terms] OR ("surgical"[All Fields] AND "procedures"[All Fields] AND "operative"[All Fields]) OR "operative surgical procedures"[All Fields] OR "general surgery"[MeSH Terms] OR ("general"[All Fields] AND "surgery"[All Fields]) OR "general surgery"[All Fields] OR "surgery s"[All Fields] OR "surgerys"[All Fields] OR "surgeries"[All Fields]) AND ("spine"[MeSH Terms] OR "spine"[All Fields] OR "spines"[All Fields] OR "spine s"[All Fields]).	



Chapter 2

Diagnostic and Treatment Pitfalls in a Patient with Lumbosacral Transitional Vertebrae: A Real-life Case Based Review.

Liebrand B, van der Weegen W, Vissers K, Van Zundert J, van der Wal S.

(Submitted and under review Pain Physician)

§2.1 Abstract

This case-based review addresses the challenges encountered in diagnosing and treating patients with lumbosacral transitional vertebrae and lumboradiculair pain in interventional pain management. The possible pitfalls such as the discrepancies in diagnostic approaches, the complicated clinical decision-making process, the variability in fluoroscopic imaging techniques and the limitations of current MRI protocols may lead to misidentification of the correct treatment level and suboptimal outcomes. All case reports between 2000 and 2025 related to patients with lumbosacral transitional vertebrae and diagnostic ambiguities have been reviewed in PubMed and the Web of Science.

An evidence-based, standardized approach for vertebral level determination in the presence of anomalies is absent and improving communication between radiologists, neurologists, surgeons, and interventionalists is essential. Enhancing imaging quality during procedures, establishing clear counting protocols, and multidisciplinary collaboration may help reduce the risk of wrong-level interventions and improve patient outcomes.

§2.2 Introduction

Lumbosacral transitional vertebrae (LSTV) are anomalies of the lumbar spine with an average estimated prevalence of 12.3 % in the population (1). LSTV are classified according to the Castellvi classification (2). Four, five, or six lumbar vertebrae (LV) may be present in the lumbar spine (3-5). Four LV are often considered a sacralization, where the fifth LV is assimilated to the sacrum, and six a lumbarization. Tatara et al. recommended the vertebra below the Castellvi type-IIIb LSTV should be recognized as S1, but clinically it is better to recognize it as S2, highlighting the possible complexity of level determination in patients with LSTV (4).

Standardized MRI protocols in patients with lumboradiculair pain consider the lowest lumbar vertebra as L5 and level determination is therefore inaccurate in this patient group (6, 7). In Dutch hospitals a similar MRI protocol is used. Radiologists start counting at the supposed fifth lumbar level with patients in supine position, using the mid-sagittal image (8). The limited sagittal and transversal images prevent the diagnosis of an LSTV and frequently the first discovery occurs during fluoroscopy in the Pain Management Department (PMD).

Further inconsistencies arise due to differences in used terminology and treatment approach between the involved physicians (9). A systematic review describes 1.4 % wrong level surgical treatment in patients with LSTV (5). Several surveys in the literature underscore the existence of pitfalls and wrong level treatment (10-13). The possible consequences in interventional pain medicine are longer and more costly healthcare pathways (14)

This case based review of the literature (15) is the first to present the process of clinical discission-making, level determination and potential pitfalls during the treatment of a patient with an LSTV and lumboradiculair pain referred to the PMD. The literature of all case reports in PubMed and Web of Science has been reviewed. An informed consent was obtained from the patient concerning publication of the report and using the anonymized data.

§2.3 Case Presentation

A 55-year-old female patient was referred by her general practitioner to the neurology department with lower back pain radiating to the right leg, occurring throughout several weeks. Her medical history included decompression surgery with posterior lumbar interbody fusion (PLIF) at the L4-L5 level in 2022. A lumbar spine X-ray (Figure 1) revealed the presence of six lumbar vertebrae—an anatomical variation not mentioned in the radiology report, but first identified by the neurologist, who had recently participated in research involving spinal anomalies.

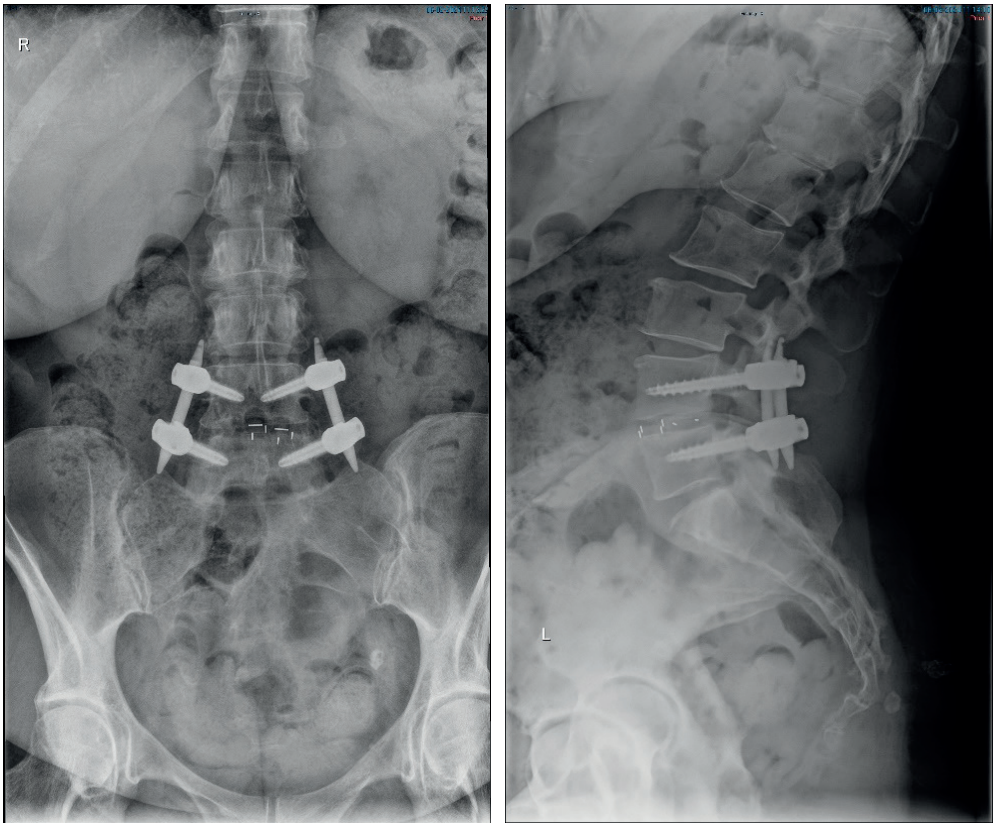


Figure 1: X-ray lumbar spine with six lumbar vertebrae.

The patient subsequently underwent an MRI and was evaluated by a clinical neurologist. Findings were consistent with sciatica involving the L5 nerve root (with possible contribution from L4) on the right side, due to compression of the cauda equina/lumbar nerve roots at the L4-L5 level, caused by the spondylodesis. The MRI (Figure 2) report however, identified the lowest lumbar vertebra as L5 and noted prior PLIF at the L4-L5 level, with additional findings of disc bulging at L3-L4.

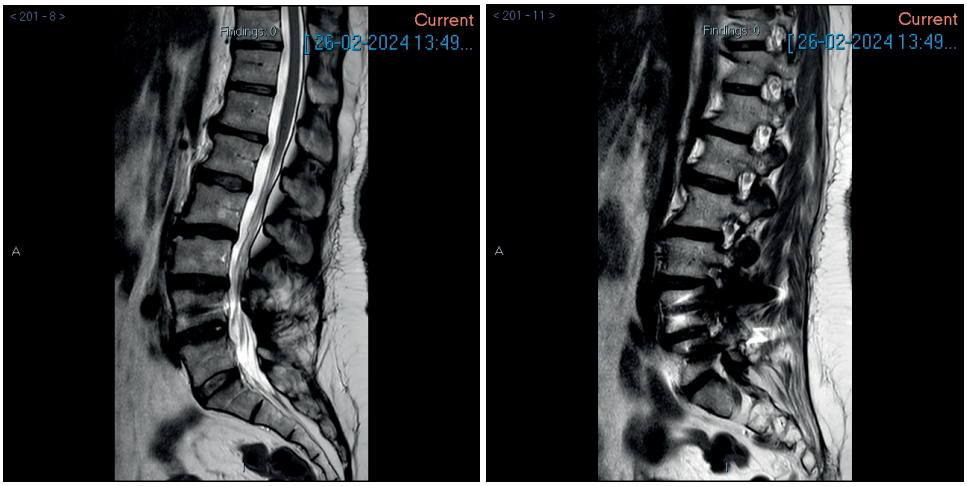


Figure 2: MRI lumbar spine, sagittal T2 weighed images mid sagittal and paramedial to the right. The lowest LV is considered the L5.

The referral to the PMD described a lumbar radicular syndrome at the L5 level in the context of six lumbar vertebrae, with compression from a herniated nucleus pulposus above the level of the prior fusion. A right-sided L5 nerve root block was requested. The PMD report confirmed right-sided L5 sciatica and identified a spondylodesis at the L5-L6 level. Additionally, a new disc herniation at L4-L5 was observed.

The patient underwent pulsed radiofrequency (PRF) treatment of the right L5 dorsal root ganglion. The procedure was performed by a Fellow of Interventional Pain Practice, certified by the World Institute of Pain (16). PRF was applied for six minutes at a frequency of 4 Hz. Correct foraminal needle placement at the L5 level was confirmed by fluoroscopy (Figure 3).

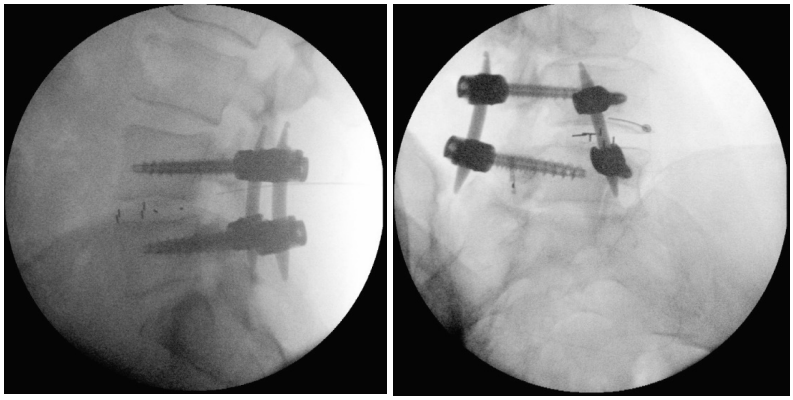


Figure 3: Fluoroscopy images during interventional pain treatment in de PMD. The spondylodesis situated at the L5 and L6 level with needle placement in the neuroforamen of the L5 nerve root.

Eight weeks after the procedure, the patient reported a decrease of the numeric rating scale score from 9 pre-treatment to 4 post-treatment. While some lower back pain persisted, the radiating pain along the lateral aspect of the lower right leg was almost completely resolved.

§2.4 Methods

The review of the literature was conducted between 2000 and 2025 for case reports published in PubMed and Web of Science. The search terms used were Bertolotti syndrome, lumbosacral transitional vertebrae and lumbar spine anomalies. The web application Rayyan QCRI was used to organize and select publications (17). The primary reviewer screened all titles and abstracts for the presence of level nomination or determination. The complete search was supervised by two independent reviewers.

Found publications were uploaded into Rayyan for the first review round. Inclusion criteria were: 1) Must include lumbosacral transitional vertebrae or Bertolotti syndrome 2) Availability of images showing the issue with the level determination 3) Study is a case report or case series 4) Refer directly or indirectly to a level determination of the lumbar spine 5) English language. Exclusion criteria were: 1) The study does not refer to or describes level determination in the lumbar spine 2) Publications before the year 2000 3) Animal studies 4) Cadaver studies 4) Age under eighteen.

Publications passing the initial screening, were assessed for full text analyzation. During meetings with the secondary reviewers, the articles were further discussed, and final selections were made to include articles in this study.

§2.5 Results

A total of 548 case reports and series were available for screening after removing the duplicates. See the flow chart in Figure 4. Based on the in- and exclusion criteria, 518 articles were excluded. Thirty studies underwent full review. Twenty-four studies were then excluded because level determination was not considered an issue. Three studies were excluded according to the exclusion criteria, not described in the abstract (no LSTV, child, cadaver).

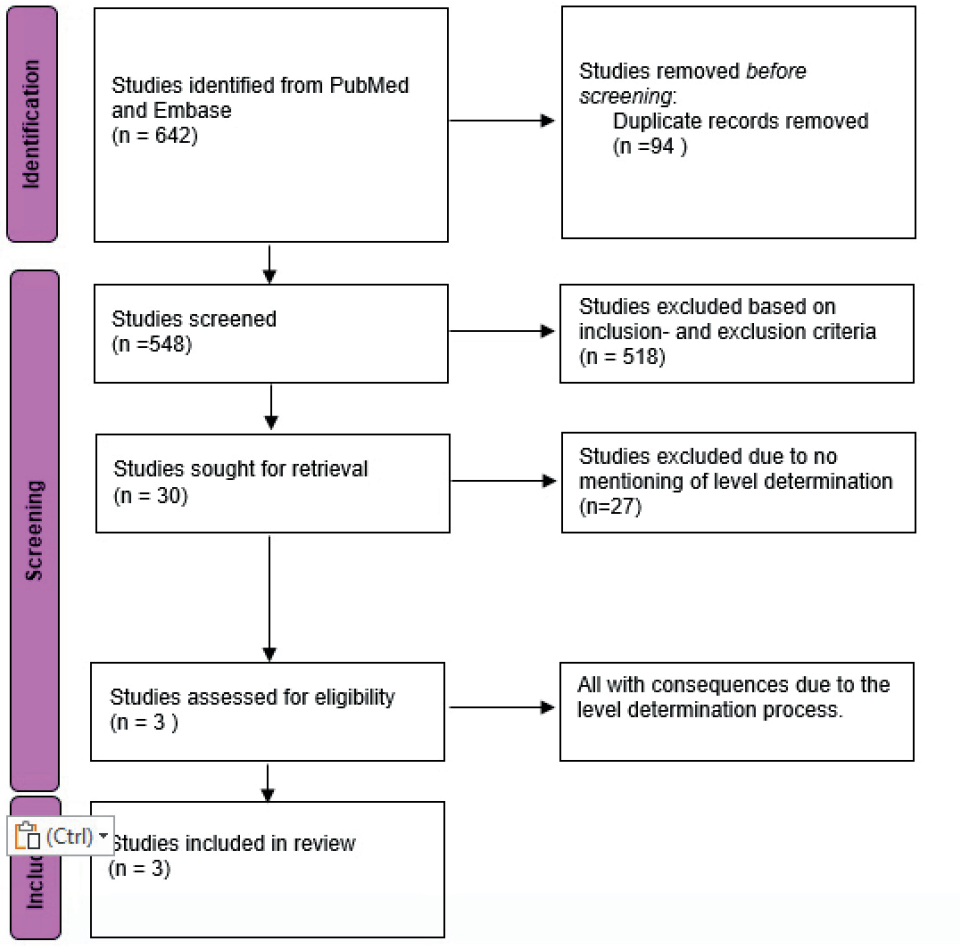


Figure 4: Prisma flow chart of identification of studies

Three studies were included. A case report about the misinterpretation of the lumbar sequence with a lumbar MRI by Hou et al. (18). The two levels of calcified herniated disks were adjusted from L4-5 and L5-S1 to L5-S1 and S1-S2 after performing a whole spine MRI. Crawford et al.

reported a case about conflicting calculations of pelvic parameters before surgery and after the discovery of transitional lumbosacral anatomy during the surgery (19). Albano et al. reported about the risks associated with surgical management of LSTV. In their case a newly discovered L1 burst fracture was adjusted to L2 after CT scan of the whole spine revealing 5 LV and a transitional vertebra (5). All three cases described the discrepancies between level diagnosis before and after discovery of transitional vertebrae around an interventional procedure.

§2.6 Discussion

This case highlights the clinical challenges encountered during multidisciplinary diagnostic evaluation when a lumbar spine variant is present. Three additional cases, found in the review, underscore these risks. Such anomalies can result in discrepancies between the spinal levels treated during interventional pain procedures and those identified by referring neurologists or radiologists, increasing the risk of incorrect level targeting and suboptimal treatment outcomes (5, 7, 20).

Upon hospital admission, clinicians typically base decisions on referral information, patient symptoms, and physical examination. While this workflow is standard, diagnostic accuracy in localizing lumbosacral radicular pain is known to be limited. Systematic reviews demonstrate poor clinical performance in pinpointing the affected nerve root levels, with neurological tests showing low sensitivity for confirming disc herniation on imaging (e.g., sensitivities around 0.32) (6, 21).

Anatomical variations such as LSTV further complicate clinical decision-making. A lumbarized S1 vertebrae may function as the usual L5 nerve root, but this is not always consistent (22). Similarly, with a sacralized L5 vertebrae, the L4 nerve root usually assumes functions of the L5 nerve root (23). Studies have demonstrated that nerve root innervation patterns in patients with six lumbar vertebrae differ from those with the standard five, affecting both diagnosis and intervention (24).

Magnetic resonance imaging (MRI) remains the standard for detecting disc herniation, with T1- and T2-weighted sequences in sagittal and axial planes routinely acquired in Dutch hospitals (8). Recent literature reviews indicate a similar MRI technique in various countries (25, 26). Although coronal images may improve accuracy, it is not routinely employed for lumbar radiculopathy assessment (27).

Interventional pain specialists rely on fluoroscopic guidance for level identification, starting from T12 in a posterior-anterior view. Radiologists typically count from the presumed L5 upwards in the supine position. This practice, combined with anatomical variants such as the presence

of four or six lumbar vertebrae, introduces wrong level diagnosis and potentially wrong-level interventions (7, 9, 28). If a thoracolumbar or lumbosacral transitional vertebra is seen on the fluoroscopic image, a whole spine image to permit accurate numbering of the lumbar vertebra is recommended (3). Reviews on wrong-level spine surgery identify anatomical anomalies and inadequate imaging as leading causes of errors (29).

Comparing fluoroscopic images with MRI scans is essential for accurate level localization during invasive procedures. Nevertheless, no standardized or universally accepted protocol exists for vertebral level counting, resuming in continuing inconsistencies. Consensus guidelines for preventing wrong-level spine surgery acknowledge the need for improved intraoperative imaging and communication but do not fully resolve challenges posed by transitional vertebrae (30, 31). For instance, identifying T12 can be complicated when the presence of ribs is uncertain, leading to variations in how subsequent lumbar vertebrae are numbered (32, 33), and identifying lower lumbar levels when degenerative spondylolisthesis is present, especially in patients with sacralization (34, 35).

From an anatomical perspective, variations in the number and configuration of thoracic and lumbar vertebrae are well documented, with seven possible combinations occurring in LSTV patients (3, 4, 36-39). Comprehensive imaging studies that include the entire spine, sacrum, and coccyx are necessary to accurately distinguish lumbarization from sacralization (40). These anatomical nuances have significant implications for precise vertebral counting and procedural planning.

§2.7 Conclusion

This case report along with three additional cases demonstrate the potentially inaccurate treatment of patients with lumbar spine anomalies and lumboradicular pain in interventional pain medicine. Given the lack of an evidence-based, standardized approach for vertebral level determination in the presence of anomalies, improving communication between radiologists, neurologists, surgeons, and interventionalists is essential. Enhancing intraoperative imaging quality, comparison with total spine images, establishing uniform counting protocols, and multidisciplinary collaboration may result in reducing the risk of wrong-level interventions and improve patient outcomes.

§2.8 References

1. Jancuska JM, Spivak JM, Bendo JA. A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. Int J Spine Surg. 2015;9:42.
2. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984;9(5):493-5.
3. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, et al. The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul). 2020;15(1):103-10.
4. Tatara Y, Niimura T, Sekiya T, Mihara H. Changes in Lumbosacral Anatomy and Vertebral Numbering in Patients with Thoracolumbar and/or Lumbosacral Transitional Vertebrae. JB JS Open Access. 2021;6(3).
5. Albano S, Brown NJ, Pennington Z, Nguyen A, Hsu TI, Pham MH, et al. Risks Associated with Surgical Management of Lumbosacral Transitional Vertebrae: Systematic Review of Surgical Considerations and Illustrative Case. World Neurosurg. 2024;186:e54-e64.
6. van der Windt DA, Simons E, Riphagen, II, Ammendolia C, Verhagen AP, Laslett M, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. The Cochrane database of systematic reviews. 2010(2):CD007431.
7. Liebrand B, Brakel K, Boon A, van der Weegen W, van der Wal S, Vissers KCP. Diagnostic treatment-level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies. Regional Anesthesia and Pain Medicine. 2022;47(3):177-82.
8. Robin Smithuis RdotRhiL, the Netherlands. . Lumbar Disc Herniation and other causes of nerve compression: Educational site of the Radiological Society of the Netherlands; 2014 [updated 2014-12-14. Available from: https://radiologyassistant.nl/neuroradiology/spine/lumbar-disc-herniation#mri-protocol.
9. Berger R, Bulloch L, Hysong A, Huggins B, Horan N, Van Der Noord R, et al. Establishing a common language for lumbar transforaminal epidural steroid injections. J Spine Surg. 2021;7(4):467-74.
10. Mody MG, Nourbakhsh A, Stahl DL, Gibbs M, Alfawareh M, Garges KJ. The prevalence of wrong level surgery among spine surgeons. Spine (Phila Pa 1976). 2008;33(2):194-8.
11. Groff MW, Heller JE, Potts EA, Mummaneni PV, Shaffrey CI, Smith JS. A survey-based study of wrong-level lumbar spine surgery: the scope of the problem and current practices in place to help avoid these errors. World Neurosurg. 2013;79(3-4):585-92.
12. Mayer JE, Dang RP, Duarte Prieto GF, Cho SK, Qureshi SA, Hecht AC. Analysis of the techniques for thoracic- and lumbar-level localization during posterior spine surgery and the occurrence of wrong-level surgery: results from a national survey. Spine J. 2014;14(5):741-8.
13. Naqvi AZ, Magill H, Anjarwalla N. Intraoperative practices to prevent wrong-level spine surgery: a survey among 105 spine surgeons in the United Kingdom. Patient Saf Surg. 2022;16(1):6.
14. Liebrand B, van der Wal S, Slob M, Boon A, Henssen D, Zundert J, et al. Diagnostic precision in lumbar radiculopathy: Impact of transitional vertebrae on treatment level selection and outcomes. Pain Med. 2025;26(10):681-8.
15. Benlidayi IC, Gupta L. CAse-BAsed REview sTandards (CABARET): Considerations for Authors, Reviewers, and Editors. J Korean Med Sci. 2024;39(30):e225.

16. Fellow of Interventional Pain Practice (FIPP)® Examinations, provided by the World Institute of Pain [Available from: https://www.worldinstituteofpain.org/fipp-examination/.
17. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210.
18. Lisheng H, Feng G, Dong Z, Tianjun G, Shaokui N, Xuedong B, et al. Complete lumbarization with calcified disc herniations at L5S1 and S1-2 levels treated with percutaneous endoscopic interlaminar discectomy: a case report and technique note. Front Surg. 2023;10:1079245.
19. Crawford CH, Glassman SD, Gum JL, Carreon LY. Conflicting calculations of pelvic incidence and pelvic tilt secondary to transitional lumbosacral anatomy (lumbarization of S-1): case report. Journal of Neurosurgery-Spine. 2017;26(1):45-9.
20. Nakagawa T, Hashimoto K, Tsubakino T, Hoshikawa T, Inawashiro T, Tanaka Y. Lumbosacral Transitional Vertebrae Cause Spinal Level Misconception in Surgeries for Degenerative Lumbar Spine Disorders. Tohoku J Exp Med. 2017;242(3):223-8.
21. Al Nezari NH, Schneiders AG, Hendrick PA. Neurological examination of the peripheral nervous system to diagnose lumbar spinal disc herniation with suspected radiculopathy: a systematic review and meta-analysis. Spine J. 2013;13(6):657-74.
22. Chang HS, Nakagawa H. Altered function of lumbar nerve roots in patients with transitional lumbosacral vertebrae. Spine (Phila Pa 1976). 2004;29(15):1632-5; discussion 5.
23. Kim YH, Lee PB, Lee CJ, Lee SC, Kim YC, Huh J. Dermatome variation of lumbosacral nerve roots in patients with transitional lumbosacral vertebrae. Anesthesia and analgesia. 2008;106(4):1279-83.
24. Hinterdorfer P, Parsaei B, Stieglbauer K, Sonnberger M, Fischer J, Wurm G. Segmental innervation in lumbosacral transitional vertebrae (LSTV): a comparative clinical and intraoperative EMG study. Journal of Neurology, Neurosurgery & Psychiatry. 2010;81(7):734-41.
25. Pojskic M, Bisson E, Oertel J, Takami T, Zygourakis C, Costa F. Lumbar disc herniation: Epidemiology, clinical and radiologic diagnosis WFNS spine committee recommendations. World Neurosurg X. 2024;22:100279.
26. Zhang AS, Xu A, Ansari K, Hardacker K, Anderson G, Alsoof D, et al. Lumbar Disc Herniation: Diagnosis and Management. Am J Med. 2023;136(7):645-51.
27. Farshad-Amacker NA, Lurie B, Herzog RJ, Farshad M. Interreader and intermodality reliability of standard anteroposterior radiograph and magnetic resonance imaging in detection and classification of lumbosacral transitional vertebra. Spine J. 2014;14(8):1470-5.
28. Grimm BD, Laxer EB, Blessinger BJ, Rhyne AL, Darden BV. Wrong-Level Spine Surgery. JBJS reviews. 2014;2(3).
29. Epstein N. A perspective on wrong level, wrong side, and wrong site spine surgery. Surg Neurol Int. 2021;12:286.
30. Vitale M, Minkara A, Matsumoto H, Albert T, Anderson R, Angevine P, et al. Building Consensus: Development of Best Practice Guidelines on Wrong Level Surgery in Spinal Deformity. Spine Deform. 2018;6(2):121-9.
31. Srivatsa S, Vira S, Schils J, Shook S, Gill A, Krishnaney AA. Reducing Wrong-level Spinal Surgeries Through Root Cause Analyses: A 10-year Longitudinal Analysis of a Single Tertiary Institution's Iterative Policy Improvements. Spine (Phila Pa 1976). 2021;46(11):E648-e54.
32. Park SK, Park JG, Kim BS, Huh JD, Kang H. Thoracolumbar junction: morphologic characteristics, various variants and significance. The British Journal of Radiology. 2016;89(1064):20150784.

33. Hanson EH, Mishra RK, Chang DS, Perkins TG, Bonifield DR, Tandy RD, et al. Sagittal whole-spine magnetic resonance imaging in 750 consecutive outpatients: accurate determination of the number of lumbar vertebral bodies. J Neurosurg Spine. 2010;12(1):47-55.
34. Mahmoodkhani M, Naeimi A, Zohrevand A, Rabbanifard A, Rezvani M. Lumbosacral transitional vertebra in spondylolisthesis: frequency, demographic findings, and clinical characteristics. BMC Musculoskelet Disord. 2024;25(1):243.
35. Coskun Benlidayi I, Tirasci E. The effect of lumbosacral transitional vertebra on lumbar spine degeneration and spondylolisthesis among patients with low back pain. Pain Pract. 2024;24(1):52-61.
36. Tins BJ, Balain B. Incidence of numerical variants and transitional lumbosacral vertebrae on whole-spine MRI. Insights Imaging. 2016;7(2):199-203.
37. Gonzales-Portillo GS, Rizvi O, Avila MJ, Dumont TM. The prevalence of 11 ribs and its potential implications in spine surgery. Clin Neurol Neurosurg. 2021;203:106544.
38. Chiu CK, Chin TF, Chung WH, Chan CYW, Kwan MK. Variations in the Number of Vertebrae, Prevalence of Lumbosacral Transitional Vertebra and Prevalence of Cervical Rib Among Surgical Patients With Adolescent Idiopathic Scoliosis: An Analysis of 998 Radiographs. Spine (Phila Pa 1976). 2024;49(1):64-70.
39. Sugiura K, Morimoto M, Higashino K, Takeuchi M, Manabe A, Takao S, et al. Transitional vertebrae and numerical variants of the spine : prevalence and relationship to low back pain or degenerative spondylolisthesis. Bone Joint J. 2021;103-b(7):1301-8.
40. Krenn VA, Fornai C, Webb NM, Woodert MA, Prosch H, Haeusler M. The morphological consequences of segmentation anomalies in the human sacrum. Am J Biol Anthropol. 2022;177(4):690-707.



Chapter 3

Diagnostic treatment level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies.

Liebrand B, Brakel K, Boon A, van der Weegen W, van der Wal SV, Vissers KC.

Reg Anesth Pain Med. 2022 Mar;47(3):177-182.
doi: 10.1136/rapm-2021-103174. Epub 2021 Dec 17. PMID: 34921051

§3.1 Abstract

Background

Lumbosacral transitional vertebra can result in an anomalous number of lumbar vertebrae associated with the wrong level treatment. The primary aim of this study was to characterize discrepancies between reported referring levels and levels from MRI reports with treated levels. The secondary aim was to analyse interobserver variability between a pain physician and a radiologist when determining levels and classifying lumbosacral transitional vertebrae.

Methods

Between February 2016 and October 2019, a retrospective case series of prospectively collected data of the affected levels mentioned in referrals, MRI reports, and treated levels was performed. The counting process, level determination, classification of lumbosacral transitional vertebrae, and a secondary control were carried out by independent researchers using a standard methodology.

Results

Of the 2443 referrals, 143 patients had an anomalous number of lumbar vertebrae; of these, 114 were included for analysis. The vertebral level noted in the patient's file, in the referral, and the reported level of treatment differed in 40% of these cases. The vertebral level between the MRI reports and treatment differed in 46% of cases. The interobserver reliability (radiologist versus pain physician) for classifying a transitional vertebra was fair (($\kappa = 0.40$) and was substantial ($\kappa = 0.70$) when counting the vertebrae.

Conclusion. In the presence of lumbar transitional vertebrae, we report a high prevalence of discrepancies between referral levels and MRI pathological findings with treatment levels. Further research is needed to better understand clinical implications.

§3.2 Introduction

Lumbosacral transitional vertebra (LSTV) is a spectrum of morphological anomalies of the lumbosacral junction and transverse processes, and can be an element of an anomalous number of lumbar vertebrae (LV).(1) On radiographic imaging, four or six lumbar vertebrae appear rather than the commonly expected five.(2) These anatomical anomalies can be difficult to recognize and detect.(3-5)The prevalence of LSTV in the general population varies depending on differences in research populations, but averages at approximately 12%.(6) The presence of spinal anomalies, including LSTV, in patients referred with lumbar herniated discs or discopathies with radiation is a diagnostic challenge, as it increases the risk of treating these patients at the wrong vertebral level.(3, 7-11) In cases where LSTV is present and recognized, current best practice is to count the vertebral bodies starting from C2 and moving caudal.(4)

To be able to make a correct level diagnosis, physicians have to be aware of these potential discrepancies. During fluoroscopy an anomaly and LSTV is often first discovered during level determination and the possibility to make perpendicular images of the lumbosacral transition. To understand the clinical consequence of these potential discrepancies it is important first to analyse the accuracy of this diagnosing process.

The primary aim of the present study was to analyse the number of discrepancies between spinal levels (1) reported by referring physicians and (2) from diagnostic MRI reports, and the levels treated by the pain specialists in patients with a different number of LV. A second aim was to analyse the interobserver variability between a pain physician and a radiologist when determining levels and classifying LSTV in clinical practice.

§3.3 Methods

Ethics

This research was approved by the Maxima Medical Center Regional Committee of Medical Ethics (N18.166).

Patients

In a tertiary care hospital, all patients referred to the Pain Management department between February 2016 and October 2019 and diagnosed as having acute-/ subacute neurologic lower back pain with radiation or chronic neurologic lower back pain with radiation according to a nationwide Dutch Health Care Authority code system were screened for LSTV.

The Principal Investigator (PI) and a second pain physician, both accredited for the national board of Anaesthesiology and Pain Medicine and FIPP-certified, identified patients by fluoroscopy and

held mutual consultations on a weekly basis. The PI included these patients in the database (table 1) as well as their personal data collected from electronic patient files (Castor Electronic Data Capture 2012).(12)

Table 1: Inclusion- and exclusion criteria

Inclusion criteria
• LSTV (either sacralization or lumbarization) visible with fluoroscopic radiographs. • Available MR images of the complete LS, including the most caudal thoracic vertebrae and the sacrum, available prior to the last day of the study. • Invasive treatment of the lumbar spine (transforaminal and intralaminar epidural procedures).
Exclusion criteria
• No LSTV in the secondary assessment • No appropriate radiological images available (X-ray or CT- imaging) to diagnose an TLTV, the first LV and an LSTV, to classify an LSTV, and to count the number of lumbar vertebrae. • Absence of MR images of the lumbar spine.

Diagnostic analysis and counting the thoracolumbar junction and lumbar spine

A pain physician (PI) and a radiologist performed the analyses for counting the vertebrae, defining lumbarization, sacralization and Castellvi(13) classification independently. In order to count the exact number of LV, the first LV and a possible thoracolumbar transitional vertebra (TLTV) were identified according to Park et al.(14) in their research on CT examinations. A thoracic vertebra is identified by the presence of paired ribs that are 3.8 cm or more in length and originate from the facet at the pedicle (or body of the vertebra).

The reviewers used fluoroscopy images and anterior-posterior (AP) lumbar spine X-rays. If these AP images did not provide a clear view of the thoracolumbar junction, X-rays of the abdomen, thorax, and CT scans, if available, were used to identify the first lumbar vertebra. This process is comparable to counting lumbar vertebrae as reported by Hinterdorfer et all.(15) Patients were excluded from the study group if there was no clear view of the thoracolumbar region on any of the radio-diagnostic images, and if no accurate measurements could be taken. After determining the first lumbar LV, counting the amount of vertebra was performed in a cranio-caudal order. Patients were defined as having a sacralization at four lumbar vertebrae; six lumbar vertebrae were considered a lumbarization.

If available, lumbar spine X-rays, CT scans and fluoroscopy images (30º) were assessed to classify the lumbosacral transition according to Castellvi.(13) These methods correspond with those recommended as an interventional spine specialist's practical approach for treatment.(16)

Processing the discrepancies in the diagnostic analysis- and counting process

The lumbar spine level mentioned by the referring doctor, the affected level stated in the MRI reports, and the level of treatment mentioned by the pain specialist were collected from the files for each patient and entered in the database. Any observed differences and mutual agreements between the radiologist and pain physician were also entered.

To check accuracy of both the Castor database and the level determination by the pain physician, a second independent physician, a neurologist, assessed 20 randomly chosen patients to see if the levels in the referrals and MRI reports had been correctly copied and whether the treated levels mentioned by the pain physician corresponded with the true level determined during fluoroscopy using a counting process according to Furman et. all.(16) Figure 1 shows an example of a patient referred to the department of pain medicine with a difference in level nomination between physicians.

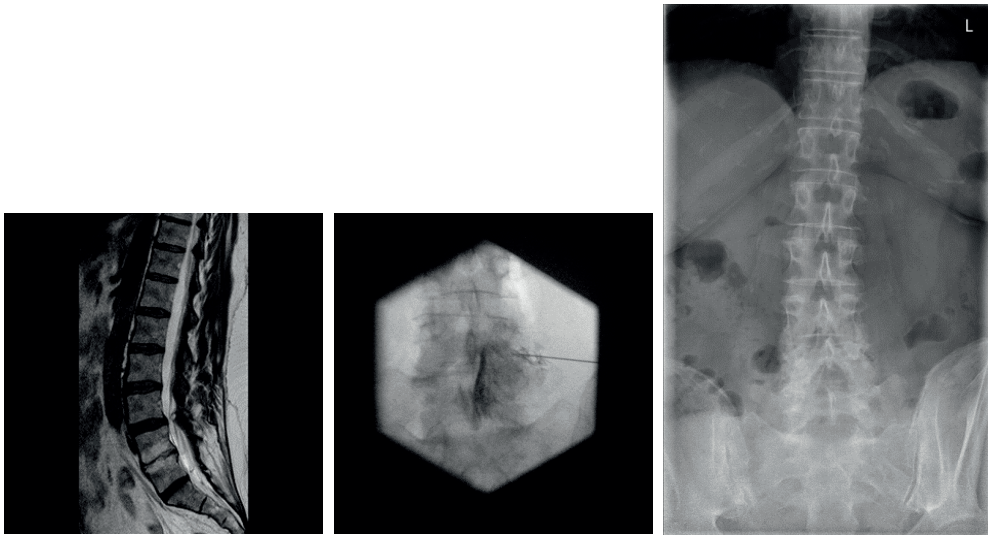


Figure 1: Patient case showing difference in level nomination
Female, age 72, referral by the neurologist mentioning lumbar four. The level mentioned in the MRI report was lumbar three to four (left picture white arrow). The level mentioned by the pain physician was lumbar five (middle picture) The patient has a lumbarization of S1 and six LV (right picture, white arrow on first lumbar vertebrae).

Statistics

The database was transferred for statistical analysis to IBM SPSS version 21 (IBM Corp., Armonk, NY). Descriptive statistics were used to characterize patient demographics and to describe the differences in the determined levels between the referrals, the MRI reports and the treated levels. Statistical testing between groups, lumbarization sacralization and undetermined, was

planned for the described differences with $p < 0.05$ considered as significant. Interobserver reliability was assessed using kappa statistics for detecting the amount of LV (with sacralization or lumbarization) and the Castellvi classification. Reported kappa values (κ) were interpreted according to Landis and Koch with values between 0.0-0.2 being slight, 0.2-0.4 fair, 0.4-0.6 moderate, 0.6-0.8 substantial, and 0.8-1.0 almost perfect.(17)

§ 3.4 Results

During the study period, 2443 patients were referred to the department of pain medicine. Figure 2 summarizes the process of inclusion, LV counting and level assessment. They were mostly referred by neurologists (50%), neurosurgeons (12%), general practitioners (25%) and orthopaedic surgeons (9%).

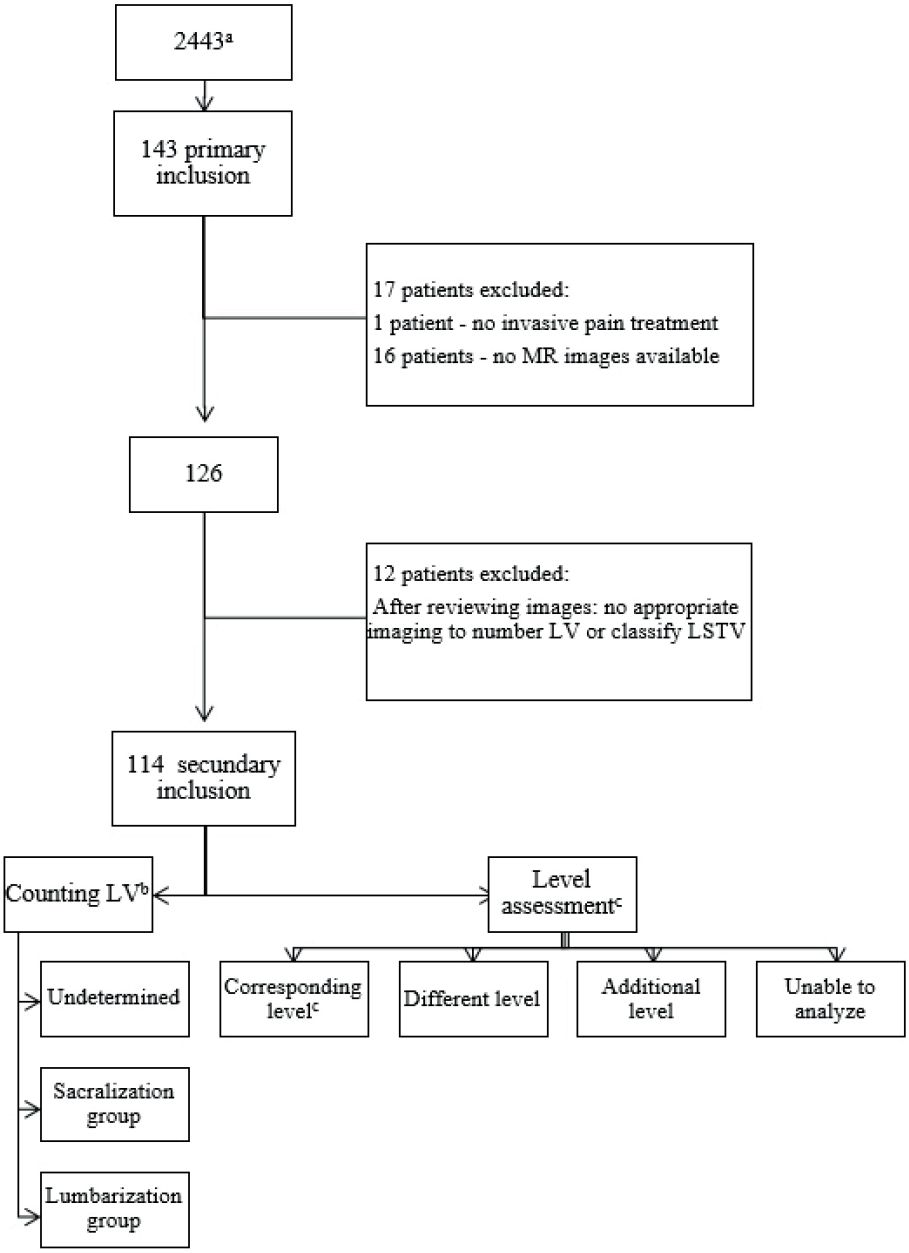


Figure 2: Flow chart of study population's inclusion, LV counting and level assessment

a: inclusion process, n number of patients

b: counting lumbar vertebrae and distribution in groups

c: final analyses level discrepancies to one of four assessments

A total of 143 patients (5.9%) met the primary inclusion criteria; of these 29 were excluded because of inappropriate radiological images for classifying an LSTV or counting the number of lumbar vertebrae. Of the 114 patients enrolled for statistical analysis, 110 had radiating leg pain in one of the dermatomes during the referral according to the Netter Diagram.(18)

In the study group, 92 patients (81%) had a lumbarized S1 vertebra, 15 (13%) a sacralized L5 vertebra and 7 (6%) showed no distinction between lumbarization and sacralization.

Demographics and other patient characteristics did not differ between these three groups (table 2). However, the undetermined group needed more consultations at the pain department after intake compared to the lumbarization group (9.4 vs 6.2, p=0.04).

Table 2: Patient characteristics in lumbarization, sacralization, and undetermined.

Variables	Lumb	Sacr	Und	Total	P-value
Sample size, n	92	15	7	114	
Characteristics					
Mean age (SD) in years	58.1 (14.5)	59.9 (14.7)	57.1(18.0)	58.3 (14.6)	0.89
Sex n (%)					
Male	36 (39.1)	7	3	46 (40.4)	0.85
Female	56 (60.9)	8	4	68 (59.6)	
Leg pain at intake					
Yes	89	14	7	110	0.70
No	3	1	0	4	
Mean cons at pain department after intake (SD)	6.2 (3.9)	8.1 (3.9)	9.4 (5.7)	6.6 (4.1)	0.04
Mean cons with invasive pain treatments at pain department after intake (SD)	2.9 (1.8)	3.7 (2.4)	4.0 (2.3)	3.1 (1.9)	0.15
Mean n MR images pp (SD)	2.4 (1.7)	2.1 (1.6)	3.0 (1.8)	2.4 (1.7)	0.52
Mean n LS X-ray images pp (SD)	1.5 (0.8)	1.5 (1.0)	2.0 (1.4)	1.5 (0.9)	0.72

Abbreviations: Lumb, lumbarization; Sacr, sacralization; Und, undetermined; SD, standard deviation; cons, consultations; n, number; LS, lumbar spine

a: independent sample t-test to compare means and cross tabs with chi square to compare proportions

b: P-value calculated between the Lumb Sacr and Und group in its entirety

We found a difference in 45 patients (39.4%) between the vertebral level noted in the referrals and the reported level of treatment. In 32 patients (28.1%), the levels corresponded and in 10 (8.8%) the level corresponded but a second level of treatment below or above the corresponding level was performed in the same treatment session. In 27 patients (23.7%), the level at intake, MRI report or the treatment was not described in the electronic patient files. Moreover, we found a difference in 52 patients (45.6%) between the vertebral level mentioned in the MRI reports and the treatment level in the patient's files. The levels corresponded in 26 patients (22.8%) and the same 10 patients had the second level of treatment. A total of 26 patients (22.8%) had insufficient data in their files. These results are summarised in table 3.

Table 3: Assessment of spinal levels reported in the referral and diagnostic MRI reports versus the levels treated by the pain physician.

	Referral- vs treatment level	MRI- vs treatment level
Possible assessment, n (%)		
Difference	45 (39.4)	52 (45.6)
Correspondence	32 (28.1)	26 (22.8)
Correspondence + sl [a]	10 (8.8)	10 (8.8)
Unable to analyse [b]	27 (23.7)	26 (22.8)

Abbreviation: n, number; vs, versus; sl, second level of treatment
a: two levels treated, one corresponded with the referral level
b: no analysis possible because of insufficient file data

In the lumbarization group, 41% of the patients had differences between the level at intake and the reported treatment level compared to 33% with a sacralized L5 (p=0.75). The level mentioned in the MRI reports differed from the reported level of treatment by 47% (p=0.96) in both lumbarization and sacralization.

Of the 92 patients with lumbarization, 10% were classified as type Ib, and 29% as Castellvi IIa or IIb (table 4). In the sacralization group, 12 of 15 patients were classified as type IIIb; Castellvi type IIb and IIIb were most common in the undetermined group. We were unable to classify 40 patients (44%) using the Castellvi method, naming them 'unclassified'; these had six lumbar vertebrae and a transverse process less than 19 millimetres.

Table 4: Castellvi classification in the lumbarization, sacralization and undetermined group separately.

	Lumbarization	Sacralization	Undetermined
Sample size, n (%)	92(80.7)	15 (13.2)	7 (6.1)
Castellvi Classification			
Unclassified	40(43.5)[a]	0	1 (14.3)
Type Ia	0	0	0
Type Ib	9 (9.8)	0	1 (14.3)
Type IIa	17 (18.5)	1 (6.7)	1 (14.3)
Type IIb	9 (9.8)	1 (6.7)	2 (28.6)
Type IIIa	0	0	0
Type IIIb	6 (6.5)	12 (79.9)	2 (28.6)
Type IV	11 (11.9)	1 (6.7)	0

a: percentages of the individual Castellvi classifications calculated within each group (i.e., lumbarization, sacralization, undetermined)

When using the Castellvi classification to distinguish between a pseudo-arthrosis as a lumbar-sacral connection (unclassified, type Ia Ib IIa and IIb) or a tight connection (type IIIa IIIb and IV) for lumbarization and sacralization, 75 of 92 patients (82%) in the lumbarization group had a pseudo-arthrosis and 13 of 15 patients in the sacralization group (87%) had a tight connection. A Pearson Chi-Square test on lumbarization, sacralization, and division of the Castellvi classifications, showed that a lumbarized L5 has significantly more Castellvi classifications 1 and 2 or was unclassified ($p<0.001$), and a sacralized L5 significantly more types 3 and 4 ($p<0.001$).

For interobserver reliability between the pain physician and the radiologist, the kappa measurement of agreement for classifying an LSTV according to the Castellvi classification was fair ($\kappa = 0.40$) while for counting the number of lumbar vertebrae, it was substantial ($\kappa = 0.70$).

The second observer checked the referrals in 20 patients with 44 treatments, a 12% sample. Mean age of the sample group (14 females and 7 males) was 56 years. The demographics in the sample group did not differ from the demographics of the whole patient group. In 43 treatments, the pain physician and the neurologist noted the same level, in one treatment a difference in level of treatment was recorded.

§3.5 Discussion

In the 110 patients with LSTV and radicular pain, we found a 40% discrepancy between the affected lumbar level reported by the referring physician and the lumbar level treated by the

pain physician. The discrepancy between the levels mentioned in the 114 MRI reports and the treated levels was even higher, at 46%.

The clinical level determination in patients with lumbosacral radicular pain is inaccurate according to reviews by van der Windt et al and Hinterdorfer et al.(19) (15) Hinterdorfer et al. also found, in a clinical and intraoperative EMG study of segmental innervation in patients with LSTV, that the presence of lumbarization did not significantly affect the segmental innervation. (15) Patients with four lumbar vertebrae were not investigated, which represent 13% of the patients in our study population. This may add to the observed differences.

An LSTV is often discovered during fluoroscopy. In this study, an LSTV was mentioned in 14 of the 114 reports of the first lumbar spine Xray and in four reports of the first MRI. Contradictory information in the referral or MRI report before level determination for treatment can result in a discrepancy between referral and treatment level.

Numerical variants of the spine are common. Studies using whole-spine imaging have identified transitional lumbosacral vertebrae in 3.3% of the population, and a 7.7% incidence of numerical variants of the spine.(1) Hanson et al. showed that 14.5% had six, 3% had four, and 0.13% had three lumbar-type vertebrae.(20) In an MRI study of the total spine, an anomalous total number of vertebrae was present in 12 (8.2%) of 147 subjects.(21) TLTVs were present in 6 (4.1%) and LSTVs in 22 (15.0%) of 147 subjects. An LSTV was associated with an anomalous total number of vertebrae. Studies report possible combinations of 11, 12 and 13 thoracic vertebrae and four, five or six LV in a total number of 23, 24 or 25 vertebrae.

In general, standard MRI images of the lumbar spine are transversal and sagittal. The classification and numbering of LSTVs is problematic on sagittal MRI.(16) The existence of four or six lumbar vertebrae and a caudal to cranial counting process causes differences between the reported MRI level and the level noted during fluoroscopy.

Research for accurate level diagnosis has been performed in different ways. Peh et al. compared correct lumbar level determination on sagittal and coronal MRI T1 localizer images with a method of caudal counting with additional sagittal cervico-thoracic and lumbo-sacral localizer images. [(5)] Concordance between radiologists was reached in 80% of patients. A limitation of this study was the assumption of 7 cervical and 12 thoracic vertebrae. Tokgoz et al. numbered vertebral segments on lumbar MRI alone versus whole-spine localizer, revealing a diagnostic error for vertebral numeration on lumbar MRI alone of 14.1%.(22) In coronal MRI scans however, the inter-reader reliability was very good for detection (κ =0.93) and classification (κ =0.83) an LSTV.(23)

Fluoroscopy has limitations recognizing a T12 vertebrae because of TLTVs and dysplastic ribs.(24) In our study, in 33% of the cases the levels corresponded because of difficulties determining the upper lumbar vertebrae, leading to a different counting process. Furthermore, the PI noticed the tendency to adjust the original described level to that mentioned in the MRI reports by the neurologists and the pain physician.

In our study, the inter-observer agreement for determining the Castellvi classification was fair (κ =0.4); for counting the number of lumbar vertebrae it was substantial (κ=0.7). Radiologists have better software at their disposal to more accurately measure the transverse process and determine the lowest thoracic vertebrae. Most disagreements were about measuring the transverse process of the lowest lumbar vertebrae in the lumbarization group (29 patients (32%)), about fixation between the LSTV and the sacrum and therefore about different Castellvi classifications (21 of 67 patients (31%)) and about determining the lowest thoracic vertebrae in 8 patients (7%).

Standard AP radiographs demonstrate 76% - 84% accuracy for LSTV detection and 53% - 58% accuracy when classifying LSTV.(24) The inter-reader reliability was moderate for detecting (κ=0.53) and fair for classifying (κ=0.39) LSTV. Performing Castellvi classification in lumbar plane radiographs compared to coronal CT scans showed inconsistencies in 35.2% of the cases.(25) Incomplete joint-like structures or bony union structures and remnants of sclerotic band between the transverse process and sacrum were the main reasons for misclassification in about one third of our study group. Compared to the use of abdominal CT scans for the Castellvi grading, the intra-rater and inter-rater agreements were excellent (κ = 0.928 and 0.855, respectively).(26)

As this was a single centre study, a multicentre study is necessary to confirm the magnitude of the discrepancies. In this study, we focused on the lumbar spine. Although we performed the counting and classification process according to the methods available in literature and as accurately as possible in clinical practice, the golden standard when determining levels remains counting from C2 caudally in whole spine images. Furthermore, we focused on the number of discrepancies and the accuracy of physicians in diagnosing the correct level. The clinical consequences of the discrepancies or wrong level treatment will be the subject of a follow-up study.

§3.6 Conclusion

In patients with lumbar spine anomalies and lumbosacral radicular pain, significant discrepancies were noted between physicians when identifying levels to target for intervention(s). These discrepancies could have clinical outcome implications and merit further study.

§3.7 References

1. Tins BJ, Balain B. Incidence of numerical variants and transitional lumbosacral vertebrae on whole-spine MRI. Insights into imaging. 2016;7(2):199-203.
2. Paik NC, Lim CS, Jang HS. Numeric and Morphological Verification of Lumbosacral Segments in 8280 Consecutive Patients. Spine. 2013;38(10):E573-E8.
3. Konin GP, Walz DM. Lumbosacral Transitional Vertebrae: Classification, Imaging Findings, and Clinical Relevance. American Journal of Neuroradiology. 2010;31(10):1778-86.
4. Lian J, Levine N, Cho W. A review of lumbosacral transitional vertebrae and associated vertebral numeration2018.
5. Peh WCG, Siu TH, Chan JHM. Determining the Lumbar Vertebral Segments on Magnetic Resonance Imaging. Spine. 1999;24(17):1852.
6. Jancuska JM, Spivak JM, Bendo JA. A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. International Journal of Spine Surgery. 2015;9:42.
7. Nakajima A, Usui A, Hosokai Y, Kawasumi Y, Abiko K, Funayama M, et al. The prevalence of morphological changes in the thoracolumbar spine on whole-spine computed tomographic images. Insights into imaging. 2013;5(1):77-83.
8. Longo UG, Loppini M, Romeo G, Maffulli N, Denaro V. Errors of level in spinal surgery. The Journal of Bone and Joint Surgery British volume. 2012;94-B(11):1546-50.
9. Malanga GA, Cooke PM. Segmental anomaly leading to wrong level disc surgery in cauda equina syndrome. Pain physician. 2004;7(1):107-10.
10. Yun S, Park S, Park JG, Huh JD, Shin YG, Yun JH. Spinal Enumeration by Morphologic Analysis of Spinal Variants: Comparison to Counting in a Cranial-To-Caudal Manner. Korean J Radiol. 2018;19(6):1140-6.
11. Mody MG, Nourbakhsh A, Stahl DL, Gibbs M, Alfawareh M, Garges KJ. The prevalence of wrong level surgery among spine surgeons. Spine (Phila Pa 1976). 2008;33(2):194-8.
12. Castor Electronic Data Capture 2012 [Available from: www.castoredc.com.
13. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984;9(5):493-5.
14. Park SK, Park JG, Kim BS, Huh JD, Kang H. Thoracolumbar junction: morphologic characteristics, various variants and significance. The British Journal of Radiology. 2016;89(1064):20150784.
15. Hinterdorfer P, Parsaei B, Stieglbauer K, Sonnberger M, Fischer J, Wurm G. Segmental innervation in lumbosacral transitional vertebrae (LSTV): a comparative clinical and intraoperative EMG study. Journal of Neurology, Neurosurgery & Psychiatry. 2010;81(7):734-41.
16. Furman MB, Wahlberg B, Cruz EJ. Lumbosacral Transitional Segments: An Interventional Spine Specialist's Practical Approach. Phys Med Rehabil Clin N Am. 2018;29(1):35-48.
17. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159-74.
18. Netter FH, M.D., . Atlas of human anatomy. . 6th ed: Philadelphia: Saunders/Elsevier; 2015.

19. van der Windt DA, Simons E, Riphagen, II, Ammendolia C, Verhagen AP, Laslett M, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. The Cochrane database of systematic reviews. 2010(2):CD007431.
20. Hanson EH, Mishra RK, Chang DS, Perkins TG, Bonifield DR, Tandy RD, et al. Sagittal whole-spine magnetic resonance imaging in 750 consecutive outpatients: accurate determination of the number of lumbar vertebral bodies. J Neurosurg Spine. 2010;12(1):47-55.
21. Carrino JA, Campbell PD, Jr., Lin DC, Morrison WB, Schweitzer ME, Flanders AE, et al. Effect of spinal segment variants on numbering vertebral levels at lumbar MR imaging. Radiology. 2011;259(1):196-202.
22. Tokgoz N, Ucar M, Erdogan AB, Kilic K, Ozcan C. Are spinal or paraspinal anatomic markers helpful for vertebral numbering and diagnosing lumbosacral transitional vertebrae? Korean J Radiol. 2014;15(2):258-66.
23. Farshad-Amacker NA, Lurie B, Herzog RJ, Farshad M. Interreader and intermodality reliability of standard anteroposterior radiograph and magnetic resonance imaging in detection and classification of lumbosacral transitional vertebra. Spine J. 2014;14(8):1470-5.
24. Farshad M, Aichmair A, Hughes AP, Herzog RJ, Farshad-Amacker NA. A reliable measurement for identifying a lumbosacral transitional vertebra with a solid bony bridge on a single-slice midsagittal MRI or plain lateral radiograph. The Bone & Joint Journal. 2013;95-B(11):1533-7.
25. Hou L, Bai X, Li H, Gao T, Li W, Wen T, et al. Lumbar plain radiograph is not reliable to identify lumbosacral transitional vertebra types according to Castellvi classification principle. BMC Musculoskelet Disord. 2020;21(1):333.
26. Hanhivaara J, Määttä JH, Niinimäki J, Nevalainen MT. Lumbosacral transitional vertebrae are associated with lumbar degeneration: retrospective evaluation of 3855 consecutive abdominal CT scans. Eur Radiol. 2020;30(6):3409-16.



Chapter 4

Diagnostic Precision in Lumbar Radiculopathy: Impact of Transitional Vertebrae on Treatment Level Selection and Outcomes

Liebrand B, van der Wal S, Slob M, Boon A, Henssen D, Van Zundert J,
van der Weegen W, Vissers K.

Pain Med. 2025 Oct 1;26(10):681-688.
doi: 10.1093/pm/pnaf061.PMID: 40408166

§4.1 Abstract

Background

In patients with lumbosacral transitional vertebrae, discrepancies in determining the correct vertebral level of lumboradicular pain occur. This study evaluates the consequences of the real-world diagnostic process and subsequent treatment differences due to misidentified levels.

Methods

This retrospective analysis used prospectively collected data on involved spinal levels (February 2016 - October 2022) reported in the referrals, MRI- and treatment reports. Variables analyzed included the number of referrals, consultations, invasive treatments, duration of treatment, radiographs, operations, and hospitalization. Independent clinical researchers conducted vertebral counting, transitional vertebra classification, and wrong level determination using standard methods.

Results

Of a total of 4184 patients assessed, 214 included patients (5.1%) with lumbosacral transitional vertebrae were divided into three groups: correct level determination (72), wrong level determination (36) and ambiguous level diagnosis (106). The ambiguous level group had more consultations, interventional treatments, radiographic diagnostics, longer treatment duration and more referrals to other hospitals ($p<0.04$) at the pain management department and significantly less consultations of other specialisms (p 0.01-0.02) compared to the other groups due to uncertain level diagnosis. Discrepancies between reported MRI- and treatment levels in the records increased the chance for wrong level treatment ($p<0.001$).

Conclusion

In patients with lumbosacral transitional vertebrae and lumboradicular pain, discrepancies between referral, MRI, and treatment levels are common, leading to uncertain diagnoses and treatment due to incorrect level determination. Interdisciplinary consultation to reach consensus on the most appropriate spinal level for treatment and clear spine images may prevent such discrepancies. A multicentre study with a larger patient sample is strongly recommended.

§4.2 Summary

In patients with lumbosacral transitional vertebrae discrepancies in level diagnosis of lumboradicular pain often occurs, more accuracy of the exact anatomical level determination should be formulated and implemented.

This study evaluates the real-life diagnostic process and consequences in terms of the number of the referrals, consultations and treatments, treatment episodes, radiographs, operations, and hospitalization days.

Potentially longer healthcare pathways with more consultations and treatments occur. Therefore, interdisciplinary consultation between involved physicians should take place to obtain consensus about the correct spinal level determination.

§4.3 Introduction

The human spine generally consists of seven cervical, twelve thoracic and five lumbar vertebrae resulting in twenty-four mobile vertebrae (MV). Spine anomalies, like thoracic and lumbar transitional vertebrae, cause variations in the number (i.e., 23, 24 or 25) of MV (1, 2). Eleven, twelve or thirteen thoracic and four, five, or six lumbar vertebrae (LV) in seven different combinations are possible (3-6).

The segmental development of vertebrae, a process called somitogenesis, takes place during the organogenesis in the embryonal period (7). The subdivision into cervical, thoracic, lumbar, and caudal regions is controlled by a set of transcription factors located on the so-called Hox genes. The variations in the number of vertebrae in these regions originate from errors in these Hox genes (8).

The presence of thoracolumbar and lumbosacral transitional vertebrae (LSTV) in patients with lumboradicular pain causes significant diagnostic level discrepancies if doctors do not pay special attention to these anatomical variations, especially since there is no daily clinical applicable golden standard to determine the exact anatomical level of lumboradicular pain (9, 10). Transitional vertebrae are often overlooked because of the limitations (only sagittal and axial images) of standard spine MRI protocols (11, 12) whichprevents correct identification of the thoracolumbar and lumbosacral junction, hypoplastic ribs and transverse processes (10, 13).

The risks and consequences of operating on patients with LSTV at the wrong level (WL) have been described well in spine surgery (14-16). In invasive pain management there is no golden standard for level determination or evaluation of WL treatment available in literature. The current best practice for level determination in patients with LSTV is to count the vertebral bodies

starting from C2 and moving caudally (17). In interventional pain medicine the current practice for lumbar level determination is counting from T12 with the lowest rib bearing vertebrae, caudally (18). Wrong level procedures may prove less effective: thus, precise and consistent determination of vertebral levels is imperative in procedure planning and performance.

This clinical observational study explores the amount and consequences of possible wrong-level determination and treatment in a cohort of patients with LSTV. The analyzed variables are referrals to- and the number of consultations and interventional treatments within the pain management department (PMD), the consultations of all involved physicians, the number of X-rays and MRI's, operations, days in the hospital and transfers to other hospitals.

Furthermore, patients with available whole spine images were analyzed to explore specific patterns and possible influence on the counting process. The amount MV and LV will be related.

§4.4 Methods

Ethics

This research was approved by the Maxima Medical Center Regional Committee of Medical Ethics (N18.166).

Patients

In a general community hospital, all patients referred to the PMD between February 2016 and October 2022 and diagnosed, according to the Dutch Health Care Authority code system (19), with acute, subacute, or chronic neurologic lower back pain with radiation to the legs were screened for LSTV.

Two experienced and Fellow of Interventional Pain Practice (FIPP)-certified pain physicians (World Institute of Pain Certification program) assessed all patients consecutively and identified LSTV by fluoroscopy during their regular interventional pain treatments. The eligibility criteria for possible inclusion were (1) diagnosis according to the Dutch Health Care Authority code system, (2) indication for invasive treatment of the lumbar spine (transforaminal and intralaminar epidural procedures), (3) confirmation of LSTV (either sacralization or lumbarization) identified with fluoroscopic images as part of the regular pain interventional treatment and (4) additional available MR images of the complete LS, including the most caudal thoracic vertebrae and the sacrum. Exclusion criteria were (1) no LSTV during the secondary assessment by the principal investigator (PI), (2) absence of MR images of the lumbar spine and (3) no appropriate radiological images available (X-ray or CT- imaging) diagnosing a TLTV, determination of the first lumbar vertebrae, classification of the LSTV and counting the number of lumbar vertebrae.

Demographic, medical data and other variables were collected from the hospital electronic patient files and were entered into a study specific data collection system (Castor Electronic Data Capture 2012)(20). Before considering including patients in the study, the fluoroscopy images of all patients with a possible LSTV were reviewed retrospectively by the principal investigator in a secondary assessment.

Counting and classifying the lumbar vertebrae in the research group.

A pain physician and radiologist independently identified the first LV, counted the number of LV, and classified the lumbosacral transition in all eligible patients. In a next step, they tried to reach consensus on their findings. If consensus was reached, the patient could be included in this study. If consensus could not be reached, the patient was excluded.

Fluoroscopic images with 30º cranio-caudal angle, X-rays of the lumbar spine, abdomen, thorax, and CT scans were used in this part of the research. The first LV was determined according to criteria set by Park et al. (21). A thoracic vertebra is identified by the presence of paired ribs that are 3.8 cm or more in length and originate from the facet at the pedicle (or body of the vertebra). The counting of LV was conducted in a craniocaudal manner as reported by Hinterdorfer et al. (22). If four LV were present and the fifth assimilated with the sacrum it was classified as sacralization, the presence of six LV was classified as lumbarization. The LSTV was classified according to Castellvi (23). To ensure best practice in the study, we compared the used methods with those recommended in an interventional spine specialist's practical approach for treatment (24).

Determination of correct and wrong diagnosis and treatment levels

In the study group, the diagnostic and treatment levels recorded in medical files may not accurately reflect the true levels in patients with LSTV if the number of LV is misidentified during MRI reporting or the clinical decision-making process. To establish the true diagnostic levels, MRI scans were utilized, while fluoroscopic images were used for determining true treatment levels, both in relation to the number of lumbar vertebrae identified previously. Counting was performed in a craniocaudal order, and vice versa. In cases with six lumbar vertebrae, the counting began caudally at six, continuing with five and four. The pain physician and a second researcher, a certified clinical neurologist, independently performed this part of the research. Any discrepancies or disagreements were addressed in consensus meetings.

Patients were categorized into three groups. When the researchers agreed on the true levels of diagnosis and treatment, patients were assigned to either the correct level determination group (CLD) or the wrong level determination (WLD). In case of a disagreement, patients were placed in the third group, the ambiguous determination group (ALD). In this group, a true level could not be confidently determined, primarily due to unclear or multilevel mentioning of the affected level in the MRI report or incomplete fluoroscopic image storage. Figure 1 shows an example of a patient referred to the PMD with an incorrect level nomination in the report and a correct treated level.

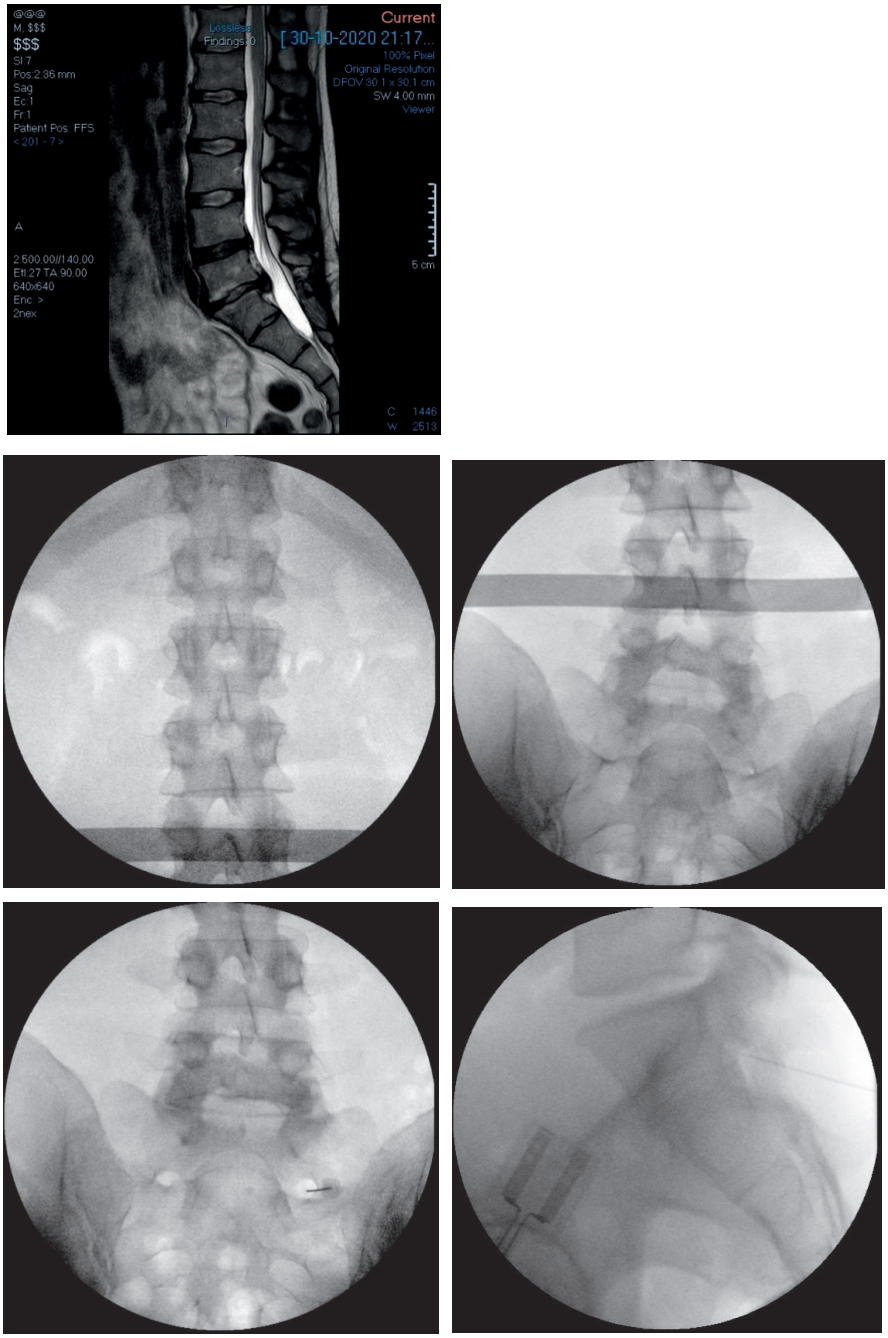


Figure 1: A patient with an incorrect level nomination in the report and a different true treated level. MRI report level: L5/S1. Referral level report: L5. Treatment level report S1.

Relating the amount of MV and LV.

The counting process of the MV was similar to that performed by Chiu et al. (6) assuming seven cervical vertebrae and counting from the first thoracic level. If clear images of the thoracic and lumbar spine with accurate vertebrae counting possibilities were available, patients were included; otherwise, they were excluded. The pain physician and radiologist performed this part of the research independently, a consensus meeting was held afterwards. The amount of MV were related to the amount of LV.

Statistics

All statistical analyses were performed in IBM SPSS version 29 (IBM Corp., Armonk, NY). Descriptive statistics were used to characterize patient demographics. The analyses of the cross tabs with demographic data, referrals, amount of LV and MV, differences and similarities in reported and true levels in the referrals and treatments and the analyzed clinical variables were performed with Chi square-, Fisher-Freeman Halton exact test, Phi and Cramer's V or Kendall's tau correlation when appropriate. The independent sample t-test was used to compare the means between patient groups. In all statistical testing a p value of < 0.05 was considered significant.

§4.5 Results

During the study period a total of 4184 patients were referred to the PMD and diagnosed with acute-/ subacute or chronic neurologic lower back and leg pain (figure 2). In this group, 269 patients (6.4%) were identified with an LSTV during fluoroscopy and met the primary inclusion criteria. 55 Patients were excluded, because no appropriate radiological images were available to classify an LSTV or count the number of LV, or because no consensus was met. A total of 214 patients (5.1%) were available for analysis. The mean age was 58.7 years, 132 were female and 82 were male. Demographic data are shown in table 1. Patients were divided in groups by the number of LV. When the Castellvi classifications and amount of LV were combined, a lumbarized S1 had significantly lower Castellvi classifications and a sacralized L5 had higher classifications as found in the former research (6).

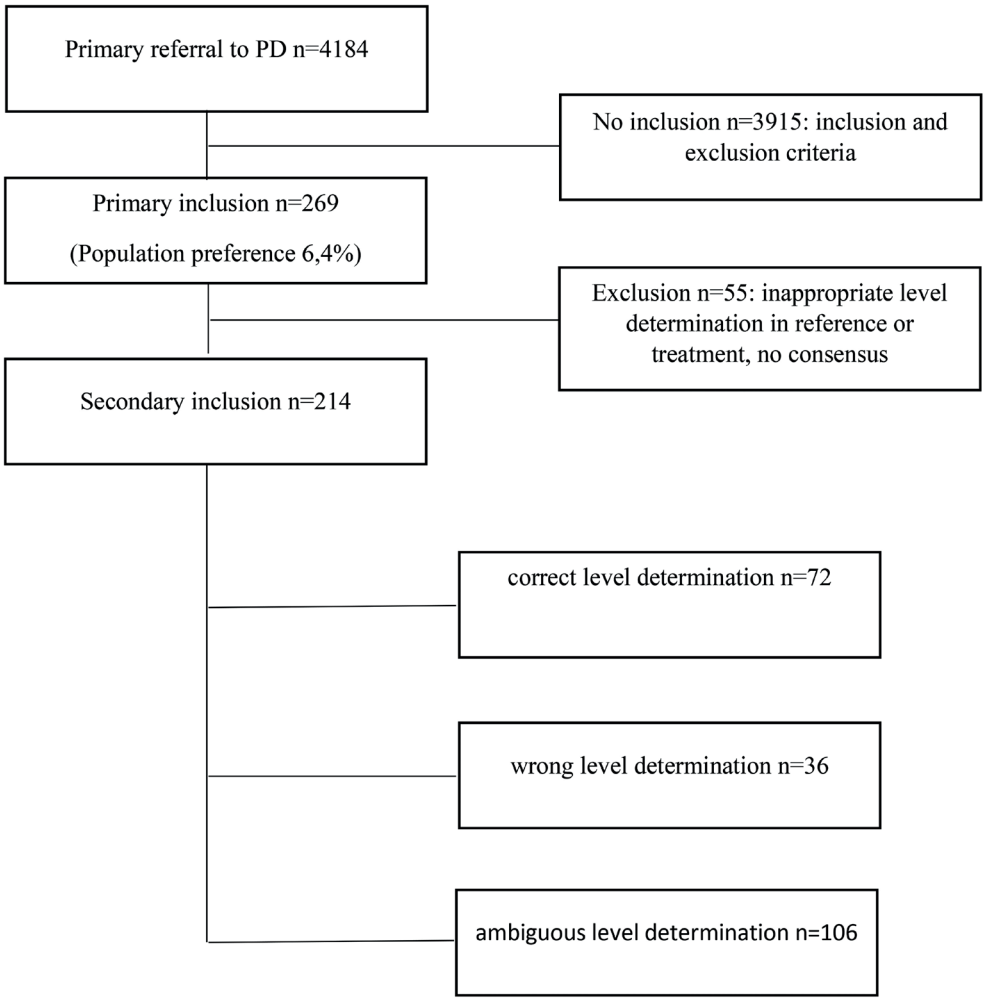


Figure 2: Flow chart of study population

Table 1: Patient characteristics of the research group and mobile vertebrae related to the number of lumbar vertebrae.

Variables	L6 (n^a=155)	L5 (n^a=25)	L4 (n^a=22)	Und (n^a=12)	Total (n^a=214)	P-value
Mean age (sd) in years	58.5 (15.4)	61.3 (15.9)	59.6 (16.9)	53.8 (15.9)	58.7 (15.6)	0.694
Male (n%)	54 (25)	12 (6)	11 (5)	5 (2)	82 (38)	0.375
Female (n%)	101 (47)	13 (7)	11 (5)	7 (3)	132 (62)	
Mobile vertebrae (n^b=68)						
23	0	0	5	-	5	<0.001
24	15	4	3	-	22	<0.001
25	39	2	0	-	41	<0.001
Totals	54	6	8	-	68	

Abbreviations: L6 L5 L4 amount of LV; Und, undetermined; sd, standard deviation; n^a, number whole research group; n^b number of patients with total spine images.

Independent sample t-test to compare means and cross tabs with chi square or Phi and Cramer's V to compare proportions. P-value calculated between the L6 L5 L4 and Und group in its entirety.

In 68 cases the number of all mobile, thoracic, and lumbar vertebrae could be determined (table 1). Patients with 24 and 25 MV had significantly more six LV and patients with 23 MV had more 4 LV (Fisher-Freeman-Halter exact test p <0,001). The correlation (Kendall's tau) between the amount of LV and total amount of vertebrae was moderate positive (0,56). These findings indicate that, in cases of transitional vertebrae, counting levels is less accurate if images of the whole spine are not available. Patients with an anomalous number of mobile vertebrae are more likely to have an anomalous number of lumbar vertebrae (3, 6).

Analyses of potential discrepancies between the reported levels of the referral, MRI and treatment were possible in 147 patients. Discrepancies between the reported referral- and MRI levels were found in 58 cases (27.1%), between reported treatment- and MRI levels in 89 cases (32.2%).

In 72 patients (33.7%) determination and treatment were at a correct anatomical level, mean age 58,7 (sd 16.5). 36 Patients (16.8%) determination and treatment were performed at a wrong anatomical level, mean age 54.6 (sd 16.2). In 106 patients (49.5%), the researchers were unable to determine with certainty the correct anatomical or treatment level due to the mentioning of more than one affected level as a possible cause of the lumboradicular pain, mean age 58.9 (sd 15.2). These patients were categorized in the ambiguous determination group. The demographic data between the three groups did not differ significantly.

Table 2 presents the referrals of the involved physicians to the PMD in the three groups. The CLD WLD groups received 78% (102 of 131) of their referrals from the neurology- and neurosurgery department. In the ALD group, 92% (68 of 74) of the referrals originated from the general practitioners and orthopedic surgery department. The differences in the origin of the referrals between the groups are significant (p 0.001).

Table 2: Overview of the referrals per medical specialty divided into the three groups.

Referral by:	CLD	WLD	ALD	Total
General practitioner	2 (0.9)	2 (0.9)	45 (21)	49 (22.9)
Neurologist	58 (27.1)	29 (13.6)	23 (10.7)	110 (51.4)
Neurosurgeon	11 (5.1)	4 (1.9)	6 (2.8)	21 (9.8)
Orthopedic surgeon	1 (0.5)	1 (0.5)	23 (10.7)	25 (11.7)
Other	0	0	7 (3.3)	7 (3.3)
Unknown	0	0	2 (0.9)	2 (0.9)
Total	72	36	106	214 (100)

Absolute values n and (percentages).
Abbreviations groups: CLD correct level determination; WLD wrong level determination; ALD ambiguous level determination.

Table 3 shows the consequences of discrepancies between the reported referral and MRI levels with the true treated levels in the medical records for both correct and wrong level determination. These analyses include 97 valid cases of the possible 108 (CLD and WLD).

The Pearson Chi square test results yielded p values of 0.18 (1df, n 97) in the analysis of the differences between the referral and treatment level, and < 0.001 (1df, n 97) in the analysis of differences between the MRI- and treatment level. Discrepancies between the level reported on MRI and treated levels in the medical records are associated with an increased likelihood of patients receiving treatment at an incorrect level.

Table 3: cross tab with analyzation of correct and wrong level treatment due to differences of level nomination in the records.

Variables		CLD	WLD	Total
Difference between reported referral- and treatment level	No/ partly same[a]	44 (45.4[b])	21 (21.6[b])	65
	Yes	23 (23.7[b])	9 (9.3[b])	32
	Total	67	30	97
Difference between reported MRI- and treatment level	No/ partly same[a]	40 (41.2[b])	18 (18.6[b])	58
	Yes	27 (27.8[b])	12 (12.4[b])	39
	Total	67	30	97

Abbreviation: n number; CLD correct level determination; WLD wrong level determination.
a: No difference between the reported levels in the files or two levels treated one corresponded with the mentioned referral level.
b: values in percentages.

Table 4 presents the clinical variables analysed between the three groups, using independent sample t-tests. The ALD group had a higher number of consultations and interventional pain treatments, a longer treatment period at the PMD, and more radiographs of the lumbar spine compared to the CLD and WLD groups. Furthermore, patients in the ALD had significantly fewer consultations at the neurology, neurosurgery, and other spine-related departments, fewer days of hospitalization, and fewer surgeries compared to the CLD and WLD groups. The patients in the ALD group experienced a different healthcare path. They were in the majority referred by general practitioners and orthopaedic surgeons with an uncertain level diagnosis and had therefore more consultations and treatments within the PMD instead of referrals by neurologists with clear level diagnosis and a treatment target. No significant differences were found between the CLD and WLD groups for any of the variables.

Table 4: Analyses of variables between the three groups.

Groups:	CLD	WLD	ALD	P[a]
Variables in means:				
Cons PMD	4.9	5.0	6.4	0.28
Invasive treatments PMD	3.5	3.5	3.8	0.45
Surgeries	0.63	0.57	0.51	0.40
X-LS	1	0.9	1.2	0.25
MRI-LS	2.3	2.6	2.4	0.41
Treatment duration (m)	19.3	19.7	24.1	0.16
Cons neurology	4	3.5	2.4	<0.01
Cons neurosurgery	1.5	1.5	0.8	0.02
Cons other physicians	6.1	5.5	4.3	0.01
Days in hospital	0.85	1.8[b]	0.4	0.1
Referral other hospital	0.24	0.43	0.41	0.04

Abbreviations: CLD correct level determination; WLD wrong level determination; ALD ambiguous level determination; cons consultations; X-LS Xray lumbar spine; m months.
a: all p values obtained from the underlined groups.
b: four people in this group had hospitalizations of 8 days or more due to other reasons.

§4.6 Discussion

This is the first study to examine the consequences of discrepancies in diagnostic and treatment levels in patients with LSTV. Analysis of 214 patients revealed that 72 (33.6%) received treatment at the correct level and 36 (16.9%) received treatment at an incorrect level. Additionally, 106 (49.5%) had an ambiguous level determination due to mentioning of more than one affected level as possible cause of the lumboradicular pain. This may impact accurate treatment. Patients in the first two groups were significantly more often referred by the neurology and neurosurgery department and had more consultations within this department. When discrepancies between the reported MRI level and the treated level occur, the likelihood of incorrect treatment increases. The group with ambiguous diagnosis had significant more referrals form general practitioners and orthopedic surgeons and more consultations, treatments, and longer treatment duration at the PMD. This suggests that precise level determination based on referral and radiological imaging may not be feasible. As a result, the patients with ambiguous transitional vertebral anatomy often follow potentially more expensive and prolonged clinical pathways compared to those with clearly defined levels of pathology.

Discrepancies between the reported referred- and MRI levels versus the reported treated levels occurred in 27.1% and 32.2% of cases, respectively. These percentages are lower than those reported in a previous study at this hospital (40% and 46%) (9), likely due to factors such as

increased awareness of LSTV among radiologists, a higher incidence of matched levels in patients with a 5 LV anatomy, and the potential adjustment of treatment levels by neurologists or pain specialists based on the MRI report.

In 36 patients wrong level treatment was observed. Factors contributing to this include variability in clinical decision-making, differences in the function of lumbosacral nerve roots in LSTV patients, and discrepancies in MRI report level determination. Pain specialists faced challenges in determining the correct level based on both clinical and MRI data. Jensen et al. (25) noted that lumboradicular pain diagnosis relies on symptom presentation and clinical examination. However diagnosing the correct level in lumbar radiculopathy with most physical tests used to identify lumbar disc herniation has a poor performance (26), which is not surprisingly due to the substantial anatomical variations in the lumbosacral plexus (27). A systematic review on neurological clinical examination in lumbar disc herniation found poor diagnostic accuracy (e.g., sensitivity of 0.32) for radiologically confirmed disc herniation, reinforcing the challenge of precise level determination in LSTV cases (28).

Additionally, Seyfert et al. found a variant position of lumbosacral dermatomes in the presence of transitional vertebrae (29). LSTV alters nerve root function. Neurological symptoms by compression of the lumbarized S1 or L6 resembles the L5 nerve root's usual function in the normal configuration (10) and sacralized L5 potentially resembles the L4 nerve root function (30). The variability in clinical presentation in patients with LSTV is further demonstrated by Hinterdorfer et al., who found both similarities and differences between patients with six and five LV configurations (22). Therefore, the clinical decision-making process in the presence of lumbosacral transitional vertebrae is potentially inaccurate and creates a substantial risk of wrong level diagnosis and treatment.

In Dutch hospitals, T1 and T2 weighted spin-echo images in sagittal and axial planes on MRI are the standard protocol for diagnosing a lumbar disc herniation (12). Similar protocols are employed internationally, suggesting that diagnostic level inaccuracies are not unique to this setting (31, 32). Radiologists count from the presumed fifth lumbar level upwards with patients in supine position while interventional pain specialists determine their level using real-time posterior-anterior fluoroscopic images with patients in prone position. This difference in methodology is a key risk factor for wrong-level treatment, as shown by this and other studies (33, 34). Improved accuracy is achievable with radiological diagnostics in patients with LSTV (35). Inter-rater reliability was very good for detection (k=0.93) and classification (k=0.83) LSTV in coronal MRI. However, coronal imaging is not routinely employed for diagnosing lumboradicular pain in clinical practice.

To date, the golden standard for level determination in the spine remains counting from C2 caudally on whole spine images (17). In the present study, patients with 23 MV had significantly

more four LV, whereas patients with 24 or 25 MV had significantly more six LV. Other studies have also documented these variations in the number of MV and the seven possible combinations of thoracic and lumbar vertebrae in patients with LSTV (1, 3-6). In the absence of whole spine images in routine clinical practice, health care providers must consider these variations when diagnosing and treating spinal anomalies (36). Clinical recommendations to overcome wrong level procedures are based on the recognition of the factors that lead to wrong level procedures (37, 38), whereas the interventional specialist is an irreplaceable piece in mitigating this risk (38, 39), a preprocedural protocol for prevention including communication might improve patients outcome (15, 40). Assessing true spinal counts with clear spine images during procedures is recommended in most studies (41-45)

This study provides insights into the daily clinical practice of treating patients with lumboradicular pain and spinal anomalies. It has a few limitations. The study was conducted in a single centre, although the literature describes similar clinical challenges for physicians in hospitals of other countries and due to limited radio diagnostic protocols the presence of LSTV is probably underestimated here as well (45, 46) . We were unable to analyse the patient-reported outcome measures, as this evaluation started in 2019 and was fully operational in 2020. Consequently, the data analysed was not yet representative for the clinical outcomes. Although we examined all other potential clinical variables, the lack of significance between the CLD and WLD groups may be due to the small sample size, treatment duration and the ignorance about the consequences of wrong level treatment in pain medicine. The subject is absent in the literature of pain medicine. The lack of mentioning a specific pathology level in the referrals in half of the patients in the research group reduces the size of the CLD and WLD groups. Independent researchers conducted the study however, it is important to note that full exclusion of bias may not be possible without a reference- or a golden standard in this retrospective study. A multicentre study with a larger patient population to explore patient reported outcome measures is recommended. Total spine imaging protocols as a reference standard should be included (44-46).

§4.7 Conclusion

In patients with LSTV and lumboradicular pain, discrepancies between referral, MRI, and treatment levels often result in uncertain diagnoses andtreatments at incorrect levels. This contributes to longer and more costly healthcare pathways. Interdisciplinary consultation, and whole spine imaging, for consensus on the most appropriate spinal level for treatment may help prevent such discrepancies, as suggested by other research (15, 34, 43-45, 47). A multicentre study with a larger patient sample is strongly recommended to establish and confirm protocols for recognizing transitional anatomy in treatment pathways.

§4.8 References

1. Tins BJ, Balain B. Incidence of numerical variants and transitional lumbosacral vertebrae on whole-spine MRI. Insights Imaging. 2016;7(2):199-203.
2. Wigh RE. The thoracolumbar and lumbosacral transitional junctions. Spine (Phila Pa 1976). 1980;5(3):215-22.
3. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, et al. The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul). 2020;15(1):103-10.
4. Tatara Y, Niimura T, Sekiya T, Mihara H. Changes in Lumbosacral Anatomy and Vertebral Numbering in Patients with Thoracolumbar and/or Lumbosacral Transitional Vertebrae. JB JS Open Access. 2021;6(3).
5. Gonzales-Portillo GS, Rizvi O, Avila MJ, Dumont TM. The prevalence of 11 ribs and its potential implications in spine surgery. Clin Neurol Neurosurg. 2021;203:106544.
6. Chiu CK, Chin TF, Chung WH, Chan CYW, Kwan MK. Variations in the Number of Vertebrae, Prevalence of Lumbosacral Transitional Vertebra and Prevalence of Cervical Rib Among Surgical Patients With Adolescent Idiopathic Scoliosis: An Analysis of 998 Radiographs. Spine (Phila Pa 1976). 2024;49(1):64-70.
7. Iimura T, Denans N, Pourquié O. Establishment of Hox vertebral identities in the embryonic spine precursors. Curr Top Dev Biol. 2009;88:201-34.
8. Dias MS. Normal and abnormal development of the spine. Neurosurg Clin N Am. 2007;18(3):415-29.
9. Liebrand B, Brakel K, Boon A, van der Weegen W, Wal SV, Vissers KC. Diagnostic treatment-level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies. Reg Anesth Pain Med. 2022;47(3):177-82.
10. Chang HS, Nakagawa H. Altered function of lumbar nerve roots in patients with transitional lumbosacral vertebrae. Spine (Phila Pa 1976). 2004;29(15):1632-5; discussion 5.
11. Akbar JJ, Weiss KL, Saafir MA, Weiss JL. Rapid MRI detection of vertebral numeric variation. AJR Am J Roentgenol. 2010;195(2):465-6.
12. Robin Smithuis RdotRhiL, the Netherlands. . Lumbar Disc Herniation and other causes of nerve compression: Educational site of the Radiological Society of the Netherlands; 2014 [updated 2014-12-14. Available from: https://radiologyassistant.nl/neuroradiology/spine/lumbar-disc-herniation#mri-protocol.
13. Konin GP, Walz DM. Lumbosacral transitional vertebrae: classification, imaging findings, and clinical relevance. AJNR Am J Neuroradiol. 2010;31(10):1778-86.
14. Naqvi AZ, Magill H, Anjarwalla N. Intraoperative practices to prevent wrong-level spine surgery: a survey among 105 spine surgeons in the United Kingdom. Patient Saf Surg. 2022;16(1):6.
15. Srivatsa S, Vira S, Schils J, Shook S, Gill A, Krishnaney AA. Reducing Wrong-level Spinal Surgeries Through Root Cause Analyses: A 10-year Longitudinal Analysis of a Single Tertiary Institution's Iterative Policy Improvements. Spine (Phila Pa 1976). 2021;46(11):E648-e54.
16. Saito R, Fujibayashi S, Shimizu T, Murata K, Otsuki B, Onishi E, et al. Wrong-level spine surgery: A multicenter retrospective study. J Orthop Sci. 2023.
17. Lian J, Levine N, Cho W. A review of lumbosacral transitional vertebrae and associated vertebral numeration. Eur Spine J. 2018;27(5):995-1004.

18. Fellow of Interventional Pain Practice (FIPP)® Examinations, provided by the World Institute of Pain [Available from: https://www.worldinstituteofpain.org/fipp-examination/.
19. Nederlandse Zorgautoriteit 2023 [Available from: https://puc.overheid.nl/nza/.
20. Castor Electronic Data Capture 2012 [Available from: www.castoredc.com.
21. Park SK, Park JG, Kim BS, Huh JD, Kang H. Thoracolumbar junction: morphologic characteristics, various variants and significance. The British Journal of Radiology. 2016;89(1064):20150784.
22. Hinterdorfer P, Parsaei B, Stieglbauer K, Sonnberger M, Fischer J, Wurm G. Segmental innervation in lumbosacral transitional vertebrae (LSTV): a comparative clinical and intraoperative EMG study. Journal of Neurology, Neurosurgery & Psychiatry. 2010;81(7):734-41.
23. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984;9(5):493-5.
24. Furman MB, Wahlberg B, Cruz EJ. Lumbosacral Transitional Segments: An Interventional Spine Specialist's Practical Approach. Phys Med Rehabil Clin N Am. 2018;29(1):35-48.
25. Jensen RK, Kongsted A, Kjaer P, Koes B. Diagnosis and treatment of sciatica. Bmj. 2019;367:l6273.
26. van der Windt DA, Simons E, Riphagen, II, Ammendolia C, Verhagen AP, Laslett M, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. The Cochrane database of systematic reviews. 2010(2):CD007431.
27. Matejcík V. Anatomical variations of lumbosacral plexus. Surg Radiol Anat. 2010;32(4):409-14.
28. Al Nezari NH, Schneiders AG, Hendrick PA. Neurological examination of the peripheral nervous system to diagnose lumbar spinal disc herniation with suspected radiculopathy: a systematic review and meta-analysis. Spine J. 2013;13(6):657-74.
29. Seyfert S. Dermatome variations in patients with transitional vertebrae. J Neurol Neurosurg Psychiatry. 1997;63(6):801-3.
30. Kim YH, Lee PB, Lee CJ, Lee SC, Kim YC, Huh J. Dermatome variation of lumbosacral nerve roots in patients with transitional lumbosacral vertebrae. Anesthesia and analgesia. 2008;106(4):1279-83.
31. Pojskic M, Bisson E, Oertel J, Takami T, Zygourakis C, Costa F. Lumbar disc herniation: Epidemiology, clinical and radiologic diagnosis WFNS spine committee recommendations. World Neurosurg X. 2024;22:100279.
32. Zhang AS, Xu A, Ansari K, Hardacker K, Anderson G, Alsoof D, et al. Lumbar Disc Herniation: Diagnosis and Management. Am J Med. 2023;136(7):645-51.
33. Berger R, Bulloch L, Hysong A, Huggins B, Horan N, Van Der Noord R, et al. Establishing a common language for lumbar transforaminal epidural steroid injections. J Spine Surg. 2021;7(4):467-74.
34. Grimm BD, Laxer EB, Blessinger BJ, Rhyne AL, Darden BV. Wrong-Level Spine Surgery. JBJS reviews. 2014;2(3).
35. Farshad-Amacker NA, Lurie B, Herzog RJ, Farshad M. Interreader and intermodality reliability of standard anteroposterior radiograph and magnetic resonance imaging in detection and classification of lumbosacral transitional vertebra. Spine J. 2014;14(8):1470-5.
36. Krenn VA, Fornai C, Webb NM, Woodert MA, Prosch H, Haeusler M. The morphological consequences of segmentation anomalies in the human sacrum. Am J Biol Anthropol. 2022;177(4):690-707.
37. George KJ. Wrong site spine surgery in the U.K.: a review of current practice. Br J Neurosurg. 2023;37(5):1131-4.

38. Epstein N. A perspective on wrong level, wrong side, and wrong site spine surgery. Surg Neurol Int. 2021;12:286.
39. Albano S, Brown NJ, Pennington Z, Nguyen A, Hsu TI, Pham MH, et al. Risks Associated with Surgical Management of Lumbosacral Transitional Vertebrae: Systematic Review of Surgical Considerations and Illustrative Case. World Neurosurg. 2024;186:e54-e64.
40. Algie CM, Mahar RK, Wasiak J, Batty L, Gruen RL, Mahar PD. Interventions for reducing wrong-site surgery and invasive clinical procedures. Cochrane Database Syst Rev. 2015;2015(3):Cd009404.
41. Nakagawa T, Hashimoto K, Tsubakino T, Hoshikawa T, Inawashiro T, Tanaka Y. Lumbosacral Transitional Vertebrae Cause Spinal Level Misconception in Surgeries for Degenerative Lumbar Spine Disorders. Tohoku J Exp Med. 2017;242(3):223-8.
42. Devine J, Chutkan N, Norvell DC, Dettori JR. Avoiding wrong site surgery: a systematic review. Spine (Phila Pa 1976). 2010;35(9 Suppl):S28-36.
43. MG M, A N, DL S, M G, M A, KJ G. The prevalence of wrong level surgery among spine surgeons. Spine. 2008;33(2):194-8.
44. Vitale M, Minkara A, Matsumoto H, Albert T, Anderson R, Angevine P, et al. Building Consensus: Development of Best Practice Guidelines on Wrong Level Surgery in Spinal Deformity. Spine Deform. 2018;6(2):121-9.
45. Thawait GK, Chhabra A, Carrino JA. Spine segmentation and enumeration and normal variants. Radiol Clin North Am. 2012;50(4):587-98.
46. Neelakantan S, Anandarajan R, Shyam K, Philip B. Multimodality imaging in Bertolotti's syndrome: an important cause of low back pain in young adults. BMJ Case Rep. 2016;2016.
47. Lee SH, Kim JS, Jeong YC, Kwak DK, Chun JH, Lee HM. Patient safety in spine surgery: regarding the wrong-site surgery. Asian Spine J. 2013;7(1):63-71.



Chapter 5

Accuracy in Spinal Level Determination, Including Transitional Vertebrae: An ASReview supported Systematic Review.

Liebrand B, Braunhofer L, van der Weegen W, Vissers K, Van Goethem J, Van Zundert J, van den Boogaart M, van der Wal S.

Eur Spine J. 2026 Apr 20.
doi: 10.1007/s00586-026-09925-x.

§5.1 Abstract

Purpose

Accurate spinal level determination is crucial in spinal imaging and in interventional procedures of the spine. In particular, transitional vertebrae can significantly complicate accurate level identification. This systematic review aims to assess the accuracy of conventional and advanced methods for spinal level determination, with particular attention to thoracic and lumbar transitional vertebrae.

Methods

A literature search, supported by the machine learning tool ASReview, was conducted in PubMed Web of Science and Embase for studies published between 1962 and 2026, leading to the inclusion of twenty-nine relevant studies. These were categorized into three groups: conventional methods (fluoroscopy, US, CT, MRI, n = 20), transitional vertebrae-specific studies (n = 4), and advanced methods (intra-operative navigation, algorithms and machine learning, n = 5).

Results

With conventional methods, varying levels of accuracy were achieved with up to 100% accuracy reported in nine studies. In the studies involving transitional vertebrae no 100% was achieved. Inconsistencies in study designs, patient selection, and risk of bias were noted across the studies. This is considered representative for daily practice. The advanced methods showed an accuracy of 100% in most studies. Clinical recommendations of the existing literature on this topic are summarised.

Conclusions

This review highlights variability in radio-diagnostic use and level determination of spine procedures between medical specialists. Recognizing transitional vertebrae, clear intraoperative imaging, and collaboration between radiologists and interventionists are key. Preoperative MRI or CT scans should be compared with intra operative imaging and, a full spine image obtained if needed. Further research is needed to establish specialization transcending protocols for recognizing transitional anatomy during procedures. The advanced methods show promise, but their cost-effectiveness needs evaluation. Deep learning–based studies progress rapidly and have achieved near-perfect accuracy in detecting spinal anomalies; however, they are not yet applicable to routine clinical use.

§5.2 Introduction

Accurate determination of the correct spinal level for treating back- and radicular pain originating from the thoracic and lumbar spine can still be a radiologic and clinical challenge, particularly in the presence of transitional vertebrae. Wigh et al. were among the first to describe this challenge in transitional junctions of the spine in 1980 [1]. Wrong level treatment has persisted [2-4], with 50% of the American neurosurgeons reported having performed one or more wrong-level surgeries during their career [5], and to this day, transitional vertebrae continue to pose a risk for wrong-level treatment [6-8] with 1.3 % wrong-level surgeries reported in the systematic review of Albano et al. [6]. Notably, the interventional pain medicine literature, addressing this problem is scarce.

Thoracic transitional vertebrae (TLTV), are vertebrae that exhibit characteristics of both thoracic and lumbar vertebrae [9], have a prevalence of 3.4-4.8 % [10] and may result in 11, 12 or 13 thoracic vertebrae. Individuals with TLTV are more likely to present with lumbosacral transitional vertebra (LSTV) [11]. LSTV, refers to the lowest lumbar vertebra with enlarged transverse processes and a, by Castellvi classified anatomical relationship to the sacrum [12], may result in four, five or six lumbar vertebrae and have a 12% prevalence in the population [13]. If transitional vertebrae are present, seven possible combinations of thoracic- and lumbar vertebrae occur, resulting in a total of 23, 24 or 25 mobile vertebrae.

Magnetic resonance imaging (MRI) in supine position is probably the most used imaging modality for the diagnosis of neurologic lumbosacral radicular pain caused by degenerative disc disease [14]. In Dutch hospitals, standard MRI protocols typically include T1 and T2 weighted spin-echo images taken in sagittal and axial planes [15]. However, this protocol fails to detect transitional vertebrae due to limited imaging of the thoracolumbar and lumbosacral junction and therefore identification of the typical characteristics [16].

Level counting on MRI is unreliable [17] since the final rib is not an appropriate landmark for accurate spinal counting [7] and relying solely on sagittal images underestimates the presence of LSTV [18, 19]. Anomalous numbers of vertebrae are frequently discovered during interventional procedures [5] with an associated risk of inaccurate MRI or fluoroscopy based level nomination reaching 45-54% [6, 7, 11, 20]. Currently, there is no gold standard that will completely eliminate this risk, and accuracy data for the commonly used imaging modalities are lacking [4]. To our knowledge no previous reviews have analysed the entire process of spinal level determination and its accuracy in clinical practice.

The aim of this machine learning supported systematic review is to analyze the accuracies in spine level determination methods in general, with a particular focus on cases involving transitional vertebrae. We hypothesize that level determination is less accurate in patients with

LSTV. This review includes both level determination by conventional methods (fluoroscopy, x-ray, ultrasound, CT-scan MRI-scan) and advanced methods (intra-operative navigation (ION), 3d-2d algorithm, systematic deep-learning models (DLM)).

§5.3 Materials and Methods

This systematic review was conducted in accordance with the updated Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [21, 22]. The review protocol was registered in the PROSPERO database (International Prospective Register of Systematic Reviews) with the identification number: CRD42023416228 [23]. We used the PRISMA-trAIce checklist to enhance transparency in the reporting of AI assisted screening process [24]. The PICO method was used to refine the research question and search strategy, ensuring a focused and systematic approach. The population of interest included adult patients undergoing interventional thoracic and lumbar spine procedures (P). Eligible studies had to provide a clear description of the spinal determination process and report the accuracy of these methods (I). To allow for meaningful comparison, included studies were required to use an explicit reference standard for spinal level determination, such as intraoperative verification or validated image based methods (C). The primary outcome assessed was the accuracy in spinal level determination in clinical procedures (O).

Literature Search Strategy

A literature search was conducted in PubMed, and Web of Science for studies published between 1962 - 2026 and in Embase for studies between 2000-2026. Keywords were combined using Boolean operators with the complete search strategy detailed in Appendix 1. The search strings were developed collaboratively by the research team (all authors) in consultation with medical librarians of the Maastricht University to ensure its comprehensiveness and accuracy.

Study selection and data extraction

A preliminary search was performed using the web application Rayyan Qatar Computing Research Institute [25]. Four reviewers participated: two primary reviewers (Liebrand, Braunhofer) performed the complete review process in an independent and blinded manner and, were overseen by two secondary reviewers (van der Wal, van der Weegen). Titles and abstracts were screened against the in/exclusion criteria displayed in Appendix 2. After conflict resolution and full text assessment, 26 relevant and 365 irrelevant records were selected (Appendix 3), exported, deduplicated using EndNote and uploaded into ASReview [26] for further title/abstract screening. The researchers used classifier, model, balancing technique, query strategy settings for AI-assisted screening [27]. To rank articles by relevance, the researchers employed a Naïve Bayes classifier combined with Term Frequency-Inverse Document Frequency text mining [28]. Screening was terminated after 160 irrelevant records were encountered consecutively.

Eligible studies underwent full-text screening and were assessed for the type and quality of the counting process, level determination accuracy, and other predefined data which included: Journal type; country of origin; main research topic; involved medical specialties; research design (retrospective, prospective, other); demographic data; sample size (number of patients); specificity regarding transitional vertebrae; radiological methods used, including the region of the spine, scanning techniques employed; the use of a device for level determination; communication between medical professionals to improve accuracy; description of the level determination process; description of the counting process; accuracy statements.

The results were entered into a Microsoft Excel spreadsheet and categorized into three groups: (1) conventional level determination methods without transitional vertebrae, (2) with transitional vertebrae, and (3) advanced methods. During meetings with the secondary reviewers, the articles were further discussed, and final selections were made for analysis. To enhance methodological rigor, backward snowballing was applied to the references of the included articles any additional records identified were screened using the same eligibility criteria [29].

Data quality assessment

The Cochrane Methods Bias and Latitudes network websites were consulted to identify the most appropriate bias assessment tool for the review [30]. The QUADAS-2 assessment tool was selected and displayed in Appendix 4. After conducting a pilot test to ensure the suitability, an additional signalling question assessed whether level determination was performed by independent physicians, as single-physician assessments (e.g., fluoroscopy, ultrasound or CT by the same operator) were considered less reliable [31] and noted as a potential source of bias. Quality assessment scores were managed in Microsoft Office Access, as recommended by the University of Bristol [32]. Descriptive statistics were used for data analysis.

§5.4 Results

Literature search

The systematic search in PubMed Web of Science and Embase yielded 4344 articles after removal of duplicates. Of these, 4181 titles and abstracts did not meet the inclusion and were excluded. The remaining 163 articles underwent full review. Thirty-seven articles about the wrong topic were excluded, thirty-six for not reporting a counting or labelling process or an accuracy of the level determination, five for absence of full images, thirty described experimental development of level determination methods, three were case reports and one had the wrong language. Eight studies were excluded because their lumbar counting procedures on MRI could only be indirectly inferred from level nominations in images. These and the SDLM studies with a similar counting process, are displayed in Appendix 5. Eleven DLM-studies were excluded because the

level determination methods were evaluated in a pre-clinical setting. These are displayed in Appendix 6.

In total, 29 studies met the inclusion criteria, were analysed based on their counting process and level determination methods and categorized into the three groups.

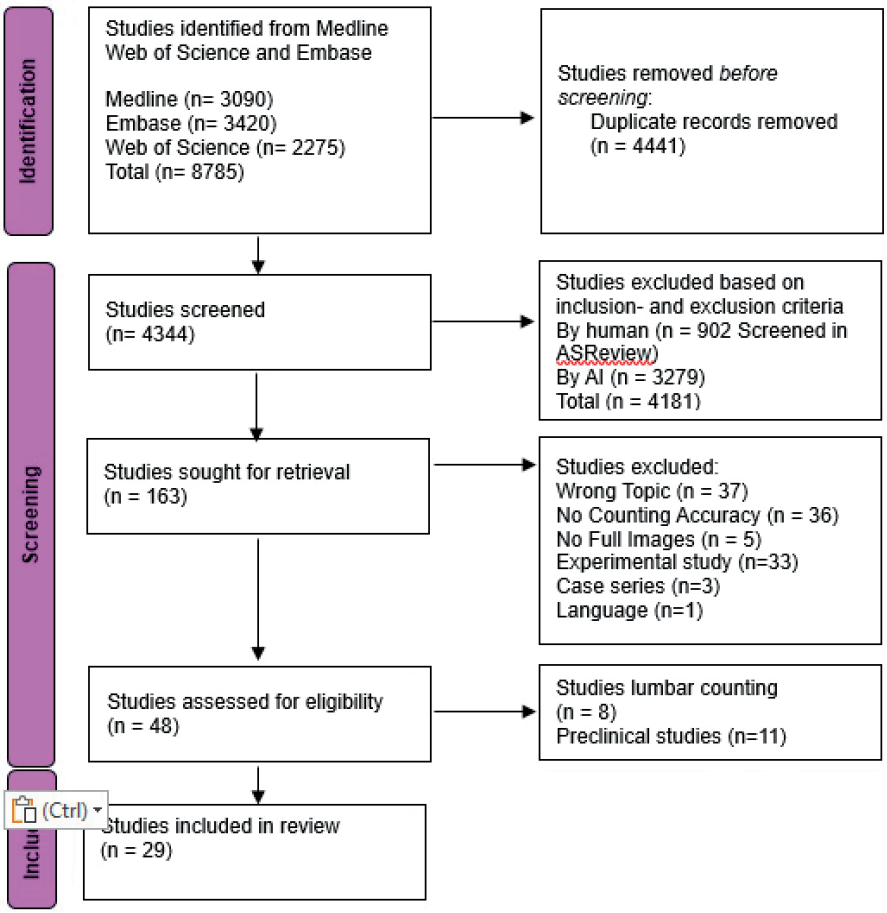


Figure I: Prisma flow chart of identification of studies from PubMed, Web of Science, and Embase.

5.4.1 Conventional level determination methods for the thoracic and lumbar spine without transitional vertebrae

Twenty studies addressed conventional level determination methods for the thoracic and lumbar spine and are summarized in Table I. The number of patients per study ranged from 14 to 1.986, with specialties including neurosurgery, neurology, radiology, anaesthesiology and orthopaedic surgery. The radio-diagnostic modalities used included fluoroscopy, ultrasound, CT, MRI, and their combinations.

Nine studies reported 100% accuracy, with varying sample sizes but small (n = 14-43) in four studies [33-36]. One of the nine used only fluoroscopy and performed thoracic level determination with a marker [33], the other eight used Xray, Ultrasound, CT, MRI, and combinations with fluoroscopy and markers. Three studies performed lumbar spine level determination [37, 38], five focused on thoracic vertebrae and only one used the whole spine as a reference [35]. Six studies began counting from C2 or T1 and proceeded caudally. Patel Upadhuyaya and Yu counted from S1 cranially. Notably Krishnan and Siminski specifically analysed communication between involved physicians for improving accuracy, only Siminski achieved 100%. Givens reported a kappa of 1.00 for intra-rater agreement in one of the five participants regarding the distance to a landmark vertebra. Level determination using landmarks by trauma surgeons had an accuracy 40% [39].

Table I: Counting process and level determination with conventional radio diagnostic methods.

Study (ref) (year)	Country	Patients	Involved med spec	Index-test	Device	Reference standard	Level determination	Accuracy
Ahmadi [40] (2014)	Germany	96	N-R	CT-t	Wire	CT-t	T1 caud	97%
Ammerman [41] (2006)	USA	100	Ne-N	Fluo-l	Marker	X-l	L1 caud	85%
Binning [33] (2010)	USA	14	N	Fluo-t	Coil and needle	MRI-t or CT-t	T1 caud	100%
Connor [42] (2013)	UK	100	R	MRI-t	None	MRI-ct	Ten anatomical LM	98% for 1 LM rest lower
Daghighi [43] (2013)	Iran	25	N	MRI-l	Oil caps, ink	MRI-l	S1 cran	96%
Givens [44] (2024)	USA	99	O	X	None	None	Dist to LMV	82-100%
Hanson [45] (2010)	USA	750	MI-S-A	MRI-l	None	MRI-w	C2 caud	98%
Holmaas [46] (2006)	Norway	92	A	MRI-tl	Oil caps	MRI-w	C2 caud, L5 cran	26.7%
Huang [47] (2023)	China	33	N	MRI-t Fluo-t	Meth blue	MRI-t	T1 caud	100%
Ishak [48] (2020)	Germany	57	N	CT-t	Marker	Fluo-t	T1 caud	100%
Kam [35] (2024)	Australia	32	N-O-R	CT-w Fluo-t	Coil	CT-w	C2 caud S1 cran	100%
Krishnan [49] (2020)	Indian	18	S-O	CT-w or MRI-w	None	CT-w or MRI-w with fluo-w	C2 caud S1 cran	88,9%
Madaelil [34] (2017)	USA	19	S-O-N-R	CT-t or Fluo-t	Needle and marker	CT-t	T1 caud	100%

Patel [37] (2019)	USA	1986	O	X-l MRI-l Fluo-l	Two needles	X-l	lat/ sag MRI Fluo	100%
Peh [17] (1999)	HK	129	R	MRI-l	Localizer scan	MRI-w	C2 caud	88,40%
Siminski [38] (2023)	USA	179	Nr R	Fluo-l CT-l	Marker	CT-w	C2 caud	100%
Tee [39] (2017)	Canada Australia Dutch	30	Trauma	Manual	Tape gridlines, ink mark	X-t	Anatomical LM	40%
Turel [50] (2014)	Indian	35	Ne	MRI-t	9 Oil caps	MRI-t	LM, oil caps	97.1 %
Upadhuyaya [51] (2012)	USA Taiwan	52	N-R-SoM-P	CT-t	26 Screw 26 Needles	Fluo-t	S1 cran	100%
Yu [36] (2021)	China	43	O-R	US-l	Kirschner	GX-l	Caud-cran	100%

Abbreviations: med spec medical specialism; N neurosurgery; Ne neurology; R radiology; MI medical imaging; S science; A anaesthesiology; SH spine hospital; O orthopaedic surgery; Nr neuroradiology; SoM school of medicine; P pharmacology; Fluo fluoroscopy; GX G arm X ray; -t thoracic spine; -l lumbar spine; -w whole spine; cran cranially counting; caud caudally counting; LM landmarks; HK Hongkong, lat lateral; sag sagittal; Dist to LMV distance to landmark vertebrae.

5.4.2 Conventional level determination methods in patients with transitional vertebrae

Four studies focused specifically on conventional level determination in patients with transitional vertebrae, as summarized in Table II. Nakagawa et al. found incorrect spinal counts in 54% (38/71) LSTV cases. Peker et al. evaluated 13 LSTV cases (9% of their cohort) to determine vertebrae numbering accuracy using auxiliary parameters. They concluded that no single MRI parameter could accurately determine vertebral numbering without comprehensive level counting. In the study of Yan et al. disagreements occurred in 10 out of 293 cases between spine surgeons and radiologists on vertebral counts. Yun et al. compared methods for identifying the first lumbar vertebra and found discrepancies in 1 out of 100 of only Castellvi I and II classified cases [12]. Studies focusing on the full spine showed high accuracies, whereas lumbar-oriented studies had very low accuracies.

Table II: Counting process and level determination with conventional radio diagnostic methods in patients with an LSTV.

Study (ref) (year)	Country	No patients	Involved med spec	Index test	Device	Reference standard	Level determination	Accuracy
Nakagawa [7] (2017)	Japan	550	O	MRI-l X-l	None	X-w	C2 caud	54% incorrect
Peker [52] (2019)	Turkisch	143	FoM	MRI-l	None	MRI-w	C2 caud	not accurate
Yan[53] (2018)	China	293	O	X-w	None	none	T1 caud	96,6%
Yun [54] (2018)	South Korea	100	R	CT-w X-w	None	CT-w	C2 caud	99%

Abbreviations: med spec medical specialism; O orthopaedic surgery; FoM faculty of medicine; R radiology; caud caudally counting.

5.4.3 Advanced level determination methods for the thoracic and lumbar spine

Five studies evaluated advanced methods for spinal level determination, including a three-dimensional (3D) intraoperative navigation (ION) and an algorithm that match three dimensional (3D) CT images into two-dimensional (2D) intraoperative fluoroscopic images (summarized in Table III).

Vaishnav et al. assessed a 3D ION for the lumbar spine, using the SpineMask Tracker, SpineMap 3D Software, and the NAV3i Platform achieving a 100% accuracy.

Algorithm-based methods, such as LevelCheck, calculate image similarity (3D-2D) between digitally reconstructed radiographs from CT images and intraoperative radiographs, enabling automatic registration and labelling of spinal levels on fluoroscopy images. Accuracy is evaluated

using the mean projection distance error (mPDE), which depends on the computation time of the images expressed in the number of multistarts.

Otake et al. evaluated the LevelCheck algorithm on 50,000 images from 10 patients, achieving 99.99% accuracy with the mPDE under 5mm. Only one image showed a minor translational shift due to a technical failure. Lo et al. tested LevelCheck's performance in clinical images in 10,000 trials involving 20 patients, finding 100% accuracy with 200 multistarts (26 seconds computation time), and 99.3% with 50 multistarts (7 seconds), showing a trade-off between speed and accuracy. DaSilva et al. analysed 51 patients and 115 radiographs, with vertebral labels annotated by a neuroradiologist and reported 0% registration failure with 200 multistarts. Manbachi et al. assessed LevelCheck's impact on surgical localization in 20 patients, confirming 100% accuracy.

Table III: Counting process and level determination with advanced methods.

Study (ref) (year)	Country	No Patients	Involved med spec	Index test	Device	Reference standard	Level determination	Accuracy
Vaishnav [55] (2020)	USA	326	HoS	3D nav	Nav system	Fluo-l	Nav system	100%
De Silva [56] (2016)	USA	51	N-CS-R-BE	A 3D-2D	None	CT-lt Fluo-lt	A 3D-2D	94-100%
Lo [57] (2015)	USA	20	N-BE	A 3D-2D	None	CT-lt Fluo-lt	A 3D-2D	99.3-100%
Manbachi [58] (2018)	USA	62/20	BE-N-R	A3D-2D	None	CT-lt Fluo-lt MRI-lt	A 3D-2D	97.6-100%
Otake [59] (2012)	USA	10	BE-CS-O	A 3D-2D	None	CT-lt Fluo-lt	A 3D-2D	99.99%

Abbreviations: med spec medical specialism; HoS hospital of surgery; N neurosurgery; R radiology; BE biomechanical engineering; CS computer science: A algorithm; Fluo fluoroscopy; l lumbar spine; t thoracic spine.

Eleven studies focused on DLM in pre-clinical settings (Appendix 6) and demonstrate a significant technological shift toward automated vertebrae localization and identification. Research from 2024–2026 specifically highlights the use of contrastive learning (SCL) and transformer-based architectures (e.g., T-U-Net) to address anatomical variability. Accuracy trends upward, with recent models (Zhang [60]) achieving 100% identification by combining SCL and T-U-Net architectures. Research data reflects strong international presence (China, South Korea, USA, Europe) and interdisciplinary collaboration (radiology, neurosurgery, orthopedics, AI). While these models achieve high technical accuracy (up to 100% in some trials), they currently focus

on image processing performance rather than clinical level determination for interventional procedures.

Quality assessment

The results of the QUADAS-2 risk of bias and applicability assessment are detailed in Table IV for each group. Among studies using conventional methods, and reporting 100% accuracy, only Madaelil's study showed no concerns regarding bias and applicability. The studies by Binning, Huang, Ishak, and Patel had unclear judgements regarding patient selection, index test, or reference standard. Siminski's study showed had a risk of bias related to the reference standard while Upadhuyaya's demonstrated a high-risk regarding study flow and timing, along with unclear concerns about patient selection and reference standard. The studies of Kam and Yu demonstrated a high risk concerning the reference standard and flow and timing. Given's study did not incorporate a reference test.

In the group analysing the transitional vertebrae, Nakagawa and Peker had low accuracies and an unclear risk of bias. The two studies with high accuracies (approaching 96-99%) had a high risk of bias, with Yan et al. having additional concerns regarding flow and timing of the patient inclusion and Yun et al. additional issues with both patient selection and study flow and timing.

For advanced methods, the 3D ION study, was rated as having unclear risk of bias and applicability. For three of the four algorithm-based studies, patient selection was unclear due to a non-consecutive selection procedure.

Table IV: bias assessment and applicability concerns in the studies with conventional level determination, transitional vertebrae and advanced level determination studies.

Studies	**Risk of Bias**				**Applicability** concerns		
	Patient selection	Index test	Reference standard	Flow& Timing	Patient selection	Index test	Reference standard
	conventional level determination						
Ahmadi	L	U	L	L	L	L	L
Ammerman	L	U	U	L	L	L	L
Binning	L	U	U	L	L	L	L
Connor	L	L	L	L	L	L	L
Daghighi	L	L	L	L	L	L	L
Givens	U	U	H	U	H	H	H
Hanson	L	U	L	L	L	U	L
Holmaas	U	U	U	L	L	L	U
Huang	U	U	U	L	L	L	L
Ishak	L	L	U	L	U	L	U
Kam	L	U	H	H	L	L	L
Krishnan	U	H	U	L	L	L	L
Madaelil	L	L	L	L	L	L	L
Patel	L	L	U	L	L	L	U
Peh	L	H	H	U	L	L	L
Siminski	L	L	H	L	L	L	U
Tee	L	L	U	H	L	L	U
Turel	L	L	U	H	L	L	L
Upadhuyaya	U	L	U	H	L	L	H
Yu	U	U	H	H	L	L	U
	transitional vertebrae studies						
Nakagawa	L	U	L	L	L	U	L
Peker	U	L	L	U	L	L	L
Yan	U	L	U	H	L	L	U
Yun	H	L	L	H	H	L	L
	advanced level determination studies						
Vaishnav	L	L	U	L	L	L	U
De Silva	L	L	L	L	L	L	L
Lo	U	L	L	L	L	L	L
Manbachi	U	L	L	L	U	L	L
Otake	U	L	L	L	L	L	L

Abbreviations: L Low; U Unclear; H High.

§5.5 Discussion

This systematic review is the first to comprehensively assess conventional and advanced spinal level determination methods, with particular emphasis on accuracy and challenges posed by transitional vertebrae. In patients without spinal anomalies, conventional techniques—such as fluoroscopy combined with CT or MRI—achieved 100% accuracy in nine of twenty studies (six thoracic, three lumbar). However, these methods are substantially less reliable in the presence of lumbar transitional vertebrae due to anatomical variability. Navigation systems and algorithm-based approaches offer near-perfect accuracy but are limited by high costs, complex setup, and the need for specialized preoperative calibration. Although deep learning–based automatic vertebral labeling shows promise, it has not yet been applied to clinical level determination for specific pathologies.

Conventional level determination methods for the thoracic and lumbar spine without transitional vertebrae

Accurate spinal level determination is critical for preventing wrong-level surgeries and minimal invasive pain treatments. Several studies provided recommendations to improve precision. Srivatsa et al. [61] emphasized the need for improved communication among the surgical team and better intraoperative imaging techniques to reduce wrong-level surgeries, acknowledging that no single policy completely eliminates this risk. Similarly, Watts et al. [3] found that 27 of 32 wrong-site spine surgeries were due to issues with radiograph quality or interpretation and recommended improving image quality as a first step toward reducing errors. Lindley et al. [62] suggested a preoperative vertebral labelling method that prioritizes anatomical landmarks, close collaboration with radiologists to identify unusual anatomy and a consistent reporting system of pathological levels.

Longo et al. [63],) reviewed prevention strategies for wrong-level surgeries, concluding that while protocols such as intraoperative radiographs and patient communication are helpful, they don't fully eliminate the risk.

Strong et al. [31] advocated for combining radio-diagnostic techniques when fluoroscopy is insufficient. Dablouk et al. [64] also highlighted the need for multiple X-rays to improve accuracy, noting variability in practices among surgeons. In a follow–up review, Devine at al. [65], recommended intraoperative image confirmation, marking anatomical structures with metallic instruments and compare these images with routine preoperative studies.

Survey data reinforce these findings. Mayer et al. [4] reported that most North American spine surgeons use fluoroscopy or a combination of radiographs and fluoroscopy for level localization, with only a few (4%) incorporating MRI. Among those who performed wrong level surgeries, 56% had used plain radiographs and 44% fluoroscopy. In a more recent survey, Naqvi et al. [66] found

an 86.7% consensus on the use of fluoroscopy for preoperative marking, but also significant heterogeneity in the use of anatomical landmarks. The study of Tee at all. [39] analysed the use of anatomical landmarks by surgeons and found an accuracy of only 40%. These findings underscore the need for standardized protocols to reduce variability and improve accuracy.

Conventional level determination methods in patients with transitional vertebrae

Studies included in this review revealed either low accuracy or a high risk of bias in level determination for patients with LSTV, even when reported accuracy was nearly 100%. Only a limited number of studies in the literature, specifically reported recommendations for LSTV cases. Nakaijma et al. [67], advocated for high-quality, full-spine imaging and strong communication between radiologists and clinicians while Doo et al. [11] highlighted that anatomical anomalies complicate standard counting techniques. Lian et al. [68] suggested adding a sagittal whole-spine view to standardize vertebral numbering with counting caudally from C2 as the most reliable method. Shah et al. [69] recommended close collaboration with radiologists and thorough preoperative examination. Albano et al. [6], in a systematic review, noted a lack of high-quality evidence and significant heterogeneity, emphasizing individual physician responsibility and the elevated risk of wrong-level surgery in LSTV patients. Epstein [70] further identified anatomical variations, inadequate imaging, failure to follow level verification protocols, and communication errors as major contributors to wrong-level surgery, recommending proactive recognition and mitigation of these risks.

Advanced level determination methods for the thoracic and lumbar spine

Advanced methods such as ION systems, and algorithm-based approaches, have shown promise in improving accuracy. One ION study met the inclusion criteria [55]. No wrong-level surgeries occurred in the 232-patient ION cohort, but unclear verification via fluoroscopy suggests potential bias. These systems enhance safety by identifying landmarks, but high costs and complex requirements demand further evidence of their clinical and economic value. Several (systematic) reviews concluded there was an absence of studies providing adequate cost-benefit analyses [71], while at the same time not showing clinical superiority in any of the studies to date [72]. Studies on cost-effectiveness, operator efficiency, and differences in clinical outcome are less clear [73] or further innovation is necessary to improve performance and show cost-effectiveness compared to alternative technologies [74].

Nowitzke et al. [75] used FluoroNav software with a standard image intensifier; while potentially safer, it offered no accuracy advantage over existing methods. Due to its indirect MRI-based counting method, the study was excluded and moved to Appendix 5.

Algorithm based methods, such as LevelCheck, have demonstrated the highest accuracy with minimal bias and applicability concerns. These algorithms allow direct comparison of sagittal

images for level determination. However, limitations are first, the assumption of 12 thoracic vertebrae in CT image definition, second, most studies measure technical registration, not true clinical accuracy and third, the costs and need for specialized equipment and personnel to operate the system as stated in most studies [57, 58].

Studies using DLM represent the technological evolution with artificial intelligence. They approach the real live clinical setting, supporting physicians performing level determination in spine procedures. CT remains the dominant modality for vertebral research with deep learning methods and recent studies (2024–2026) emphasize a combined approach of vertebrae localization**,** segmentation, and identification, however not level determination.

Notably, fifteen excluded studies, including DLM (Appendix 5), originating from thirteen different countries, determined lumbar levels by assuming the lowest lumbar level as L5, a method commonly used in Dutch hospitals [15], and internationally [76, 77]. This lumbar counting process can lead to significant misdiagnosis in patients with LSTV [7, 20].

This systematic review highlights that variability complicates the development of a universally accurate "gold standard" and reflects the realities of daily clinical practice. Radiologists count vertebral levels from the presumed fifth lumbar vertebra upward with the patient in supine. Interventional pain specialists use real-time posterior-anterior fluoroscopic images with the patient prone. These methodological differences are key risk factors for wrong-level treatment [2, 78, 79] and several studies have emphasized the importance of interdisciplinary communication [61, 62, 67, 69, 70].

Advanced level determination procedures show promise and may be applied differently in spine surgery and less complex pain medicine procedures. However, evidence demonstrating clinical superiority and cost-effectiveness is still lacking. Deep-learning models are expected to evolve toward near-perfect accuracy, even in the presence of spinal anomalies, although models trained on standard anatomy (twelve thoracic and five lumbar vertebrae) are not suitable for such patients. Bridging the gap between research and clinical practice will require large-scale validation studies to confirm the efficacy and reliability of these emerging techniques.

Although the PRISMA guidelines were followed and, the search strategies were carefully developed, there are limitations. Multiple databases, but not all, were included in this research. This review focused on English, Dutch and German publications, relevant studies in other languages might be missed. ASReview [26] was applied and its use was considered robust and accurate due to several methodological decisions. The model was trained using a substantial prior set of 26 relevant and 365 irrelevant studies. The search was terminated after labeling 160 irrelevant studies, exceeding the typical requirement of 100. These methodology taken steps addressed common methodological and technical challenges such as unreliable stopping

criteria, the need for thorough deduplication, the potential for insufficient prior knowledge, and the necessity of robust screening methods.

It is important to note that traditional human-based screening has an average error rate of 10.76%, indicating that roughly 1 in 9 abstracts is incorrectly classified, underscoring the value of rigorous, often technology-assisted, methods [80].

§5.6 Conclusion

This systematic review of literature underscores the persistent heterogeneity in radio-diagnostic practices and spinal level determination processes. In real life this heterogeneity remains an avoidable risk contributor to misdiagnosis and wrong-level procedures, particularly in patients with transitional vertebrae, comprising approximately a 12% of the population [13]. The best current advice, based on the literature and this review, emphasizes heightened awareness of transitional vertebrae, clear intraoperative imaging, marking of levels, and close collaboration between interventionists and radiologists. Comparing preoperative MRI or CT scans with intraoperative findings, and full spine images will help prevent wrong level procedures. This research clarifies the need for unified interdisciplinary protocols for recognizing and managing transitional anatomy during spine procedures. While advanced methods such as ION and the LevelCheck algorithm show great promise, further research is needed to assess their application in patient care and economic viability. Research on deep learning methodologies is advancing rapidly, showing near-perfect accuracy in identifying spinal anomalies, however, are not yet ready for implementation in everyday clinical practice.

§5.7 References

1. Wigh RE (1980) The thoracolumbar and lumbosacral transitional junctions. Spine 5:215-222
2. Grimm BD, Laxer EB, Blessinger BJ, Rhyne AL, Darden BV (2014) Wrong-Level Spine Surgery. JBJS reviews 2. doi: 10.2106/jbjs.rvw.m.00052
3. Watts BV, Rachlin JR, Gunnar W, Mills PD, Neily J, Soncrant C, Paull DE (2019) Wrong Site Spine Surgery in the Veterans Administration. Clin Spine Surg 32:454-457. doi: 10.1097/bsd.0000000000000771
4. Mayer JE, Dang RP, Duarte Prieto GF, Cho SK, Qureshi SA, Hecht AC (2014) Analysis of the techniques for thoracic- and lumbar-level localization during posterior spine surgery and the occurrence of wrong-level surgery: results from a national survey. Spine J 14:741-748. doi: 10.1016/j.spinee.2013.06.068
5. Mody MG, Nourbakhsh A, Stahl DL, Gibbs M, Alfawareh M, Garges KJ (2008) The prevalence of wrong level surgery among spine surgeons. Spine (Phila Pa 1976) 33:194-198. doi: 10.1097/BRS.0b013e31816043d1
6. Albano S, Brown NJ, Pennington Z, Nguyen A, Hsu TI, Pham MH, Oh MY (2024) Risks Associated with Surgical Management of Lumbosacral Transitional Vertebrae: Systematic Review of Surgical Considerations and Illustrative Case. World Neurosurg. doi: 10.1016/j.wneu.2024.02.033
7. Nakagawa T, Hashimoto K, Tsubakino T, Hoshikawa T, Inawashiro T, Tanaka Y (2017) Lumbosacral Transitional Vertebrae Cause Spinal Level Misconception in Surgeries for Degenerative Lumbar Spine Disorders. TOHOKU JOURNAL OF EXPERIMENTAL MEDICINE 242:223-228. doi: doi:10.1620/tjem.242.223
8. Saito R, Fujibayashi S, Shimizu T, Murata K, Otsuki B, Onishi E, Matsuda S, Yasuda T (2024) Wrong-level spine surgery: A multicenter retrospective study. J Orthop Sci 29:1359-1363. doi: 10.1016/j.jos.2023.11.005
9. Carrino J, Campbell P, Lin D, Morrison W, Schweitzer M, Flanders A, Eng J, Vaccaro A (2011) Effect of Spinal Segment Variants on Numbering Vertebral Levels at Lumbar MR Imaging. RADIOLOGY 259:196-202. doi: doi:10.1148/radiol.11081511
10. GS G-P, O R, MJ A, TM D (2021) The prevalence of 11 ribs and its potential implications in spine surgery. In., Netherlands. p. 106544.
11. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, Han YJ, Son JS (2020) The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul) 15:103-110. doi: 10.17085/apm.2020.15.1.103
12. Castellvi AE, Goldstein LA, Chan DP (1984) Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976) 9:493-495
13. Jancuska JM, Spivak JM, Bendo JA (2015) A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. International Journal of Spine Surgery 9:42. doi: 10.14444/2042
14. Farshad-Amacker NA, Farshad M, Winklehner A, Andreisek G (2015) MR imaging of degenerative disc disease. Eur J Radiol 84:1768-1776. doi: 10.1016/j.ejrad.2015.04.002
15. Robin Smithuis RdotRhiL, the Netherlands. (2014) Lumbar Disc Herniation and other causes of nerve compression. Educational site of the Radiological Society of the Netherlands. https://radiologyassistant.nl/neuroradiology/spine/lumbar-disc-herniation#mri-protocol.
16. Konin GP, Walz DM (2010) Lumbosacral transitional vertebrae: classification, imaging findings, and clinical relevance. AJNR Am J Neuroradiol 31:1778-1786. doi: 10.3174/ajnr.A2036

17. Peh W, Siu T, Chan J (1999) Determining the lumbar vertebral segments on magnetic resonance imaging. SPINE 24:1852-1855. doi: doi:10.1097/00007632-199909010-00017
18. Thawait GK, Chhabra A, Carrino JA (2012) Spine segmentation and enumeration and normal variants. Radiol Clin North Am 50:587-598. doi: 10.1016/j.rcl.2012.04.003
19. Neelakantan S, Anandarajan R, Shyam K, Philip B (2016) Multimodality imaging in Bertolotti's syndrome: an important cause of low back pain in young adults. BMJ Case Rep 2016. doi: 10.1136/bcr-2016-217121
20. Liebrand B, Brakel K, Boon A, van der Weegen W, Wal SV, Vissers KC (2021) Diagnostic treatment-level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies. Reg Anesth Pain Med. doi: 10.1136/rapm-2021-103174
21. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Bmj 372:n71. doi: 10.1136/bmj.n71
22. Page MJ, Moher D, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, McKenzie JE (2021) PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. Bmj 372:n160. doi: 10.1136/bmj.n160
23. PROSPERO: International prospective register of systematic reviews. https://www.crd.york.ac.uk/prospero/.
24. Holst D, Moenck K, Koch J, Schmedemann O, Schüppstuhl T (2025) Transparent Reporting of AI in Systematic Literature Reviews: Development of the PRISMA-trAIce Checklist. Jmir ai 4:e80247. doi: 10.2196/80247
25. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A (2016) Rayyan-a web and mobile app for systematic reviews. Syst Rev 5:210. doi: 10.1186/s13643-016-0384-4
26. ASReview LAB developers. ASReview LAB: A Tool for AI-Assisted Systematic Reviews [Software v.2.1.1]. Zenodo; 2023. Available from: https://doi.org/10.5281/zenodo.3345592. In.
27. Van De Schoot R, De Bruin J, Schram R, Zahedi P, De Boer J, Weijdema F, Kramer B, Huijts M, Hoogerwerf M, Ferdinands G (2021) An open source machine learning framework for efficient and transparent systematic reviews. Nature machine intelligence 3:125-133
28. Ferdinands G, Schram R, de Bruin J, Bagheri A, Oberski DL, Tummers L, Teijema JJ, Van de Schoot R (2023) Performance of active learning models for screening prioritization in systematic reviews: a simulation study into the Average Time to Discover relevant records. Systematic Reviews 12:100
29. C. W (2014) Guidelines for snowballing in systematic literature studies and a replication in software engineering. EASE '14: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering:1-10. doi: http://dx.doi.org/10.1145/2601248.2601268
30. P Whiting RW, J Savović, S Mallett, B Devine, the LATITUDES group. LATITUDES network. 2023. (2023). https://www.latitudes-network.org/
31. Strong MJ, Santarosa J, Sullivan TP, Kazemi N, Joseph JR, Kashlan ON, Oppenlander ME, Szerlip NJ, Park P, Elswick CM (2022) Pre- and intraoperative thoracic spine localization techniques: a systematic review. J Neurosurg Spine 36:792-799. doi: 10.3171/2021.8.Spine21480

32. Whiting P University of Bristol-population-health-sciences-projects quadas-2. https://www.bristol.ac.uk/population-health-sciences/projects/quadas/quadas-2/.
33. Binning MJ, Schmidt MH (2010) Percutaneous placement of radiopaque markers at the pedicle of interest for preoperative localization of thoracic spine level. Spine (Phila Pa 1976) 35:1821-1825. doi: 10.1097/BRS.0b013e3181c90bdf
34. Madaelil T, Long J, Wallace A, Baker J, Ray W, Santiago P, Buchowski J, Zebala L, Jennings J (2017) Preoperative Fiducial Marker Placement in the Thoracic Spine A Technical Report. SPINE 42:E624-E628. doi: doi:10.1097/BRS.0000000000001890
35. Kam JKT, Castle-Kirszbaum M, Dhaliwal T, Maingard J, Chandra R, Quan G, Gonzalvo CA, Goldschlager T (2024) Preoperative coil localization for spinal surgery is accurate, safe and effective: a single-centre initial experience. ANZ J Surg 94:840-845. doi: 10.1111/ans.18991
36. Yu B, Huang P, Luo Y, Zhang M (2021) Feasibility and Efficacy of the Segmental Localization of Lumbar Vertebrae by Ultrasound vs X-ray Examination: A Prospective Comparative Study. Advanced Ultrasound in Diagnosis and Therapy 5:212-218. doi: https://dx.doi.org/10.37015/AUDT.2021.200062
37. Patel A, Runner RP, Bellamy JT, Rhee JM (2019) A reproducible and reliable localization technique for lumbar spine surgery that minimizes unintended-level exposure and wrong-level surgery. Spine J 19:773-780. doi: 10.1016/j.spinee.2018.12.005
38. Siminski CP, Carr CM, Kallmes DF, Oien MP, Atkinson JLD, Benson JC, Diehn FE, Kim DK, Liebo GB, Lehman VT, Madhavan AA, Mark IT, Morris PP, Shlapak DP, Verdoorn JT, Morris JM (2023) Fluoroscopy- and CT-Guided Gold Fiducial Marker Placement for Intraoperative Localization during Spinal Surgery: Review of 179 Cases at a Single Institution-Technique and Safety Profile. AJNR Am J Neuroradiol 44:618-622. doi: 10.3174/ajnr.A7854
39. Tee JW, Rutges J, Marion T, Street J, Paquette S, Ailon T, Kwon BK, Dvorak M, Boyd M (2017) Factors predictive of topographical accuracy in spine level localization. J Spine Surg 3:23-30. doi: 10.21037/jss.2017.02.06
40. Ahmadi SA, Slotty PJ, Schröter C, Kröpil P, Steiger HJ, Eicker SO (2014) Marking wire placement for improved accuracy in thoracic spinal surgery. Clin Neurol Neurosurg 119:100-105. doi: 10.1016/j.clineuro.2014.01.025
41. Ammerman JM, Ammerman MD, Dambrosia J, Ammerman BJ (2006) A prospective evaluation of the role for intraoperative x-ray in lumbar discectomy. Predictors of incorrect level exposure. Surg Neurol 66:470-473; discussion 473-474. doi: 10.1016/j.surneu.2006.05.069
42. Connor S, Shah A, Latifoltojar H, Lung P (2013) MRI-based anatomical landmarks for the identification of thoracic vertebral levels. CLINICAL RADIOLOGY 68:1260-1267. doi: doi:10.1016/j.crad.2013.07.009
43. Daghighi M, Shokouhi G, Zarrintan S, Shakeri-Bavil M, Asghari M, Salehpour F, Pouisa M, Emamalizadeh M (2013) Accuracy of Marker Placement by Magnetic Resonance Imaging in the Determination of the Incision Site in Lumbar Disk Surgeries. NEUROSURGERY QUARTERLY 23:85-90. doi: doi:10.1097/WNQ.0b013e31825a693f
44. Givens RR, Malka MS, Lu K, Mizerik A, Bainton N, Zervos TM, Roye BD, Lenke LG, Vitale MG (2025) Making wrong site surgery a "never event" in spinal deformity surgery by use of a "landmark vertebra" to eliminate variability in identifying a target vertebral level. Spine Deform 13:339-350. doi: 10.1007/s43390-024-00996-8
45. Hanson E, Mishra R, Chang D, Perkins T, Bonifield D, Tandy R, Cartwright P, Peoples R, Orrison W (2010) Sagittal whole-spine magnetic resonance imaging in 750 consecutive outpatients: accurate determination

of the number of lumbar vertebral bodies Clinical article. JOURNAL OF NEUROSURGERY-SPINE 12:47-55. doi: doi:10.3171/2009.7.SPINE09326

46. Holmaas G, Frederiksen D, Ulvik A, Vingsnes S, Ostgaard G, Nordli H (2006) Identification of thoracic intervertebral spaces by means of surface anatomy: a magnetic resonance imaging study. ACTA ANAESTHESIOLOGICA SCANDINAVICA 50:368-373. doi: doi:10.1111/j.1399-6576.2006.00922.x
47. Huang H, Wei M, Fan J, Peng R, Ding X, Xi J (2023) Oblique radiograph with methylene blue marking: A reliable technique for upper thoracic level localization. Heliyon 9:e17589. doi: 10.1016/j.heliyon.2023.e17589
48. Ishak B, Abdul-Jabbar A, Tawfik T, Yilmaz E, von Glinski A, Unterberg A, Oskouian R, Chapman JR (2020) Prevention of Wrong-level Surgery in the Thoracic Spine: Preoperative Computer Tomography Fluoroscopy-guided Percutaneous Gold Fiducial Marker Placement in 57 Patients. Spine (Phila Pa 1976) 45:1720-1724. doi: 10.1097/brs.0000000000003691
49. Krishnan A, Devanand D, Mayi S, Kulkarni M, Reddy C, Singh M, Rai R, Dave B (2020) Transforaminal Thoracic Interbody Fusion for Thoracic Disc Prolapse: Surgicoradiological Analysis of 18 Cases. GLOBAL SPINE JOURNAL 10:706-714. doi: doi:10.1177/2192568219870459
50. Turel M, Rajshekhar V (2014) Magnetic resonance imaging localization with cod liver oil capsules for the minimally invasive approach to small intradural extramedullary tumors of the thoracolumbar spine. JOURNAL OF NEUROSURGERY-SPINE 21:882-885. doi: doi:10.3171/2014.9.SPINE14199
51. Upadhyaya CD, Wu JC, Chin CT, Balamurali G, Mummaneni PV (2012) Avoidance of wrong-level thoracic spine surgery: intraoperative localization with preoperative percutaneous fiducial screw placement. J Neurosurg Spine 16:280-284. doi: 10.3171/2011.3.Spine10445
52. Peker E, Hursoy N, Akkaya H, Unal S, Gulpinar B, Arikan B, Anamurluoglu E, Erden I (2019) Evaluation of spinal-paraspinal parameters to determine segmentation of the vertebrae. POLISH JOURNAL OF RADIOLOGY 84:E470-E477. doi: doi:10.5114/pjr.2019.90227
53. Yan YZ, Li QP, Wu CC, Pan XX, Shao ZX, Chen SQ, Wang K, Chen XB, Wang XY (2018) Rate of presence of 11 thoracic vertebrae and 6 lumbar vertebrae in asymptomatic Chinese adult volunteers. J Orthop Surg Res 13:124. doi: 10.1186/s13018-018-0835-9
54. Yun S, Park S, Park J, Huh J, Shin Y, Yun J (2018) Spinal Enumeration by Morphologic Analysis of Spinal Variants: Comparison to Counting in a Cranial-To-Caudal Manner. KOREAN JOURNAL OF RADIOLOGY 19:1140-1146. doi: doi:10.3348/kjr.2018.19.6.1140
55. Vaishnav A, Merrill R, Sandhu H, McAnany S, Iyer S, Gang C, Albert T, Qureshi S (2020) A Review of Techniques, Time Demand, Radiation Exposure, and Outcomes of Skin-anchored Intraoperative 3D Navigation in Minimally Invasive Lumbar Spinal Surgery. SPINE 45:E465-E476. doi: doi:10.1097/BRS.0000000000003310
56. De Silva T, Lo S, Aygun N, Aghion D, Boah A, Petteys R, Uneri A, Ketcha M, Yi T, Vogt S, Kleinszig G, Wei W, Weiten M, Ye X, Bydon A, Sciubba D, Witham T, Wolinsky J, Siewerdsen J (2016) Utility of the LevelCheck Algorithm for Decision Support in Vertebral Localization. SPINE 41:E1249-E1256. doi: doi:10.1097/BRS.0000000000001589
57. Lo SF, Otake Y, Puvanesarajah V, Wang AS, Uneri A, De Silva T, Vogt S, Kleinszig G, Elder BD, Goodwin CR, Kosztowski TA, Liauw JA, Groves M, Bydon A, Sciubba DM, Witham TF, Wolinsky JP, Aygun N, Gokaslan ZL, Siewerdsen JH (2015) Automatic localization of target vertebrae in spine surgery: clinical evaluation of the LevelCheck registration algorithm. Spine (Phila Pa 1976) 40:E476-483. doi: 10.1097/brs.0000000000000814

58. Manbachi A, De Silva T, Uneri A, Jacobson M, Goerres J, Ketcha M, Han R, Aygun N, Thompson D, Ye X, Vogt S, Kleinszig G, Molina C, Iyer R, Garzon-Muvdi T, Raber MR, Groves M, Wolinsky JP, Siewerdsen JH (2018) Clinical Translation of the LevelCheck Decision Support Algorithm for Target Localization in Spine Surgery. Ann Biomed Eng 46:1548-1557. doi: 10.1007/s10439-018-2099-2
59. Otake Y, Schafer S, Stayman J, Zbijewski W, Kleinszig G, Graumann R, Khanna A, Siewerdsen J (2012) Automatic Localization of Target Vertebrae in Spine Surgery using Fast CT-to-Fluoroscopy (3D-2D) Image Registration
60. Zhang S, Li H, Chen M, Li M, Liu M, Wu J, Xue C, Kong Y (2026) SpineCLUE: Automatic vertebrae identification using contrastive learning and uncertainty estimation. Artif Intell Med 171:103285. doi: 10.1016/j.artmed.2025.103285
61. Srivatsa S, Vira S, Schils J, Shook S, Gill A, Krishnaney AA (2021) Reducing Wrong-level Spinal Surgeries Through Root Cause Analyses: A 10-year Longitudinal Analysis of a Single Tertiary Institution's Iterative Policy Improvements. Spine (Phila Pa 1976) 46:E648-e654. doi: 10.1097/brs.0000000000003864
62. Lindley EM, Botolin S, Burger EL, Patel VV (2011) Unusual spine anatomy contributing to wrong level spine surgery: a case report and recommendations for decreasing the risk of preventable 'never events'. Patient Saf Surg 5:33. doi: 10.1186/1754-9493-5-33
63. Longo UG, Loppini M, Romeo G, Maffulli N, Denaro V (2012) Errors of level in spinal surgery: an evidence-based systematic review. J Bone Joint Surg Br 94:1546-1550. doi: 10.1302/0301-620x.94b11.29553
64. Dablouk MO, Sajjad J, Lim C, Kaar G, O'Sullivan MGJ (2019) Intra-operative imaging for spinal level localisation in lumbar surgery. Br J Neurosurg 33:352-356. doi: 10.1080/02688697.2018.1562030
65. DeVine JG, Chutkan N, Gloystein D, Jackson K (2020) An Update on Wrong-Site Spine Surgery. Global Spine J 10:41s-44s. doi: 10.1177/2192568219846911
66. Naqvi AZ, Magill H, Anjarwalla N (2022) Intraoperative practices to prevent wrong-level spine surgery: a survey among 105 spine surgeons in the United Kingdom. Patient Saf Surg 16:6. doi: 10.1186/s13037-021-00310-9
67. Nakajima A, Usui A, Hosokai Y, Kawasumi Y, Abiko K, Funayama M, Saito H (2014) The prevalence of morphological changes in the thoracolumbar spine on whole-spine computed tomographic images. Insights Imaging 5:77-83. doi: 10.1007/s13244-013-0286-0
68. Lian J, Levine N, Cho W (2018) A review of lumbosacral transitional vertebrae and associated vertebral numeration. Eur Spine J 27:995-1004. doi: 10.1007/s00586-018-5554-8
69. Shah M, Halalmeh DR, Sandio A, Tubbs RS, Moisi MD (2020) Anatomical Variations That Can Lead to Spine Surgery at the Wrong Level: Part III Lumbosacral Spine. Cureus 12:e9433. doi: 10.7759/cureus.9433
70. Epstein N (2021) A perspective on wrong level, wrong side, and wrong site spine surgery. Surg Neurol Int 12:286. doi: 10.25259/sni_402_2021
71. Burström G, Persson O, Edström E, Elmi-Terander A (2021) Augmented reality navigation in spine surgery: a systematic review. Acta Neurochir (Wien) 163:843-852. doi: 10.1007/s00701-021-04708-3
72. Sielatycki JA, Mitchell K, Leung E, Lehman RA (2022) State of the art review of new technologies in spine deformity surgery-robotics and navigation. Spine Deform 10:5-17. doi: 10.1007/s43390-021-00403-6
73. Wang TY, Park C, Dalton T, Rajkumar S, McCray E, Owolo E, Than KD, Abd-El-Barr MM (2021) Robotic navigation in spine surgery: Where are we now and where are we going? J Clin Neurosci 94:298-304. doi: 10.1016/j.jocn.2021.10.034

74. Rawicki N, Dowdell JE, Sandhu HS (2021) Current state of navigation in spine surgery. Ann Transl Med 9:85. doi: 10.21037/atm-20-1335
75. Nowitzke A, Wood M, Cooney K (2008) Improving accuracy and reducing errors in spinal surgery - a new technique for thoracolumbar-level localization using computer-assisted image guidance. SPINE JOURNAL 8:597-604. doi: doi:10.1016/j.spinee.2007.06.005
76. Pojskic M, Bisson E, Oertel J, Takami T, Zygourakis C, Costa F (2024) Lumbar disc herniation: Epidemiology, clinical and radiologic diagnosis WFNS spine committee recommendations. World Neurosurg X 22:100279. doi: 10.1016/j.wnsx.2024.100279
77. Zhang AS, Xu A, Ansari K, Hardacker K, Anderson G, Alsoof D, Daniels AH (2023) Lumbar Disc Herniation: Diagnosis and Management. Am J Med 136:645-651. doi: 10.1016/j.amjmed.2023.03.024
78. R B, L B, A H, B H, N H, R VDN, B S (2021) Establishing a common language for lumbar transforaminal epidural steroid injections. Journal of spine surgery (Hong Kong) 7:467-474. doi: doi:10.21037/jss-21-71
79. Liebrand B, van der Wal S, Slob M, Boon A, Henssen D, Zundert J, van der Weegen W, Vissers K (2025) Diagnostic Precision in Lumbar Radiculopathy: Impact of Transitional Vertebrae on Treatment Level Selection and Outcomes. Pain Med. doi: 10.1093/pm/pnaf061
80. Wang Z, Nayfeh T, Tetzlaff J, O'Blenis P, Murad MH (2020) Error rates of human reviewers during abstract screening in systematic reviews. PLoS One 15:e0227742. doi: 10.1371/journal.pone.0227742
81. Al-Helo S, Alomari RS, Ghosh S, Chaudhary V, Dhillon G, Al-Zoubi MB, Hiary H, Hamtini TM (2013) Compression fracture diagnosis in lumbar: a clinical CAD system. Int J Comput Assist Radiol Surg 8:461-469. doi: 10.1007/s11548-012-0796-0
82. Irace C, Corona C (2010) How to avoid wrong-level and wrong-side errors in lumbar microdiscectomy. J Neurosurg Spine 12:660-665. doi: 10.3171/2009.12.Spine09627
83. Ilyas Z, Sharif N, Schousboe JT, Lewis JR, Suter D, Gilani SZ, Ieee (2021) GuideNet: Learning Inter-Vertebral Guides in DXA Lateral Spine Images. In: International Conference on Digital Image Computing - Techniques and Applications (DICTA). null, ELECTR NETWORK. pp. 168-174.
84. Jamaludin A, Kadir T, Zisserman A (2017) SpineNet: Automated classification and evidence visualization in spinal MRIs. Med Image Anal 41:63-73. doi: 10.1016/j.media.2017.07.002
85. M N (2015) I 8F-FDG-PET/CT better localizes active spinal infection than MRI for successful minimally invasive surgery Acta radiologica (Stockholm, Sweden : 1987)
86. Nyange R, Kannan H, Chola C, Singh S, Kim J, Pise AA (2025) Analytical computation for segmentation and classification of lumbar vertebral fractures. Front Comput Neurosci 19:1536441. doi: 10.3389/fncom.2025.1536441
87. Oktay AB, Akgul YS (2013) Simultaneous localization of lumbar vertebrae and intervertebral discs with SVM-based MRF. IEEE Trans Biomed Eng 60:2375-2383. doi: 10.1109/tbme.2013.2256460
88. Paik NC, Lim CS, Jang HS (2012) Numbering of vertebrae on MRI using a PACS cross-referencing tool. Acta Radiol 53:785-789. doi: 10.1258/ar.2012.120173
89. Prod'homme M, Grasset D, Lecocq M, Boscherini D (2021) Intraoperative disc level marking with needle: a technical note and prospective study on 30 patients. J Spine Surg 7:190-196. doi: 10.21037/jss-20-671

90. Staudenmann A, Marth AA, Stern C, Fröhlich S, Sutter R (2024) Long-term CT follow-up of patients with lumbar spondylolysis reveals low rate of spontaneous bone fusion. Skeletal Radiol 53:2377-2387. doi: 10.1007/s00256-024-04650-2
91. Wanivenhaus F, Buck FM, Betz M, Farshad-Amacker NA, Farshad M (2017) Reliability of postoperative MR imaging in the determination of level and side of lumbar spinal decompression surgery. Acta Radiol 58:581-585. doi: 10.1177/0284185116661881
92. Zeybel M, Akgul YS (2020) Localization and Identification of Lumbar Intervertebral Discs on Spine MR Images with Faster RCNN Based Shortest Path Algorithm. In: 24th Conference on Medical Image Understanding and Analysis (MIUA). St Annes Coll, null, ELECTR NETWORK. pp. 143-154.
93. Zhao S, Wu X, Chen B, Li S (2021) Automatic vertebrae recognition from arbitrary spine MRI images by a category-Consistent self-calibration detection framework. Med Image Anal 67:101826. doi: 10.1016/j.media.2020.101826
94. Baka N, Leenstra S, van Walsum T (2017) Ultrasound Aided Vertebral Level Localization for Lumbar Surgery. IEEE Trans Med Imaging 36:2138-2147. doi: 10.1109/tmi.2017.2738612
95. Gao X, Tu L, Huang Y, Wang L, Liu Y (2024) Robust and Generable Vertebrae Instance Segmentation with Domain Adaptation. Annu Int Conf IEEE Eng Med Biol Soc 2024:1-4. doi: 10.1109/embc53108.2024.10781610
96. Huang Y, Uneri A, Jones CK, Zhang X, Ketcha MD, Aygun N, Helm PA, Siewerdsen JH (2021) 3D vertebrae labeling in spine CT: an accurate, memory-efficient (Ortho2D) framework. Phys Med Biol 66. doi: 10.1088/1361-6560/ac07c7
97. Huang Y, Jones CK, Zhang X, Johnston A, Waktola S, Aygun N, Witham TF, Bydon A, Theodore N, Helm PA, Siewerdsen JH, Uneri A (2022) Multi-perspective region-based CNNs for vertebrae labeling in intraoperative long-length images. Comput Methods Programs Biomed 227:107222. doi: 10.1016/j.cmpb.2022.107222
98. Lu H, Liu M, Yu K, Fang Y, Zhao J, Shi Y (2025) A Deep Learning-Based Fully Automated Vertebra Segmentation and Labeling Workflow. Br J Hosp Med (Lond) 86:1-22. doi: 10.12968/hmed.2025.0443
99. Liao H, Mesfin A, Luo J (2018) Joint Vertebrae Identification and Localization in Spinal CT Images by Combining Short- and Long-Range Contextual Information. IEEE Trans Med Imaging 37:1266-1275. doi: 10.1109/tmi.2018.2798293
100. Sekuboyina A, Rempfler M, Valentinitsch A, Menze BH, Kirschke JS (2020) Labeling Vertebrae with Two-dimensional Reformations of Multidetector CT Images: An Adversarial Approach for Incorporating Prior Knowledge of Spine Anatomy. Radiol Artif Intell 2:e190074. doi: 10.1148/ryai.2020190074
101. Yoon H, Cho Y, Ahn KS, Lee HG, Kang CH, Park BJ (2023) Using a convolutional neural network model to derive imaging landmarks for lumbar spine numbering on axial magnetic resonance images. International Journal of Imaging Systems and Technology 33:547-555. doi: 10.1002/ima.22828
102. Zhang J, Pan H, Wang F, Jia L, Chen J, Yan F, Zhang Y, Yang Y (2025) Automated vertebral identification and localization for enhanced radiotherapy patient setup. Radiother Oncol 208:110939. doi: 10.1016/j.radonc.2025.110939
103. Zhou ZK, Zhang ZY, Li MY, Song L, Kong YY, Coatrieux JL, Shu HZ (2025) Mask prompt-guided multi-stage network for vertebrae identification. Biomedical Signal Processing and Control 110. doi: 10.1016/j.bspc.2025.108091

§5.8 Appendices

Appendix 1: Search Strategies for Medline, Embase, and Web of Science.

Medline (via OVID) (01/12/2025)

Search	String	Hits
#1	(exp Neurosurgery/ or exp Neurosurgical Procedures/ or exp Orthopedics/ or exp Orthopedic Procedures/ or exp Radiology/ or exp Radiologists/ or exp "Radiology, Interventional"/ or exp Neurology/ or exp Neuropathology/ or exp Magnetic Resonance Imaging/ OR exp "Tomography, X-ray computed"/ or (Neurosurg* or Orthopedic* or Pain physician* or Pain medicine* or Radiolog* or Neurolog* or Neuropatholog* or Surg* or MRI or Magnetic Resonance or CT or Computed Tomograph*).ti,ab,kf. or (surgery or diagnosis).fs.) AND (exp Spine/ or (Lumba* or Spine* or Spinal* or Lumbo* or Vertebra* or TLTV or LSTV).ti,ab,kf.) AND ((Wrong level* or ((spinal or spine* or vertebra* or lumba* or lumbo*) adj4 (count* or determinat* or locali* or numerat* or enumerat* or numbering)) or (Level* adj6 (count* or determinat* or locali* or numerat* or enumerat* or numbering))).ti,ab,kf.)	3090

Embase (via OVID) (01/12/2025)

Search	String	Hits
#1	((exp Neurosurgery/ or exp Orthopedics/ or exp Orthopedic Surgery/ or exp Radiology/ or exp Radiologist/ or exp interventional radiology/ or exp Neurology/ or exp Neuropathology/ or exp Nuclear Magnetic Resonance Imaging/ OR exp "x-ray computed tomography"/ or (Neurosurg* or Orthopedic* or Pain physician* or Pain medicine* or Radiolog* or Neurolog* or Neuropatholog* or Surg* or MRI or Magnetic Resonance or CT or Computed Tomograph*).ti,ab,kf. or (di or su).fs.) AND (exp Spine/ or (Lumba* or Spine* or Spinal* or Lumbo* or Vertebra* or TLTV or LSTV).ti,ab,kf.) AND ((Wrong level* or ((spinal or spine* or vertebra* or lumba* or lumbo*) adj4 (count* or determinat* or locali* or numerat* or enumerat* or numbering)) or (Level* adj6 (count* or determinat* or locali* or numerat* or enumerat* or numbering))).ti,ab,kf.)) not conference abstract.pt.	3420

Web of Science Core Collection (01/12/2025)

Search	String	Hits
#1	(TS=((Neurosurg* or Orthopedic* or "Pain physician*" or "Pain medicine*" or Radiolog* or Neurolog* or Neuropatholog* or Surg* or MRI or "Magnetic Resonance" or CT or "Computed Tomograph*") AND (Lumba* or Spine* or Spinal* or Lumbo* or Vertebra* or TLTV or LSTV) AND ("Wrong level*" or ((spinal or spine* or vertebra* or lumba* or lumbo*) NEAR/3 (count* or determinat* or locali* or numerat* or enumerat* or "numbering")) or (Level* NEAR/5 (count* or determinat* or locali* or numerat* or enumerat* or "numbering"))))) NOT DT=("Meeting Abstract")	2275

Appendix 2: In- and exclusion criteria.

The inclusion criteria included: 1) Study focus on the thoracic and/or lumbar spine. 2) Counting methods, numeration, level determination, or level localization related to the spine or vertebrae clearly described. 3) Accuracy statement about the level determination. 4) Research of involved medical specialists is patient related. 5) Contains clear images produced with conventional or advanced methods and the resulting images of the whole, thoracic, or lumbar spine are from sufficient quality. 6) Patients are above 18 years old. 7) Written in English, Dutch, or German.

The exclusion criteria included: 1) Study does not focus on the spine but on other diseases or disorders (e.g., epilepsy, obesity) or entirely distinct aspects (e.g., economical and societal issues) irrelevant for this review. 2) Concerning only cervical vertebrae. 3) Animal, cadaver studies and case reports. 4) Focus on development of level determination method and no patient related research. 5) Patients younger than 18 years of age. 6) The full text version of the study is not available.

Appendix 3:

OSF | ASReview_Excludes.txt

OSF | ASReview_Includes.txt

Appendix 4:

DOMAIN	PATIENT SELECTION	INDEX TEST	REFERENCE STANDARD	FLOW AND TIMING
Description	Describe methods of patient selection: Describe included patients (prior testing, presentation, intended use of index test and setting):	Describe the index test and how it was conducted and interpreted:	Describe the reference standard and how it was conducted and interpreted:	Describe any patients who did not receive the index test(s) and/ or reference standard or who were excluded from the 2x2 table (refer to flow diagram): Describe the time interval and any interventions between index test(s) and reference standard.
Signalling questions (yes/ no/unclear)	Was a consecutive or random sample of patients enrolled? Was a case-control design avoided? Did the study avoid inappropriate exclusions?	Were the index test results interpreted without knowledge of the results of the reference standard? If a threshold was used, was it pre-specified? Did two or more researchers performed the index test?[a]	Is the reference standard likely to correctly classify the target condition? Were the reference standard results interpreted without knowledge of the results of the index test? Did two or more researchers perform the reference standard?[a]	Was there an appropriate interval between index test(s) and reference standard? Did all patients receive a reference standard? Did all patients receive the same reference standard? Were all patients included in the analysis?
Risk of bias: High/low/ unclear	Could the selection of patients have introduced bias?	Could the conduct or interpretation of the index test have introduced bias?	Could the reference standard, its conduct, or its interpretation have introduced bias?	Could the patient flow have introduced bias?
Concerns regarding applicability: High/low/ unclear	Are there concerns that the included patients do not match the review question?	Are there concerns that the index test, its conduct, or interpretation differ from the review question?	Are there concerns that the target condition as defined by the reference standard does not match the review question?	

[a]**:** added signalling questions in the quadas-2.

Appendix 5:

Studies focusing on lumbar spinal pathologies. The methodology used by clinical and engineering researchers to identify vertebral levels in the lumbar spine considering the lowest lumbar level as L5 and counting cranially to L1.

Study (ref) (year)	Country	Involved med spec	No of patients/ researches	Used Radio diagnostics / systems	Lumbar det process
Al Helo[81] (2013)	Jordan USA	R N	50	CT CADS	L5-1
Cheng (2022)	China	CS	330	DLM CT	L1-5
Irace [82] (2010)	Italy	N	818	CT MRI X	L5-1
Ilyas [83] (2021)	Australia USA	SCA INR PNOC	197	DXA GuidenetS	L5-1
Jamaludin [84] (2017)	UK	ES	2009	DLM MRI	L5-L1
Nakahara [85] (2015)	Japan	O SDD HS NM	9	CT MRI Pet	L5-1, Th12 cran
Nowitzke [75] (2008)	Australia	N	17	Fluo, FluoNav Int SW.	L5-1
Nyange [86] (2025)	India South Korea SouthAfrika	CE CS	63	DLM MRI	L5-1
Oktay [87] (2013)	Turkey	CE	80	DLM MRI	L1-5
Paik [88] (2012)	South Korea	R N	223	MRI X	L5-1
Prod'homme [89]	Switzerland	N O	30	Fluo	L5-1
Staudermann [90] (2024)	Switzerland	R SM	39	CT MRI	L5-1
Wanivenhaus [91] (2017)	Switzerland	O R	86	MRI Fluo	L5-1
Zeybel [92] (2020)	Turkey	CE	80	DLM MRI	L1-5
Zhao [93] (2025)	China Canada	CS	450	DLM MRI	L5-1

Abbreviations: med spec medical specialism; N neurosurgery; R radiology; O orthopaedic surgery; SDD spine disorder department; HS health sciences; NM nuclear medicine; CE computer engineering; DLM deep learning model; SM sports medicine; SS spine surgery; RD rheumatic disease; HPM hygiene and preventive medicine; Fluo fluoroscopy; X ray; CAD computer aided diagnosing system; DXA digital Xray Imaging; SCA Science Centre for AI & ML; INR Institute For Nutrition Research; PNOC Park Nicollet Osteoporosis Center; ES engineering science; L5 counting from lumbar 5 to 1; caud counting caudally; cran counting cranially, Th thoracic; CS computer science

Appendix 6:

Preclinical studies representing the current state of automatic vertebrae labeling using deep learning methods until 2026. It is a summary of the transition from early 2D and 3D CNN architectures toward highly sophisticated, multi-stage frameworks that integrate anatomical reasoning.

Study (ref) (year)	Country	Involved med spec	No of patients / researches	Radio	DLM used	Determination process	Accuracy ID rate (%)
Baka [94] (2017)	Netherlands	BIG N-R	43	US X	CNN U-net	IO-US and PO-X	92
Gao [95] (2024)	China	AI O	319	CT	MVGCN 3D-Res-U-Net	SR-IDA MS-IDA	97.9
Huang [96] (2021)	USA	BE EiH R	240	CT	R-CNN Ortho2D-f	MS-2D3D	91
Huang [97] (2022)	USA	BE CS R N IP	371	CT	MPRB CNN	MVMS	88.3
Lu [98] (2025)	China	R CC HNS Re	106	CT	YOLOv7 DBSCAN 3D U-Net	Lo Se La	94.4
Liao [99] (2018)	USA	CS O	302	CT	3D FCN Bi-RNN	Lo Id	92.2
Sekuboyina [100] (2020)	Germany Switzerland	Inf Nr BE	540	CT	Btrfly Net CNN	La MVF-AAC	91.4
Yoon [101] (2023)	Korea	R AI	1211	MRI-l	3 CNN	LB-ASC	99.7
Zhang [102] (2025)	China	Lab Ro Rt R MI	1053	CT	nnU-Net based	Se Id	98
Zhang [60] (2026)	China	Lab AI R	1324	CT	3D ResNet-101 SCL T-U-Net	Lo Se Id	100
Zhou [103] (2025)	China	Lab CS CRIB	515	CT	MPGMSN	Se Id	98.3

Abbreviations:: med spec medical specialism; N neurosurgery; R radiology; BIG Biomedical Imaging Group; AI airtificial intelligence department or center; O orthopedic surgery; BE biomedical engineering; EiH engineering in health; CS computer science; IP imaging physics; CC critical care; HNS head and neck surgery; Re rehabilitation; Ìnf dep of informatics; Rn radioneurology; Lab laboratory department; Ro radiooncology; Rt radiothearapy; MI medical imaging; CRIB Centre de Recherche en Information Biom´edicale Sino-français; DLM deep learning method; CNN convolutional neural network; U-net = architecture of the CVV; MVGCNIO Multi-View Graph Convolutional Network; 3D-Res-U-Net architecture used; intraoperative; US ultrasound; PO preoperative; X Xray; SR-IDA Spatial Relationships and Iterative Domain Adaptation; MS-IDA Multi-Stage Iterative Domain Adaptation; R-CNN Region-based CNN; f framework; MS-2D3D Multi-Stage 2D-to-3D Workflow; MPRB CNN Multi-perspective region-based CNN; MVMSa multi-stage Multi-View Multi-Slot network architecture; YOLOv7 you only look once version; DBSCAN Density-Based Spatial Clustering of

Applications with Noise; Lo localization; Se segmentation; La labeling; 3D FCN 3D Fully Convolutional Neural Network; Bi-RNN Bidirectional Recurrent Neural Network; Id Identification; Btrfly Net CNN butterfly-shaped fully convolutional network. MVF-AAC multi-view fusion process and adversarial anatomical constraints; MRI-l lumbar MRI; LB-ASC Landmark-Based Axial Slice Classification; nnU-Net no new U-net architecture; SCL Supervised Contrastive Learning; T-U-Net trans-U-net architecture; MPGMSN Mask prompt-guided multi-stage network for vertebrae identification; ID rate: identification ra



Chapter 6

Real-Life level identification accuracy study in patients with lumbosacral transitional vertebrae.

Liebrand B, van der Weegen W, v Slob M, S van Kuijk, Van Zundert J, Vissers K, van der Wal S.

(Submitted and under review European Spine Journal)

§6.1 Abstract

Introduction

Inaccurate lumbovertebral level identification, particularly when anatomical variations are present, can result in diagnostic errors and wrong-level interventions, undermining the safety and efficacy of spinal procedures. This study compared expert accuracy in lumbar level identification between normal and lumbar transitional vertebrae configurations.

Methods

In this accuracy and interobserver variability study of certified pain specialists, level determination was performed in consecutive selected patients' vignettes, comprising five with typical spinal anatomy and five with identified transitional vertebrae according to predefined validated protocols.

Results

Thirty-eight, NVA- or VAVP-certified pain specialists performed level determination in 190 assessments per group. This resulted in 16 (8%) incorrect level determinations in the typical anatomy- and 82 (43%) in the transitional vertebrae group, (χ^2 = 59.9 (1df), $p < 0.001$). Inter-rater agreement among 38 clinicians was lower in the transitional vertebrae group (κ = -0.138) than the typical anatomy group, reflecting substantial variability in identifying levels in patients with anatomical variations. Clinical experience was not significantly linked to accuracy (Pearson's r = 0.12, 95% CI −0.31 to 0.33).

Conclusion

Significant variability exists in identifying target lumbar levels among pain specialists, with anatomical variations presenting a higher challenge for accurate localization. Enhanced, detailed imaging and multidisciplinary coordination are essential to improve identification accuracy and prevent inappropriate level procedures.

§6.2 Introduction

Accurate identification of lumbovertebral (LV) levels is essential for safe and effective interventional spine procedures. Incorrect level identification may result in diagnostic errors, wrong-level interventions or ineffective treatment and outcome, particularly when anatomical variation are present (1-6).

Lumbosacral transitional vertebrae (LSTV) are congenital anatomical variants presenting with an estimated average prevalence of 12.3-15.3% in the general population (7, 8). LSTV may manifest as sacralization of the lowest LV, or lumbarization of the uppermost sacral segment (9, 10), and are commonly classified according to the Castellvi system (11). These variations alter the usual segmentation of the lumbosacral junction and may obscure the distinction between four or six lumbar levels hence compromising the correct concomitant nerve route identification (12, 13).

No gold standard is available to eliminate this risk of miscounting, and the diagnostic accuracy of common imaging techniques remains insufficiently documented (14) .Vertebral numbering may differ depending on whether counting is performed cranially or caudally and whether thoracic ribs are used as reference points (15). In daily clinical practice, lumbar spine magnetic resonance imaging (MRI) for patients with lumboradiculair pain, is often acquired without visualization of the entire spine (16, 17), increasing the risk of miscounting vertebral levels in patients with transitional anatomy. Landmark-based and palpation-based methods of level identification are equally prone to error (18), and even image-guided approaches may be inaccurate if vertebral enumeration is incorrect at the outset (19). Methodological differences are risk factors for wrong-level treatment (6) and several studies have emphasized the importance of interdisciplinary communication especially with transitional anatomy (19, 20). A systematic evaluation of level identification accuracy comparison in patients with and without LSTV is clinically relevant.

This study aimed to evaluate the accuracy and interobserver agreement among accredited certified pain specialists in lumbar vertebral level identification in patients with a normal five–lumbar vertebrae configuration versus those with LSTV. We hypothesized that the presence of an LSTV would be associated with a significantly higher rate of incorrect level identification compared to normal lumbar anatomy and lower interobserver agreement.

§6.3 Methods

Ethics

This prospectively performed research was approved by Maxima Medical Centre Regional Committee of Medical Ethics (N25.035).

Study design and participants

This study was designed as an accuracy and interobserver variability assessment of spinal level determination in the lumbar spine. During an annual combined congress (Nov-21-2025) of the Dutch Pain Society (NVA = Dutch Society of Anesthesiology) and the Flemish Pain Society (VAVP= Flemisch Society of Anesthesiology), pain specialists (participants) were randomly invited to independently determine the spinal level in a prepared case presentations in clinical vignettes using different clinical situations with related imaging information. Accreditation by both societies reflects formal training and demonstrated competence in recognizing the clinical features of LSTV, interpreting lumbar spine MRI, and performing accurate fluoroscopy-guided lumbar level identification.

Patient vignettes

Patient vignettes (n=10) were developed based on real patient data sourced from the Electronic Health Records of a regular second line accredited pain center in the Netherlands.

These were selected during a consensus meeting of two pain specialists (BL and SW). For inclusion patients needed to have: (1) a diagnosis of lumboradicular pain, registered according to the Dutch Health Care Authority coding system; (2) a history of a transforaminal procedure of the lumbar spine; (3) availability of high-quality fluoroscopic images suitable for vertebral level counting; (4) availability of MRI of the complete lumbosacral spine, including the most caudal thoracic vertebrae and the sacrum and (5) appointment of only one affected level in the diagnosis, treatment and MRI report.

For the five patients with a lumbosacral transitional vertebra, an additional inclusion criterion was applied: (5) the lumbosacral transitional vertebra had to be clearly visualized on the available imaging.

In this research, a total of 10 vignettes were prepared. The first five patients with a typical lumbar spinal anatomy (L5-group (g)), were consecutively selected from a clinical database. The second five patients with a clear lumbosacral transitional vertebra diagnosed were consecutively selected from a predefined database of patients with a known identified LSTV (LSTV-group (g)). All patient data provided to the participants were fully anonymized.

Level determination validation process

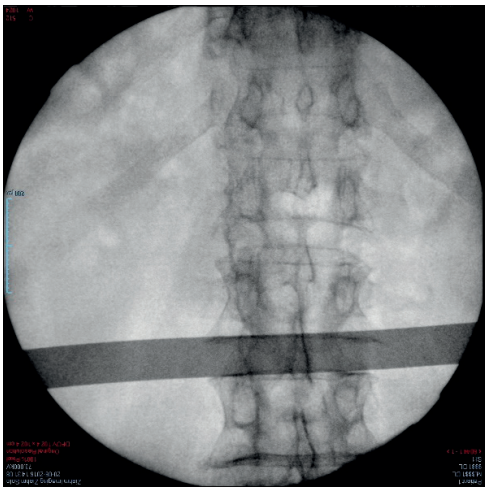
In the patients with LSTVs, the correct anatomical levels were determined in a predefined separate validation study by two independent investigators (21). In this study, used as the reference standard, a pain physician (BL) and a radiologist (MS) independently identified the first LV, counted the number of LV, and classified the type of lumbosacral transition for eligible patients, based on Xray MRI and fluoroscopy images. In patients with the regular five LV, the levels to be determined were straightforwardly established.

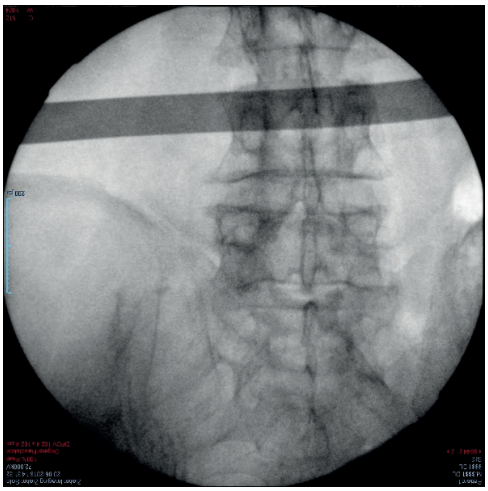
Subsequently, both investigators discussed their findings to reach consensus. Only patients for whom consensus was achieved regarding the vertebral count were included in the current study. This process ensured that the reference levels used for the interobserver survey were accurate and reproducible.

Patient presentation

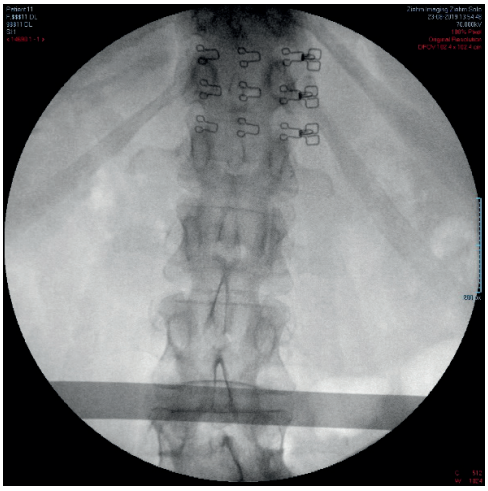
The order in which the ten vignettes were presented was randomized using ChatGPT (Appendix 1) (22). Participants were blinded to the actual anatomical spinal level and to the presence or absence of a lumbosacral transitional vertebra. The patient group consisted of three women and seven men. The age varied from 28 to 87 with an average of 57.1 years.

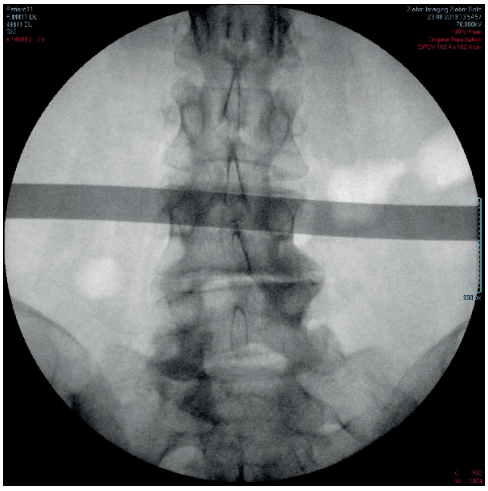
For each patient, participating pain specialists were given access to selected components of the electronic medical record to imitate a real-life situation. These included the neurologist's referral letter, treatment-related information from the pain specialist's record, and the written radiology report of the lumbar spine MRI (Appendix 2). In addition, observers were allowed to review all sagittal and transverse MRI images of the lumbar spine in detail, acquired according to a predefined protocol (23). The index test comprises both the medical record components and the associated imaging. Spinal level determination was performed independently by each participant using fluoroscopic images of the lumbar spine. For each patient, two fluoroscopic images were provided, allowing vertebral level counting (Figure 1). Participants were asked to select one of four predefined spinal levels displayed on the fluoroscopic images (Figure 2). These predefined levels did not correspond to the true anatomical spinal level in clinical practice in order to prevent disclosure of the level to be identified. In the L5-g, participants were asked to determine the L5 lumbar level in four patients and the L3 level in one patient. In the LSTV-g group, were asked to identify the L5 level in three patients with six lumbar vertebrae, and the L4 level was identified in two patients with four lumbar vertebrae.





A patient with four LV:





A patient with five LV:

Figure 1: Fluoroscopic images, obtained during interventions, for determining the amount of LV and counting.

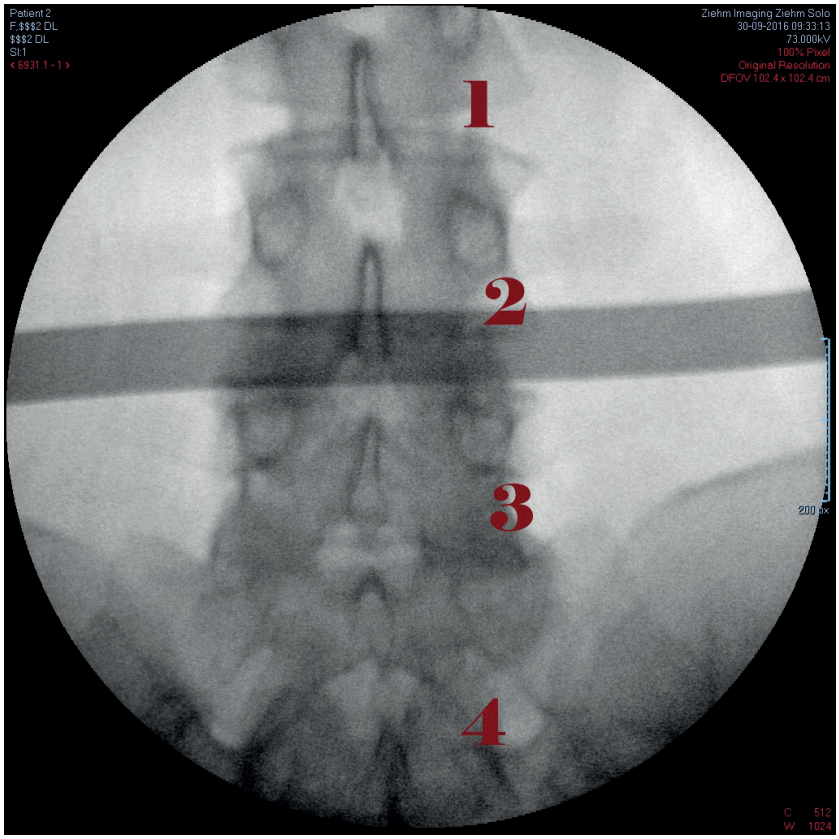


Figure 2: Fluoroscopic image with the possible choices of the required level.

Data collection

Each observer recorded their own level determinations on paper during the assessments and subsequently were entered into an online electronic data capture system (24) for further analysis. For all patients, the spinal levels to be assessed during the survey were validated by a pain specialist (BL) and an independent researcher (WW).

Statistics

A statistician (SK) was involved from the early study design phase. Differences in the accuracy of lumbar level identification between patients with five lumbar vertebrae (5LV) and those with a lumbosacral transitional vertebra (LSTV) were analyzed using a Pearson's chi-square (χ^2) test of independence, with accuracy defined as a binary outcome (correct vs. incorrect identification).

Interobserver agreement for categorical level assessments was evaluated using Cohen's kappa coefficient, calculated separately for patients with 5LV and those with LSTV. Kappa values were interpreted according to the Landis and Koch classification (25).

The association between years of clinical experience and accuracy of level determination was assessed using Pearson's correlation coefficient. Differences in the number of correctly identified levels between participants with and without a FIPP qualification were analyzed using an independent-samples t-test.

All statistical analyses were performed using IBM SPSS Statistics (version 31; IBM Corp., Armonk, NY, USA). A two-sided p-value < 0.05 was considered statistically significant.

§6.4 Results

Thirty-eight, NVA- or VAVP-certified pain specialists performed level determination in the ten patients, resulting in 380 assessments. The years of experience of the pain specialists varied from one to forty, with an average of 15.1. Fifteen (39.5%) were Fellow of Interventional Pain Practice (FIPP)-certified pain physicians (World Institute of Pain Certification program).

The survey of 190 assessments per group resulted in 16 (8%) inappropriate level determinations in the L5-g and 82 (43%) in the LSTV-g, see table 1 ($\chi^2 = 59.9$ (1df), $p < 0.001$). The effect size was moderate (Cramér's V = .397). The inter-rater agreement among the 38 clinicians assessing the lumbar level to be treated across the LSTV-g was lower (Cohen's kappa: -0.138 than in the L5-g (Cohen's kappa: , indicating substantial variability in how clinicians identified the target lumbar level in patients with anatomical variations (4 or 6 lumbar vertebrae). The variability is displayed for both groups in Figure 3.

Years of clinical experience were not significantly associated with the accuracy (i.e. the total number of correctly identified levels per person) of lumbar level determination (Pearson's r = 0.12, 95% CI −0.31 to 0.33), as illustrated in Figure 4.

Participants with FIPP registration demonstrated a slightly higher mean number of correctly identified levels (7.67) compared with non-FIPP participants (7.26); however, this difference was not statistically significant (mean difference 0.41, 95% CI −1.26 to 0.45; p = 0.34). If accuracy is averaged per participant (e.g., out of 10 cases), a mean difference of 0.41 per 10 cases would mathematically scale to about 1 extra correct determination per 25 cases (0.41 × 2.5 ≈ 1). However, the slightly higher mean number of correct determinations in FIPP-registered, was small and not statistically significant; therefore, no meaningful association between FIPP registration and accuracy could be established.

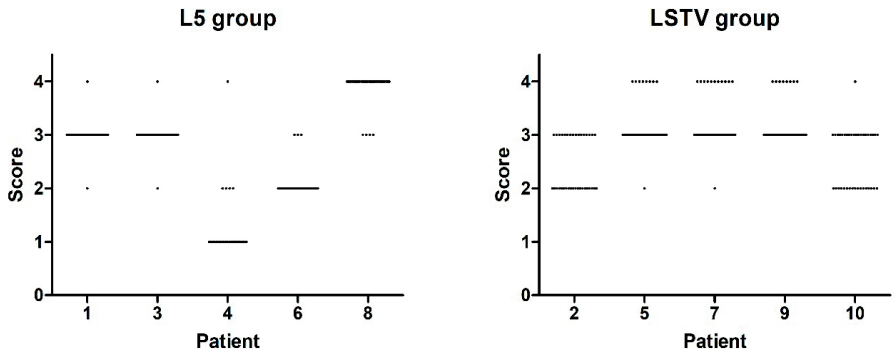


Figure 3: Variation of the level identifications in each patient of the L5G and LSTVG. The actual scores of the participants are displayed as dots in the figures.

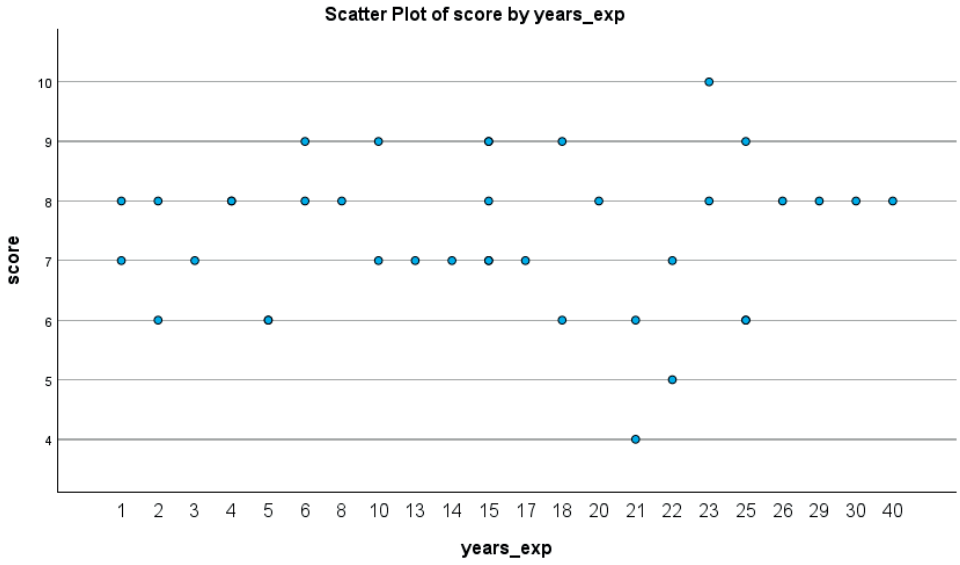


Figure 4: Years of experience participants against the amount of correct level determinations (score).

§6.5 Discussion

This is the first clinical case vignette study evaluating the interobserver variability assessment by certified pain specialists of spinal level determination in the lumbar spine among patients with and without LSTV. Incorrect level identification occurred in 43% in the LSTV group, compared to only 8% in patients with normal spinal anatomy. There is a substantial variability in how clinicians identified lumbar levels in patients with LSTV which does not correlate to the years of experience.

Accurate level determination in patients with LSTV is challenging due to multiple influencing factors. Anatomical variations complicate clinical decision-making because nerve root function may shift unpredictably (26, 27). In patients with four or six lumbar vertebrae, altered innervation patterns compared with the normal anatomy can affect both diagnosis and treatment (28).

Standardized MRI protocols for patients with lumboradicular pain typically assume the lowest lumbar vertebra to be L5 (16) which can lead to inaccurate vertebral level identification in this patient population (3). A comparable MRI protocol is used in Dutch hospitals, where radiologists determine vertebral levels by counting caudally from the presumed fifth lumbar vertebra on mid-sagittal images obtained with the patient in the supine position (23). Because the sagittal and transverse image coverage is limited, LSTV are often not recognized and therefore high misclassification rates exists when vertebral levels are defined solely by lumbar sagittal features (29). The anomaly is frequently first identified during fluoroscopic procedures in the Pain Management Department (PMD). In approximately 45% patients with lumbar spine anomalies pain physicians are confronted with a wrong level diagnosis (2, 3).

Only one study evaluated the accuracy of lumbar level determination using fluoroscopy alone (30). Vertebral levels were identified by counting caudally from L1 on lumbar spine X-rays, the reference test. Both the operating surgeon and a radiologist reviewed the images to assess agreement between the exposed level and the preoperatively identified pathological level. Accuracy was substantially lower in patients with transitional vertebrae, with correct identification in 50% (2/4) of cases, compared with 87% (83/96) in patients without transitional levels.

Although plain radiographs—including Ferguson views (31) and rib-based counting—can aid level determination and LSTV detection, their accuracy is limited and classification errors remain common, especially in complex or transitional anatomy (29). Four studies addressed conventional level determination in patients with transitional vertebrae and provided accuracy statements (2, 32-34). High error rates were reported (2, 32), with incorrect spinal counts in up to 54% of LSTV cases and frequent disagreement between observers. No single MRI parameter reliably identified vertebral levels without full-spine assessment, and studies limited to the lumbar region showed markedly lower accuracy than those evaluating the entire spine. Reported accuracy rates above 96% (33, 34) may reflect potential methodological weaknesses, such as sampling bias or inadequate validation procedures meriting closer evaluation.

Lian et al. advised counting caudally from C2 for accurate numbering in case of transitional vertebral segments (29). However standard vertebral numbering (starting from C2) is debatable for anatomical variations and careful assessment with anteroposterior spinal X-rays is necessary (8). X-rays and CT scans help evaluate transverse process morphology, and sagittal imaging

assesses the terminal vertebra and adjacent disc shape. The reliability of these methods remains uncertain due to the small sample sizes in evaluated studies (8).

The absence of plain Xray of the lumbar spine, possible collaboration with colleagues and the absence of more than the two provided fluoroscopy images are limitations of the present study. However, AP radiographs supports correct level identification but reliance on them may lead to incorrect numbering of the lower spinal levels (35) and their value is limited (36). Without high-quality whole-spine imaging, close communication between radiologists and referring clinicians, along with correlation of preoperative and intraoperative imaging, is essential (35). The limitations in the present were applied to both groups' patients however, and the variability of the level identifications was highly significant.

Guidance in the literature regarding the assessment of interobserver variability remains limited and is often poorly understood and conducted (37). Different samples of raters, even when of identical size, may yield different inter-rater agreement coefficients. This variability arises because the observed magnitude of inter-rater reliability reflects not only the raters' ability to apply a given classification system, but also the specific characteristics of both the rater sample and the subject sample included in the study (38). Although the participants in the present study differed substantially in years of professional experience, certification requirements across both societies are comparable. Therefore, the group can be considered relatively homogeneous with respect to lumbar spine level determination procedures.

§6.6 Conclusion

This study demonstrates a substantial variability in how certified pain specialists identified the target lumbar level in patients with and without anatomical variations. Correct level determination in patients with anatomical variations proved to be more challenging and may be underestimated. This study emphasizes that identifying the correct treatment level in patients with lumbosacral transitional vertebrae requires standardized counting protocols, comprehensive spinal imaging, and multidisciplinary coordination to mitigate the risk of inappropriate-level procedures.

§6.7 References

1. Naqvi AZ, Magill H, Anjarwalla N. Intraoperative practices to prevent wrong-level spine surgery: a survey among 105 spine surgeons in the United Kingdom. Patient Saf Surg. 2022;16(1):6.
2. Nakagawa T, Hashimoto K, Tsubakino T, Hoshikawa T, Inawashiro T, Tanaka Y. Lumbosacral Transitional Vertebrae Cause Spinal Level Misconception in Surgeries for Degenerative Lumbar Spine Disorders. TOHOKU JOURNAL OF EXPERIMENTAL MEDICINE. 2017;242(3):223-8.
3. Liebrand B, Brakel K, Boon A, van der Weegen W, Wal SV, Vissers KC. Diagnostic treatment-level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies. Reg Anesth Pain Med. 2022;47(3):177-82.
4. Albano S, Brown NJ, Pennington Z, Nguyen A, Hsu TI, Pham MH, et al. Risks Associated with Surgical Management of Lumbosacral Transitional Vertebrae: Systematic Review of Surgical Considerations and Illustrative Case. World Neurosurg. 2024;186:e54-e64.
5. George KJ. Wrong site spine surgery in the U.K.: a review of current practice. Br J Neurosurg. 2023;37(5):1131-4.
6. Grimm BD, Laxer EB, Blessinger BJ, Rhyne AL, Darden BV. Wrong-Level Spine Surgery. JBJS Rev. 2014;2(3).
7. Jancuska JM, Spivak JM, Bendo JA. A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. International Journal of Spine Surgery. 2015;9:42.
8. Fang H, Wang J, Kiwale JC, Cui M, Zeng X, Yang C, et al. Prevalence, diagnosis, and clinical significance of lumbosacral transitional vertebrae: A systematic review and narrative analysis. Brain Spine. 2025;5:105628.
9. Khalifé M, Vergari C, Lafage R, Elysée J, Finoco M, Gille O, et al. The Implications of Sacralized Transitional Vertebra on Spinal Alignment. Spine. 2025;50(15):1081-9.
10. Krenn VA, Fornai C, Webb NM, Woodert MA, Prosch H, Haeusler M. The morphological consequences of segmentation anomalies in the human sacrum. Am J Biol Anthropol. 2022;177(4):690-707.
11. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine. 1984;9(5):493-5.
12. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, et al. The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul). 2020;15(1):103-10.
13. Paik NC, Lim CS, Jang HS. Numeric and morphological verification of lumbosacral segments in 8280 consecutive patients. Spine. 2013;38(10):E573-8.
14. Mayer JE, Dang RP, Duarte Prieto GF, Cho SK, Qureshi SA, Hecht AC. Analysis of the techniques for thoracic- and lumbar-level localization during posterior spine surgery and the occurrence of wrong-level surgery: results from a national survey. Spine J. 2014;14(5):741-8.
15. Berger R, Bulloch L, Hysong A, Huggins B, Horan N, Van Der Noord R, et al. Establishing a common language for lumbar transforaminal epidural steroid injections. J Spine Surg. 2021;7(4):467-74.
16. Pojskic M, Bisson E, Oertel J, Takami T, Zygourakis C, Costa F. Lumbar disc herniation: Epidemiology, clinical and radiologic diagnosis WFNS spine committee recommendations. World Neurosurg X. 2024;22:100279.
17. Zhang AS, Xu A, Ansari K, Hardacker K, Anderson G, Alsoof D, et al. Lumbar Disc Herniation: Diagnosis and Management. Am J Med. 2023;136(7):645-51.

18. Tee JW, Rutges J, Marion T, Street J, Paquette S, Ailon T, et al. Factors predictive of topographical accuracy in spine level localization. J Spine Surg. 2017;3(1):23-30.
19. Epstein N. A perspective on wrong level, wrong side, and wrong site spine surgery. Surg Neurol Int. 2021;12:286.
20. Shah M, Halalmeh DR, Sandio A, Tubbs RS, Moisi MD. Anatomical Variations That Can Lead to Spine Surgery at the Wrong Level: Part III Lumbosacral Spine. Cureus. 2020;12(7):e9433.
21. Liebrand B, van der Wal S, Slob M, Boon A, Henssen D, Zundert J, et al. Diagnostic Precision in Lumbar Radiculopathy: Impact of Transitional Vertebrae on Treatment Level Selection and Outcomes. Pain Med. 2025.
22. OpenAI. ChatGPT (GPT-4) [large language model]. San Francisco (CA): OpenAI; 2024. Available from: https://chat.openai.com/ [
23. Robin Smithuis RdotRhiL, the Netherlands. . Lumbar Disc Herniation and other causes of nerve compression: Educational site of the Radiological Society of the Netherlands; 2014 [updated 2014-12-14. Available from: https://radiologyassistant.nl/neuroradiology/spine/lumbar-disc-herniation#mri-protocol.
24. Castor EDC. (2019). Castor Electronic Data Capture. [online] Available at: https://castoredc.com. [
25. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159-74.
26. Kim YH, Lee PB, Lee CJ, Lee SC, Kim YC, Huh J. Dermatome variation of lumbosacral nerve roots in patients with transitional lumbosacral vertebrae. Anesthesia and analgesia. 2008;106(4):1279-83.
27. Chang HS, Nakagawa H. Altered function of lumbar nerve roots in patients with transitional lumbosacral vertebrae. Spine. 2004;29(15):1632-5; discussion 5.
28. Hinterdorfer P, Parsaei B, Stieglbauer K, Sonnberger M, Fischer J, Wurm G. Segmental innervation in lumbosacral transitional vertebrae (LSTV): a comparative clinical and intraoperative EMG study. Journal of Neurology, Neurosurgery & Psychiatry. 2010;81(7):734-41.
29. Lian J, Levine N, Cho W. A review of lumbosacral transitional vertebrae and associated vertebral numeration. Eur Spine J. 2018;27(5):995-1004.
30. Ammerman JM, Ammerman MD, Dambrosia J, Ammerman BJ. A prospective evaluation of the role for intraoperative x-ray in lumbar discectomy. Predictors of incorrect level exposure. Surg Neurol. 2006;66(5):470-3; discussion 3-4.
31. Ferguson AB. The clinical and roentgenographic interpretation of lumbosacral anomalies. Radiology. 1934;22:548.
32. Peker E, Hursoy N, Akkaya H, Unal S, Gulpinar B, Arikan B, et al. Evaluation of spinal-paraspinal parameters to determine segmentation of the vertebrae. POLISH JOURNAL OF RADIOLOGY. 2019;84:E470-E7.
33. Yun S, Park S, Park J, Huh J, Shin Y, Yun J. Spinal Enumeration by Morphologic Analysis of Spinal Variants: Comparison to Counting in a Cranial-To-Caudal Manner. KOREAN JOURNAL OF RADIOLOGY. 2018;19(6):1140-6.
34. Yan YZ, Li QP, Wu CC, Pan XX, Shao ZX, Chen SQ, et al. Rate of presence of 11 thoracic vertebrae and 6 lumbar vertebrae in asymptomatic Chinese adult volunteers. J Orthop Surg Res. 2018;13(1):124.
35. Nakajima A, Usui A, Hosokai Y, Kawasumi Y, Abiko K, Funayama M, et al. The prevalence of morphological changes in the thoracolumbar spine on whole-spine computed tomographic images. Insights Imaging. 2014;5(1):77-83.

36. Hou L, Bai X, Li H, Gao T, Li W, Wen T, et al. Lumbar plain radiograph is not reliable to identify lumbosacral transitional vertebra types according to Castellvi classification principle. BMC Musculoskelet Disord. 2020;21(1):333.
37. Benomar A, Zarour E, Létourneau-Guillon L, Raymond J. Measuring Interrater Reliability. Radiology. 2023;309(3):e230492.
38. Gwet K. Variance Estimation of Nominal-Scale Inter-Rater Reliability with Random Selection of Raters. Psychometrika. 2008;73:407-30.

§6.8 Appendices

Appendix 1: Rearranging consecutive patient order into a randomly order for the survey by Chat GPT.

You therefore want to transform the numbers in the first sequence (1, 2, 3, 4, 5, 11, 12, 13, 14, 15) into the numbers 1 through 10 by rearranging them in a specific order, while also retaining the mapping that shows which numbers from the first sequence correspond to which numbers in the second sequence.

To structure this process, we can proceed as follows:

1. The numbers in the first sequence (1, 2, 3, 4, 5, 11, 12, 13, 14, 15) must be mapped to the numbers 1 through 10.

2. Each number in the first sequence must be assigned to exactly one number in the second sequence (1–10).

One way to achieve this is by creating a random permutation of the numbers in the first sequence and then defining the corresponding mapping. Alternatively, a specific logic or pattern can be used to establish the mapping.

We proceed step by step. We have a list of 10 numbers (the first sequence), which need to be mapped to the numbers 1 through 10. We propose using a random ordering of the first sequence and creating the corresponding mapping.

First sequence:

1, 2, 3, 4, 5, 11, 12, 13, 14, 15

Second sequence (numbers 1–10):

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

The numbers in the first sequence are then randomly reordered, after which the mapping to the numbers 1 through 10 is defined.

Random reordering of the first sequence:

Reordered first sequence:

14, 2, 12, 11, 5, 15, 4, 13, 3, 1.

Mapping:

- 14 → 1
- 2 → 2
- 12 → 3
- 11 → 4
- 5 → 5
- 15 → 6
- 4 → 7
- 13 → 8
- 3 → 9
- 1 → 10

Appendix 2: Example of a medical file in this research.

Patient.

Male, 77 years old.

Referral (Neurology):

Pain in the upper thighs, most likely L4 distribution, foraminal stenosis left > right. Please perform a diagnostic block and, if indicated, additional PRF.

Pain clinic record:

Diagnostic L4 block on the left with sleeve.

Report:

Lysis at L4–L5 with mild anterior displacement of L4 relative to L5, associated with a bulging disc. Peri discal abnormalities are also present. No central canal stenosis or nerve root compression is seen at this level. At the L3–L4 level, a bulging disc and degenerative changes are present, resulting in mild central canal stenosis and involvement of the neural foramina. No relevant abnormalities are observed at higher levels.

Task:

Select the level to be treated (left L4) from one of the provided options on the fluoroscopic image.

Note: The provided options do not correspond to the true anatomical levels.



Chapter 7

Transitional Vertebrae and Numerical Vertebral Variations: Two Distinct Embryological Mechanisms with Radiological Implications for Vertebral Level Identification.

under review at Radiology

Essentials

- Lumbosacral transitional vertebrae arise from a homeotic border shift at the lumbosacral junction, whereas numerical vertebral variations result from altered somite number or segmentation dynamics.

- These distinct developmental mechanisms lead to different patterns of vertebral counting, making standard imaging protocols that label the lowest lumbar vertebra as L5 prone to level misidentification.

- Recognizing the origins of these variations improves the reliability of vertebral level identification and supports more accurate diagnosis in patients with lumbar spine–related pathology.

§7.1 Abstract

Transitional anatomy increases the risk of wrong-level spinal interventions because altered vertebral counts challenge standard imaging protocols that assume fixed numbering. True transitional vertebrae may arise through developmental mechanisms distinct from simple numerical variation, with important consequences for clinical practice. This narrative review integrates embryologic principles with contemporary radiologic and clinical literature and research and is the first to propose two distinct developmental pathways. It synthesizes evidence on somitogenesis, Hox-regulated vertebral identity, and documented anatomical variation, linking these mechanisms to imaging-based level identification challenges.

Vertebral number and identity appear to derive from two related but separate systems: the segmentation clock, which determines somite number, and Hox gene expression, which assigns regional identity in the spine. Accordingly, true lumbosacral transitional vertebrae likely result from a homeotic border shift involving altered Hox10–11 expression, whereas numerical anomalies arise from deviations in somite number or segmentation dynamics during early somitogenesis.

Distinguishing these mechanisms is clinically essential because they differently affect vertebral morphology, nerve root function, and imaging interpretation. Current lumbar MRI protocols insufficiently account for these variations, contributing to diagnostic discordance and wrong-level interventions. Recognizing distinct developmental pathways and adopting more precise, embryologically grounded nomenclature can improve level identification and enhance diagnostic and therapeutic accuracy across spine care, including deformity surgery and spinopelvic assessment.

§7.2 Introduction

Low back pain is one of the most common and disabling health problems worldwide, with lifetime prevalence reaching 70–80% (1, 2). In the United States, 29.9% of adults experience low back pain annually, according to CDC surveillance (3), with lumbar radiculopathy accounting for 3–5% of adults and about 15% of low-back-pain cases (4). Dutch data show a similar burden, with a 17.2 per 1,000 person-years incidence, and radiculopathy present in roughly half of cases (5). Notably, about 40% of patients remain symptomatic after first-line therapy, forming the group most often referred for advanced imaging and image-guided interventional management. (5).

A challenge arises when patients have lumbosacral transitional vertebrae (LSTV), a congenital anatomical variation with an average prevalence of about 12.3-15.3% in the general population (6, 7). The typical human spine contains seven cervical, twelve thoracic, and five lumbar vertebrae, totaling twenty-four mobile vertebrae (MV). Transitional vertebrae can alter this count. Such anomaly, including thoracic and lumbar transitions, produce configurations of 23, 24, or 25 mobile vertebrae, with documented variations of 11–13 thoracic and 4–6 lumbar vertebrae occurring in seven distinct anatomical combinations (8-11). Sacralization refers to fusion of the transverse processes or body of the lowest lumbar vertebra with the sacrum, whereas lumbarization describes separation of the upper sacral segment, giving it the appearance of an additional lumbar vertebra (12).

Wrong-level spinal treatment remains a persistent and clinically significant problem, as highlighted across four systematic reviews published between 2010 and 2024 (13-16). These neurosurgical reviews report low but clinically significant error rates, which increase substantially in patients with LSTV, underscoring the need for improved preoperative detection of anatomical variants and multimodal intraoperative verification strategies. Correct level identification is particularly challenging in patients with LSTV (17, 18) and inconsistent terminology further contributes to diagnostic variability (19). Terms as sacralization and lumbarization are commonly applied to the lumbar spine because radicular symptoms typically originate there, regardless of the broader context of transitional anatomy.

This review proposes a conceptual distinction between true transitional vertebrae and numerical vertebral variation, suggesting that they may arise from partly distinct developmental mechanisms. A clearer understanding of how transitional vertebrae arise, together with the adoption of more accurate and anatomically precise spinal nomenclature, enhances clinical awareness of these variants. Such awareness may improve vertebral level identification and thereby support more precise treatment of radiculopathy.

§7.3 Understanding Transitional Vertebrae Through Embryological Development

Understanding the origin of transitional vertebrae, insight in the development of the vertebral column, a process called somitogenesis in the early embryonal period (20), is important because it clarifies why certain vertebral variants occur and how they alter normal segmental organization. Spinal embryonic development occurs in six stages (21). It begins with gastrulation (week 2), forming the three germ layers- ectoderm, mesoderm, and endoderm- and the notochord (precursor for the intervertebral discs) (22). Subsequently, the segmentation clock (a system of cyclic gene expression, primarily in the Notch, Wnt, and FGF pathways that switch on and off in waves every few hours (Fig 4)**)** regulates the formation of 42–44 pairs of somites along the craniocaudal axis by week 5 (22, 23). Fig. 1 presents an electron micrograph of the three germ layers (24).

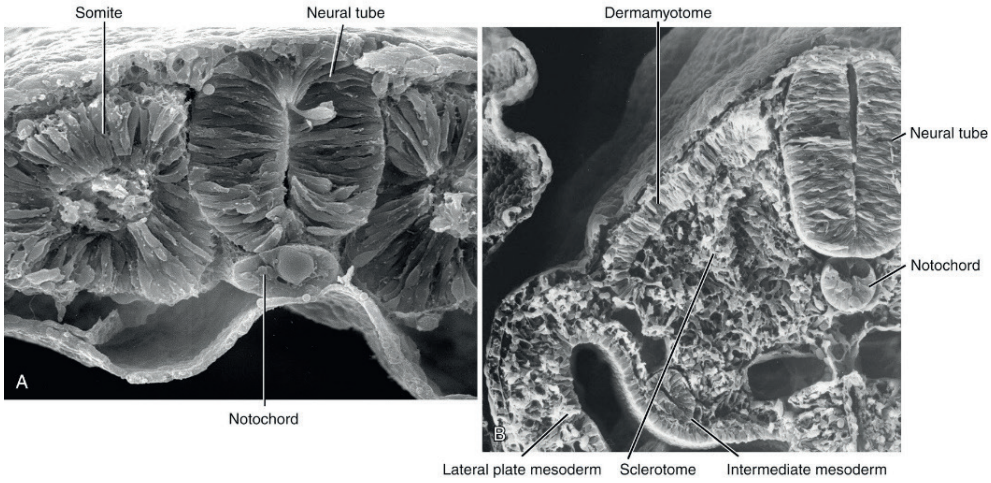


Figure 1: fig 4.25 chp 4 page 101. With permission of the publisher.

There are four occipital, eight cervical, twelve thoracic, five lumbar, five sacral and eight to ten coccygeal pairs. The first occipital and five to seven coccygeal somites will disappear. The number of somites that are formed in a given species are highly constrained but not fixed (25). In the third stage, somites reorganize into the dermomyotome and sclerotome, providing the basis for the axial skeleton (24). This is followed by resegmentation (stage 4), where sclerotomal cells recombine around the neural tube to form definitive vertebrae (21-23, 26), see Fig. 2. (23). Finally, chondrification (stage 5) and ossification (stage 6) begin, with primary centers appearing in week 8 and secondary centers fusing by adolescence (22, 23).

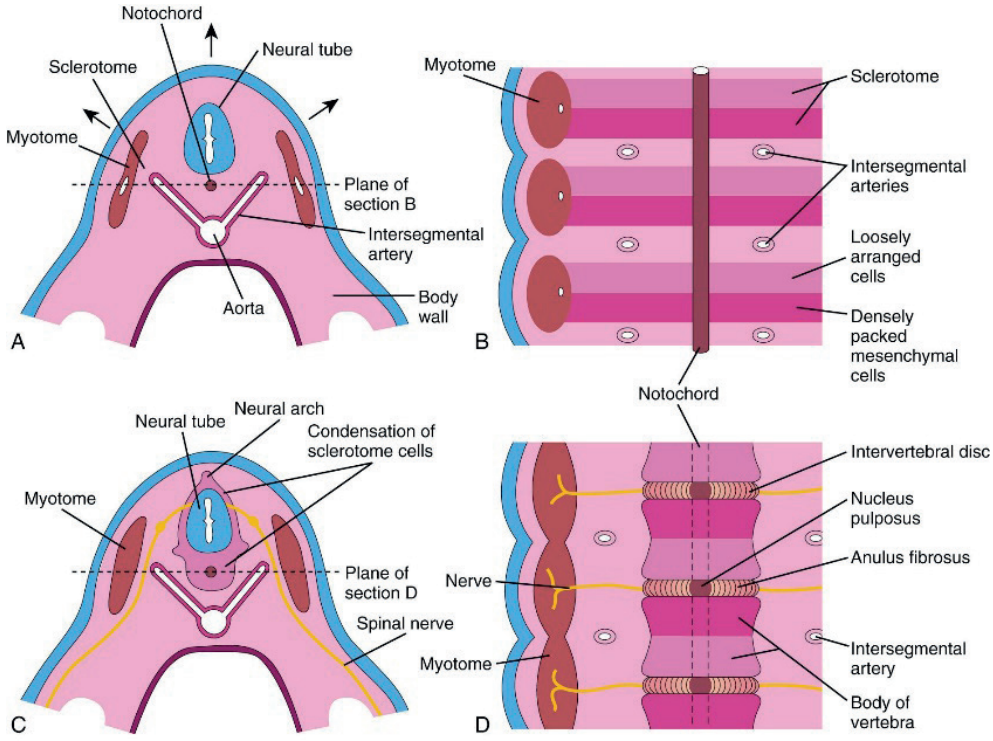


Figure 2: Page 321 fig 14.6. With permission of the publisher.

§7.4 Understanding Transitional Vertebrae Through Genetic Development

The subdivision into cervical, thoracic, lumbar, and caudal regions is controlled by a set of transcription factors located on the so-called Hox genes (20). The 39 hox genes are distributed in four clusters A-D, subdivided in 13 groups (figure 3) and located on chromosomes 7, 17, 12, and 2, respectively (27).

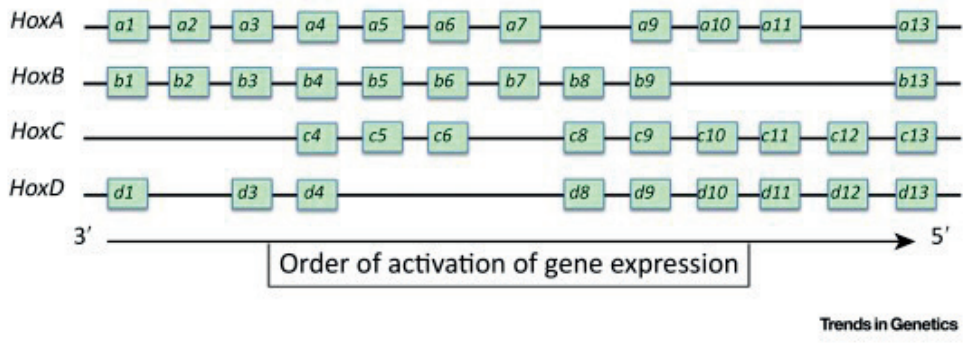


Figure 3: Basic Structure of the Mammalian *Hox* Clusters.

(Reassessing the Role of *Hox* Genes during Vertebrate Development and Evolution. Mallo, Moisés Trends in Genetics, Volume 34, Issue 3, 209 – 217). (Permission asked from the publisher)

Hox genes display hierarchical gene expression within the somites and are activated in the somite precursors during the gastrulation fase (20). Precise expression during early paraxial mesoderm development is essential and largely controls future vertebral identity (20). Their order on the chromosome mirrors and their activation along the anterior–posterior axis, create predictable regional identity domains. These domains form segment-specific boundaries, and each somite interprets the local combination of active Hox genes to acquire its regional vertebral identity (28) resulting in cervical, thoracic, lumbar, and sacral regions (29, 30).

Variations in the number of vertebrae in a specific region, originate from errors in these Hox genes (21), meaning a shift in Hox boundaries (31). The Hox 10 group expression corresponds to the genetically defined functional domain of the thoracic/lumbar transition and the Hox 11 group to the lumbosacral transition (32, 33). Hox 10 paralogous genes inhibit the development of thoracic ribs in the lumbar to sacral regions (34, 35). Hox 11 genes partially counteract Hox 10 activity in the sacral area, promoting the formation of modified ribs that, under Hox 11 regulation, fuse together to form the sacrum (33, 35). Disruptions in the expression of Hox 10 or Hox 11 genes, vertebrae might take on characteristics of adjacent regions, leading to the emergence of transitional vertebrae.

The segmentation clock and the Hox10 and 11 genes are tightly linked systems that together establish the vertebral identity along the forming embryo. The segmentation clock generates the temporal rhythm that produces somites in a head-to-tail sequence, while the Hox clusters—activated in a temporal and spatial colinear manner—translate this timing into positional identity for each segment (36). See Figure 4. The formed somite 'reads' the local Hox code at that position (32).

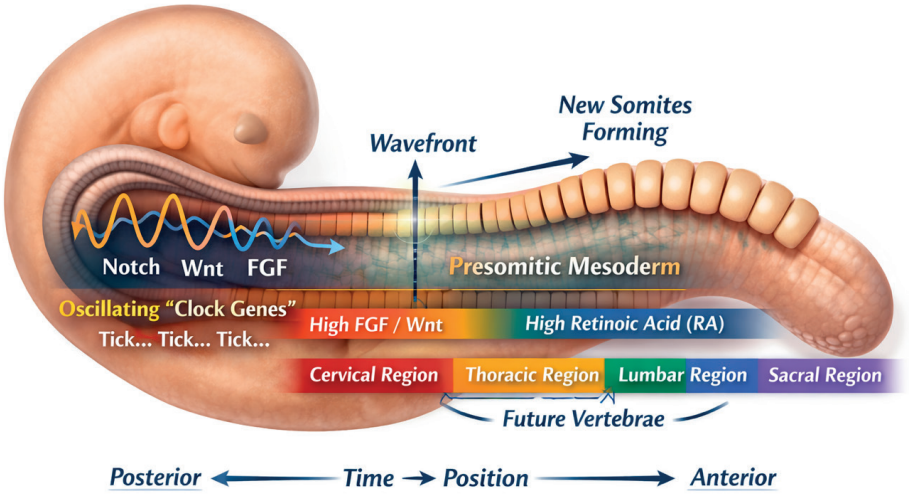


Figure 4: The embryonal segmentation clock.

§7.5 Linking the Embryological Origins of Transitional Vertebrae to Key Insights in Contemporary Literature

In summary, during the six embryonic stages 42–44 pairs of somites form along the craniocaudal axis, reorganize, and segment to generate the definitive vertebral column, with the sacral and coccygeal vertebrae developing last (13, 22, 23). The segmentation clock functions as a molecular oscillator whose periodicity matches the timimg of somite formation (37). The ratio between axial elongation speed and somitogenesis rate has been proposed to play a critical role in determining the number of body segments (37). While the segmentation clock determines when a somite forms, the sequential hierarchical expression, and activation of Hox genes determines what that somite becomes (36). As a result of these developmental processes, the human spine may present with 23, 24, or 25 mobile vertebrae, with documented variations of

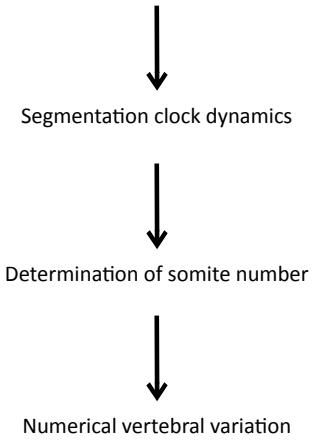
11–13 thoracic and 4–6 lumbar vertebrae occurring in seven distinct anatomical combinations, not including sacral and coccygeal segments (8, 10).

An emerging theory distinguishes true LSTV from numerical vertebral variations. A true LSTV is a congenital morphological transformation in which the lowest lumbar vertebra or highest sacral segment structurally acquires transitional features (such as enlarged transverse processes or fusion). Slight shifts in Hox expression boundaries can cause a vertebra to adopt mixed lumbar–sacral characteristics during axial patterning occurring in the second and third stage of embryonic development (week 2-3). A numerical vertebral variation is simply a difference in vertebral count, with normal morphology and no transitional anatomy and results from changes in somite formation or the timing of segmentation. This occurs later however, in the same developmental window, during axis elongation, the segmentation clock rhythmically divides the presomitic mesoderm into somites (week 3-5). Variations in somite number or segmentation dynamics can lead to numerical vertebral variations without transitional morphology. These mechanisms overlap and coexist, as demonstrated by the findings of Liebrand et al. (17, 38). Table 1 provides a paragraph summary and Figure 5 an overview schema.

Table 1: Summary of two distinct developmental mechanisms.

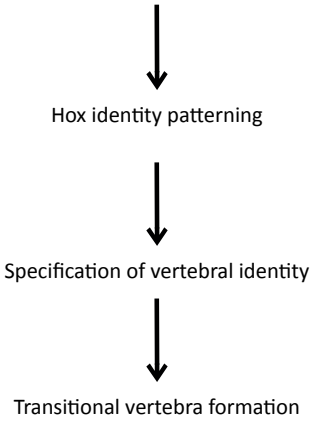
Aspect	Hox-mediated identity shift	Somite number / segmentation variation
Type of vertebral variant	True LSTV (structural transitional morphology)	Numerical vertebral variation (difference in vertebral count)
Underlying mechanism	Shift in Hox gene expression boundaries leading to altered vertebral identity	Variation in somite number or segmentation timing leading to altered vertebral count
Embryonic stage (six-stage model)	2 and 3: Hox patterning in presomitic mesoderm; axial identity established and continues into early somitogenesis	3: Segmentation clock regulates rhythmic somite formation while Hox boundaries are still being refined
Imaging appearance	Enlarged transverse processes, partial fusion, mixed lumbar–sacral morphology	Normal vertebral morphology with atypical numbering (e.g., 11-13 TV, 4-6 LV)
Clinical relevance	May affect nerve root labeling, and diagnostic and procedural level identification	Essential for correct vertebral numbering in interventions and radiology reporting

1: Segmentation Clock Pathway:



(Variation in total vertebral count without changes in vertebral identity.)

2: Hox Identity Pathway:



(Mixed or shifted vertebral identity, such as lumbar–sacral transitional vertebrae.)

Figure 5: Schematic Diagram Developmental Mechanism.

The presence of 25 MV—comprising twelve thoracic and six lumbar vertebrae, along with five sacral segments—may arise from a different developmental mechanism when the lowest MV is a true sixth lumbar vertebra, with only lumbar characteristics and no transitional features. This condition may result from an extra pair of somites during embryogenesis rather than from a homeotic shift in the lumbosacral junction which is the mechanism when 24 MV with an LSTV exhibiting characteristics of both regions are present. Notably, patients with 24 and 25 MV show a significantly higher prevalence of six LV (38). Thus, a sixth lumbar vertebra is not automatically equivalent to a true lumbarization.

Similarly, a configuration of 23 mobile vertebrae—typically four lumbar vertebrae and five sacral segments—reflects a reduced vertebral count. However, patients with 23 mobile vertebrae may also present with eleven thoracic and five lumbar vertebrae (38). Therefore, the presence of four lumbar vertebrae is not inherently a true sacralization.

Based on the literature and especially the CT-study by Krenn et al. (12), sacralization refers to the cranial border shift, in which the lowest lumbar vertebra (L5) becomes incorporated into the sacrum. This occurs when one or both transverse processes of L5 attach to the sacrum or ilium through osseous fusion (synostosis) or pseudarthrosis (false joint). The resulting configuration appears as four mobile lumbar vertebrae and six sacral segments.

Conversely, lumbarization refers to a caudal border shift, in which the first sacral segment (S1) fails to fuse with the remainder sacrum. S1 remains mobile or partially dissociated and often displays lumbar-like characteristics, such as a well-formed disc space between S1 and S2, and lumbar-type facet joints. This produces the appearance of six lumbar vertebrae and four sacral segments.

LSTV are commonly classified using the Castellvi system (39), which describes the anatomical relationship between the transverse process and the sacrum. In the lumbosacral region it is important to distinguish between a normal transition, a pseudoarthrosis forming a lumbosacral connection (Castellvi types Ia, Ib, IIa, and IIb), and complete osseous fusion (types IIIa, IIIb, and IV). These categories apply to both lumbarization and sacralization (17). In the referenced study, a presumed lumbarized L5 was significantly more frequently classified as unclassified (normal transition) or Castellvi types I and II, whereas a presumed sacralized L5 showed a significantly higher prevalence of types III and IV.

Lumbarization and sacralization in the lumbosacral region should be defined more precisely in the literature and, at minimum, in relation to the number of lumbar and sacral vertebrae. Cases with 25 or 23 mobile vertebrae without transitional morphology at the lumbosacral junction represent distinct numerical anomalies and should perhaps be considered separately from LSTV. Moreover, because 11-13 thoracic vertebrae may occur, lumbarization can also reflect a homeotic thoracolumbar border shift. Findings from recent studies addressing this topic (8, 9, 12, 17) support these interpretations. Therefore consideration should extend beyond the seven described possible combinations of thoracic and lumbar vertebrae in patients with LSTV (8-11, 40) to also include the four, five, or six sacral segments.

§7.6 Clinical Implications of Distinguishing Transitional Morphology from Numerical Variation

Magnetic resonance imaging (MRI) in the supine position is probably the most widely used modality for diagnosing lumbosacral radicular pain caused by degenerative disc disease (41). Level counting on MRI of the lumbar spine may be difficult (42). Standard protocols typically assume that the lowest lumbar vertebrae is L5, and reliance on limited sagittal images alone leads to under-recognition of LSTV due to protocol limitations (43, 44).

Diagnosing lumboradiculair pain in patients with lumbar spine anomalies therefore has several limitations. In case of true LSTV, vertebral counting on sagittal images depends on whether the lumbosacral transition is a normal, involves a pseudoarthrosis, or shows complete osseous fusion. LSTV are classified according to the Castellvi system (39). O'Driscoll et all. documented the variations of lumbosacral anatomy on sagittal MRI and correlated these with plain radiography in patients with LSTV. They found a good correlation between a fused LSTV and a type 4 MRI appearance in the O'Driscoll classification. In this pattern, a well-formed residual disc between S1 and the remainder of the sacrum, together with a squared-off appearance of the presumed upper sacral segment, leads to counting that segment as a vertebra. In contrast, when only a small residual disc is present and the associated osseous structure resembles the sacrum rather than a true vertebral body, it might not be counted.

Standardized MRI protocols in patients with lumboradicular pain assume the lowest lumbar vertebra as L5 (41, 45, 46). Consequently, the presence of a numerical variation, such as four or six lumbar vertebrae without an LSTV, will probably result in incorrect level identification. In patients with an LSTV, resulting form a proposed different development mechanism, accurate counting and therefore correct level diagnosis depend on disc height and vertebral body morphology. The assumptions built into standard imaging protocols fail to account for anatomical variation.

§7.7 Considerations

Animal studies, mainly in genetically modified mice, provide robust evidence for the genetic mechanisms outlined in the embryology section. In human however, evidence remains limited to anatomical and radiological observations of variants such as sacralization and lumbarization. To date, no direct or convincing genetic association with Hox 10 or Hox 11 mutations has been demonstrated. This absence of clear linkage is attributable to genetic redundancy, complex regulatory interactions, variable gene expression, and the inherent limitations of detecting such mechanisms in clinical populations.

Although this relationship has not been directly investigated, integrating the embryology literature on the genesis and distinction between numerical vertebral variation and true transitional vertebrae with the clinical literature on level-identification challenges in these patients highlights an important consequence: clinicians should be more aware of these complexities. More precise anatomical nomenclature may support more accurate diagnosis and treatment in patients with spinal anomalies, especially given that an internationally accepted gold standard with 100% accuracy across all clinical scenarios is still lacking (47).

The discussion centers on wrong-level treatment and radiculopathy, but the implications extend to scoliosis and deformity surgery, where spinopelvic parameters—including pelvic incidence, sacral slope, pelvic tilt, lumbar lordosis, distal lumbar lordosis, and PI–LL mismatch—depend on accurate identification of S1. In transitional anatomy, uncertainty about the true sacral base may alter these measurements and affect deformity classification, alignment targets, and selection of the lowest instrumented vertebra with potential consequences for surgical planning.

A strictly numerical variation—such as the presence of only four lumbar vertebrae, with the vertebra counted as L5 actually representing a sacral segment—can lead to vertebral enumeration errors and mismatches between radiological numbering and clinical neuroanatomical interpretation, and, in addition to these osseous discrepancies between standard spinal anatomy and such variants, nerve-root trajectories also differ in patients with transitional anatomy. A lumbarized S1 vertebra may function as an L5 nerve root (48), though inconsistently, and in cases of sacralized L5 the L4 nerve root often assumes L5 function (49). Furthermore, studies show that patients with six lumbar vertebrae exhibit nerve-root innervation patterns that differ from those with the typical five, influencing both diagnosis and intervention (50). These findings are reinforced by a recent study by Nam et al. who reported that in patients with LSTV, only 27.6% of cases showed concordance between MRI-identified compression and EMG-identified radiculopathy, while 72.4% demonstrated discordance (51).

§7.8 Conclusion

This scientific article is the first to hypothesize that true lumbosacral transitional vertebrae and simple numerical vertebral variation could plausibly arise from distinct developmental mechanisms. True LSTV reflect a homeotic border shift at the lumbosacral junction, producing vertebrae with mixed lumbar–sacral morphology. In contrast, numerical variations—such as the presence of 23 or 25 mobile vertebrae with normal morphology—likely result from differences in somite number or segmentation dynamics, rather than transitional anatomy.

Understanding this distinction is clinically important. Transitional morphology and numerical variation alter nerve root relationships and radiologic appearance. Both mechanisms affect

vertebral counting in a distinguished way. Standard imaging protocols, which assume a fixed vertebral count and designate the lowest lumbar vertebra as L5, are therefore insufficient in patients with either condition. This contributes to misidentification of vertebral levels, particularly on MRI, and increases the risk of wrong-level diagnosis and intervention.

More precise and anatomically consistent spinal nomenclature—grounded in embryological mechanisms and attentive to both transitional morphology and vertebral count—can enhance clinical awareness of these variants. Such awareness supports more reliable vertebral level identification and may ultimately improve the accuracy of diagnosis and treatment in patients with lumbosacral radiculopathy.

§7.9 References

1. Organisaion WH. World Health Organisation 2026 [Available from: https://www.who.int/.
2. Hartvigsen J, Hancock MJ, Kongsted A, Louw Q, Ferreira ML, Genevay S, et al. What low back pain is and why we need to pay attention. Lancet. 2018;391(10137):2356-67.
3. Prevention CfDCa. National Health Interview Survey: 2018 Data Release 2019 [Available from: https://www.cdc.gov/nchs/nhis/2018nhis.htm.
4. CFAH. Back Pain Statistics 2024 [Available from: https://cfah.org/back-pain-statistics/.
5. Spijker-Huiges A, Groenhof F, Winters JC, van Wijhe M, Groenier KH, van der Meer K. Radiating low back pain in general practice: incidence, prevalence, diagnosis, and long-term clinical course of illness. Scand J Prim Health Care. 2015;33(1):27-32.
6. Jancuska JM, Spivak JM, Bendo JA. A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. Int J Spine Surg. 2015;9:42.
7. Fang H, Wang J, Kiwale JC, Cui M, Zeng X, Yang C, et al. Prevalence, diagnosis, and clinical significance of lumbosacral transitional vertebrae: A systematic review and narrative analysis. Brain Spine. 2025;5:105628.
8. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, et al. The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul). 2020;15(1):103-10.
9. Chiu CK, Chin TF, Chung WH, Chan CYW, Kwan MK. Variations in the Number of Vertebrae, Prevalence of Lumbosacral Transitional Vertebra and Prevalence of Cervical Rib Among Surgical Patients With Adolescent Idiopathic Scoliosis: An Analysis of 998 Radiographs. Spine (Phila Pa 1976). 2024;49(1):64-70.
10. Tatara Y, Niimura T, Sekiya T, Mihara H. Changes in Lumbosacral Anatomy and Vertebral Numbering in Patients with Thoracolumbar and/or Lumbosacral Transitional Vertebrae. JB JS Open Access. 2021;6(3).
11. Gonzales-Portillo GS, Rizvi O, Avila MJ, Dumont TM. The prevalence of 11 ribs and its potential implications in spine surgery. Clin Neurol Neurosurg. 2021;203:106544.
12. Krenn VA, Fornai C, Webb NM, Woodert MA, Prosch H, Haeusler M. The morphological consequences of segmentation anomalies in the human sacrum. Am J Biol Anthropol. 2022;177(4):690-707.
13. Albano S, Brown NJ, Pennington Z, Nguyen A, Hsu TI, Pham MH, et al. Risks Associated with Surgical Management of Lumbosacral Transitional Vertebrae: Systematic Review of Surgical Considerations and Illustrative Case. World Neurosurg. 2024;186:e54-e64.
14. Devine J, Chutkan N, Norvell DC, Dettori JR. Avoiding wrong site surgery: a systematic review. Spine (Phila Pa 1976). 2010;35(9 Suppl):S28-36.
15. DeVine JG, Chutkan N, Gloystein D, Jackson K. An Update on Wrong-Site Spine Surgery. Global Spine J. 2020;10(1 Suppl):41s-4s.
16. Strong MJ, Santarosa J, Sullivan TP, Kazemi N, Joseph JR, Kashlan ON, et al. Pre- and intraoperative thoracic spine localization techniques: a systematic review. J Neurosurg Spine. 2022;36(5):792-9.
17. Liebrand B, Brakel K, Boon A, van der Weegen W, van der Wal S, Vissers KCP. Diagnostic treatment-level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies. Regional Anesthesia and Pain Medicine. 2022;47(3):177-82.

18. Nakagawa T, Hashimoto K, Tsubakino T, Hoshikawa T, Inawashiro T, Tanaka Y. Lumbosacral Transitional Vertebrae Cause Spinal Level Misconception in Surgeries for Degenerative Lumbar Spine Disorders. Tohoku J Exp Med. 2017;242(3):223-8.
19. Berger R, Bulloch L, Hysong A, Huggins B, Horan N, Van Der Noord R, et al. Establishing a common language for lumbar transforaminal epidural steroid injections. J Spine Surg. 2021;7(4):467-74.
20. Iimura T, Denans N, Pourquié O. Establishment of Hox vertebral identities in the embryonic spine precursors. Curr Top Dev Biol. 2009;88:201-34.
21. Dias MS. Normal and abnormal development of the spine. Neurosurg Clin N Am. 2007;18(3):415-29.
22. Sadler TW. Langman's Medial Embryology. Fifteenth Edition ed: Wolters Kluwer; 2024.
23. KL Moore TP, MG Torchia. The Developing Human, Cl,inically Oriented Embryology. 11th ed: Elsevier; 2020.
24. GC Schoenwolf SB, PR Brauer, PH Franscis-West. Larsen's Human Embryology. Sixth ed: Elsevier; 2021.
25. Asher RJ, Lin KH, Kardjilov N, Hautier L. Variability and constraint in the mammalian vertebral column. J Evol Biol. 2011;24(5):1080-90.
26. Scaal M. Early development of the vertebral column. Semin Cell Dev Biol. 2016;49:83-91.
27. Lappin TR, Grier DG, Thompson A, Halliday HL. HOX genes: seductive science, mysterious mechanisms. Ulster Med J. 2006;75(1):23-31.
28. Krumlauf R. Hox genes in vertebrate development. Cell. 1994;78(2):191-201.
29. Burke AC, Nelson CE, Morgan BA, Tabin C. Hox genes and the evolution of vertebrate axial morphology. Development. 1995;121(2):333-46.
30. Wellik DM. Hox genes and vertebrate axial pattern. Curr Top Dev Biol. 2009;88:257-78.
31. Mallo M. Revisiting the involvement of signaling gradients in somitogenesis. Febs j. 2016;283(8):1430-7.
32. Carapuço M, Nóvoa A, Bobola N, Mallo M. Hox genes specify vertebral types in the presomitic mesoderm. Genes Dev. 2005;19(18):2116-21.
33. Wellik DM, Capecchi MR. Hox10 and Hox11 genes are required to globally pattern the mammalian skeleton. Science. 2003;301(5631):363-7.
34. Guerreiro I, Casaca A, Nunes A, Monteiro S, Nóvoa A, Ferreira RB, et al. Regulatory role for a conserved motif adjacent to the homeodomain of Hox10 proteins. Development. 2012;139(15):2703-10.
35. Mallo M, Wellik DM, Deschamps J. Hox genes and regional patterning of the vertebrate body plan. Dev Biol. 2010;344(1):7-15.
36. Deschamps J, Duboule D. Embryonic timing, axial stem cells, chromatin dynamics, and the Hox clock. Genes Dev. 2017;31(14):1406-16.
37. Bénazéraf B, Pourquié O. Formation and segmentation of the vertebrate body axis. Annu Rev Cell Dev Biol. 2013;29:1-26.
38. Liebrand B, van der Wal S, Slob M, Boon A, Henssen D, Zundert J, et al. Diagnostic Precision in Lumbar Radiculopathy: Impact of Transitional Vertebrae on Treatment Level Selection and Outcomes. Pain Med. 2025.
39. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984;9(5):493-5.
40. Tins BJ, Balain B. Incidence of numerical variants and transitional lumbosacral vertebrae on whole-spine MRI. Insights Imaging. 2016;7(2):199-203.

41. Farshad-Amacker NA, Farshad M, Winklehner A, Andreisek G. MR imaging of degenerative disc disease. Eur J Radiol. 2015;84(9):1768-76.
42. Peh WC, Siu TH, Chan JH. Determining the lumbar vertebral segments on magnetic resonance imaging. Spine (Phila Pa 1976). 1999;24(17):1852-5.
43. Thawait GK, Chhabra A, Carrino JA. Spine segmentation and enumeration and normal variants. Radiol Clin North Am. 2012;50(4):587-98.
44. Neelakantan S, Anandarajan R, Shyam K, Philip B. Multimodality imaging in Bertolotti's syndrome: an important cause of low back pain in young adults. BMJ Case Rep. 2016;2016.
45. Pojskic M, Bisson E, Oertel J, Takami T, Zygourakis C, Costa F. Lumbar disc herniation: Epidemiology, clinical and radiologic diagnosis WFNS spine committee recommendations. World Neurosurg X. 2024;22:100279.
46. Zhang AS, Xu A, Ansari K, Hardacker K, Anderson G, Alsoof D, et al. Lumbar Disc Herniation: Diagnosis and Management. Am J Med. 2023;136(7):645-51.
47. Liebrand B, Braunhofer L, van der Weegen W, Vissers K, Van Goethem J, Van Zundert J, et al. Accuracy in spinal level determination, including transitional vertebrae: an ASReview supported systematic review. Eur Spine J. 2026.
48. Chang HS, Nakagawa H. Altered function of lumbar nerve roots in patients with transitional lumbosacral vertebrae. Spine (Phila Pa 1976). 2004;29(15):1632-5; discussion 5.
49. Kim YH, Lee PB, Lee CJ, Lee SC, Kim YC, Huh J. Dermatome variation of lumbosacral nerve roots in patients with transitional lumbosacral vertebrae. Anesth Analg. 2008;106(4):1279-83, table of contents.
50. Hinterdorfer P, Parsaei B, Stieglbauer K, Sonnberger M, Fischer J, Wurm G. Segmental innervation in lumbosacral transitional vertebrae (LSTV): a comparative clinical and intraoperative EMG study. J Neurol Neurosurg Psychiatry. 2010;81(7):734-41.
51. Nam Y, Yang JH, Chang D-G, Suh SW. Discordance Between Anatomical Nerve Root Compression and Functional Radiculopathy in Patients with Lumbosacral Transitional Vertebrae. Journal of Clinical Medicine. 2026;15(10):3809.



Chapter 8

General discussion

The primary objective of this thesis is to analyze inconsistencies in spinal level determination across referral documentation, MRI reports, and interventional procedures, and assessing their clinical implications, especially in the presence of spinal anomalies. Further, I evaluate whether (1) these discrepancies occur systematically between pain interventionalists at national and international levels and (2) the accuracy of specific methods and techniques pain medicine interventionalists employ to determine spinal levels during clinical procedures.

The following research questions were formulated:

1 How are patients with a lumbosacral transitional vertebra identified?

2 What is currently known about invasive pain management in patients with lumbosacral transitional vertebrae (LSTV)?

3 What are the accuracies of spine level determination methods, given the variability of transitional vertebrae?

4 Do the identified level inconsistencies found during interventional treatments occur locally, nationally, or internationally?

5 Is it possible to improve the accuracy of spinal level identification in patients with lumbosacral transitional vertebrae?

§8.1 The identification of patients with lumbar spine anomalies

In chapter 2, I explored the identification of spinal anomalies like LSTV that begins with a complex clinical decision-making process and the awareness of critical pitfalls in this process (1) including inconsistent diagnostic approaches, complex clinical decision-making, variable fluoroscopic techniques, and limitations in MRI protocols. Additionally, the referral source significantly influences patient identification, as noted in Chapter 4 (2). Patients from neurology and neurosurgery departments were significantly more accurately referred than patients from general practitioners or the orthopedic surgery department.

The identification of these patients is further complicated by the fact that nerve root innervation in LSTV cases differs from the standard five lumbar vertebra (LV) with their roots (3-5) and neurological clinical examinations often lack clinical accuracy in these instances (5-7). Furthermore, as demonstrated in Chapters 2 and 3 (8), transitional vertebra (TV) frequently were overlooked on routine lumbar spine radiographs. An LSTV was mentioned in only 14 of the 114 initial lumbar spine Xray reports and in only four initial MRI reports. This is partly due

to the limited accuracy (76–84%) of standard anteroposterior radiographs for LSTV detection (9). Applying deep learning methods (DLM) does not improve this, yielding an accuracy of 76.4%, a sensitivity of 85.1%, and a specificity of 61.9% (10). Furthermore, limited MRI views and unreliable landmarks--such as the last rib--often lead to vertebral numbering errors and underestimation of LSTV prevalence (11-14).

Discrepancies in professional methodology also play a role. Radiologists commonly count vertebral levels cranially from the presumed L5 on mid-sagittal images with the patient in the supine position (4). Conversely, interventionalists use fluoroscopy, often count caudally form the presumably T12 with the patient in the prone position (Chapter 2). Multiple surveys underscore the pitfalls in vertebral level identification, which contribute to wrong-level interventions (15-18). Collectively, these factors often lead to non-identification, as a result of which that spine anomalies, such as TV, frequently are first discovered during an interventional pain medicine procedure rather than during pre-procedural imaging or the initial referral.

Currently, the literature lacks an evidence-based, standardized golden standard approach for vertebral level determination in the presence of anomalies.

§8.2 New insights in invasive pain management in patients with LSTV

In Chapter 3 I present the results from a cohort of 114 patients, revealing significant diagnostic inconsistencies (8). A 40% discrepancy was observed between the level reported by the referring physician and the level treated by the pain specialist. Similarly, a 46% discrepancy was observed between MRI-reported levels and treatment levels. Interobserver reliability (radiologist versus pain physician) for classifying a transitional vertebra was fair (($\kappa = 0.40$) and substantial ($\kappa = 0.70$) when simply counting the vertebrae.

In a subsequent study of 214 patients (Chapter 4) I analyzed referral patterns, level determination accuracy and clinical workflows (2). In 49.5% of the cases (106) the target level was ambiguous. Referrals form general practitioners, and orthopedic surgeons were significantly more likely to lack clarity, leading to more consultations, treatments, and extended care at the pain management department (PMD), contributing to longer and more costly healthcare pathways. Among the 108 patients with a clearly identified level in their referral, 72 (33.6%) received treatment at the correct level, while 36 (16.9%) received treatment at an incorrect level. The clinical consequences of these incorrect interventions remain uncertain, as no significant outcome differences were observed between these groups. This lack of significance may be due to the limited sample size, variability in treatment duration, and a general lack of literature regarding the impact of incorrect-level interventions in pain medicine.

In the subsequent study (Chapter 4) (2), discrepancies between the referral or MRI report and the actual treatment level occurred in 27.1% and 32.2 % of cases respectively. These lower percentages likely reflect increased awareness of LSTV among radiologists, improved matching in patients with standard five lumbar vertebrae anatomy, and proactive adjustments of diagnostic levels in the files, based on MRI findings.

To date, only one more study has investigated how LSTV leads to spinal misconceptions in surgical cases (12). In a cohort of 550 patients, LSTV was identified in 12.9% (n=71), consisting of 37 cases of L5 sacralization and 34 of S1 lumbarization. Vertebral levels were miscounted in 54% of these cases (38). Nakagawa et al. concluded that failure to identify LSTV frequently leads to numbering errors and advised obtaining whole-spine AP X-rays for all lumbar surgeries to prevent suboptimal outcomes. Furthermore, a review on

wrong-level spine surgery identified anatomical anomalies and inadequate imaging as leading causes of errors (19).

Chapter 3 (8) and 4 (2) explored the morphological classification of LSTV and the clinical correlation with total vertebral count. Statistically, lumbarization significantly correlates with pseudo-arthrosis (Castellvi types I, II, or unclassified; $p<0.001$), whereas sacralization correlates with fused “tight” connections (Castellvi types III, IV; $p<0.001$). Analysis of 68 cases showed that total mobile vertebrae count significantly influences LV numbers: 24–25 MV typically result in six LV, while 23 MV correlate with four LV ($p<0.001$). These findings confirm that anomalous MV counts are predictive of anomalous LV counts, making level counting inherently inaccurate without full-spine imaging in these cases.

Recommendations to overcome wrong or incorrect level procedures focus on recognition of these risk factors (19, 20). The interventional specialist plays a critical role in mitigating this risk (19, 21), and pre-procedural protocols for prevention including communication may improve patients outcome (22, 23). Most studies recommend determining the true spinal count using clear intraprocedural imaging (12, 13, 24-26), and adopting total spine imaging protocols as a reference standard (13, 14, 26). Finally interdisciplinary collaboration with radiologists is essential (13, 23, 25-28). Seeking consensus on the most appropriate treatment level may help prevent discrepancies, as radiologists have access to advanced imaging software that facilitates more accurate vertebral level determination.

§8.3 The accuracy of treatment level determination performed in patients with LSTV

The systematic review in Chapter 5 was the first to evaluate both conventional and advanced spinal level determination methods in patients with both normal and transitional anatomy (29). A comprehensive literature search--supported by the machine learning tool ASReview--was conducted across PubMed, Web of Science and Embase for studies published between 1962 and 2026. This resulted to the inclusion of twenty-nine relevant studies, categorized into three groups: conventional methods (fluoroscopy, US, CT, MRI, n = 20), TV-specific studies (n = 4), and advanced methods (intra-operative navigation, algorithms and machine learning, n = 5). While conventional methods achieved varying levels of accuracy--with nine studies reporting up to 100%--no studies involving transitional vertebrae reached 100%. Conversely, advanced methods demonstrated 100% accuracy in most studies.

The four included studies specifically addressing LSTV indicate low diagnostic accuracy or high risk of bias offering only limited recommendations for clinical management (12, 30-32). The inconsistencies observed in study designs, patient selection, and bias are reflective of challenges in daily clinical practice. Key literature emphasizes the necessity of high-quality, full-spine imaging (33, 34) , the implementation of uniform counting techniques (33), and fostering close communication between radiologists and clinicians to mitigate the high risk of wrong-level interventions (19, 21, 34, 35).

Surveys reveal substantial heterogeneity in clinical practice, highlighting a persistent risk of incorrect level procedures and an urgent need for standardized protocols (15, 18, 36). Heterogeneity was confirmed in our study (Chapter 6), where 38 NVA- or VAVP-certified pain specialist performed level determination for ten randomly assigned patients with and without lumbar spine anomalies. Out of 380 assessments, incorrect level identification occurred in 43% of the LSTV group, significantly more than the 8% error rate in the standard L5 group. These findings demonstrate substantial variability in how clinicians identify lumbar levels in LSTV patients, regardless of their years of clinical experience.

Advanced determination methods show promise in achieving high accuracy, particularly in complex anatomy (37-42). However, widespread adoption is currently hindered by high costs, the need for specialized equipment, methodological assumptions (e.g., 12 thoracic vertebrae), and a lack of evidence regarding clinical outcomes and cost-effectiveness in pain medicine. While DLM approaches are evolving toward real-time clinical applicability they require further optimization. A key constraint remains their reliance on human-led training. Future research should prioritize clinical validation and methodological simplification to reduce costs and facilitate routine implementation.

In summary, ensuring accurate spinal level determination in patients with TV requires a multifaceted approach. Critical components include awareness and recognizing of TV, high-quality intraoperative imaging, comparison with preoperative MRI or CT scans, obtaining full spine imaging when needed and fostering interdisciplinary collaboration. While integrating multiple imaging modalities and systematic labeling helps to overcome anatomical variability, establishing a universal, evidence-based protocol requires large-scale validation of emerging technologies. Furthermore, a recent (2026) review advocates for highly structured approach-- utilizing AP radiography, CT confirmation, MRI in specific cases and Jenkins' classification for LSTV-- to mitigate risks and improve surgical outcomes (43).

§8.4 Diagnostic inaccuracies in patients with LSTV probably reflect the current global practice

The analyzed studies in our systematic review (Chapter 5) originated from sixteen countries across the globe: Australia, Canada, China, Germany, Iran, India, Italy, Japan, Jordan, Norway, The Netherlands, South Korea, Switzerland, Turkey, United Kingdom and the United States. Notably, all these studies determined lumbar levels by assuming the lowest lumbar level to be L5, a method prevalent in Dutch hospitals (44), as well as in the international medical community (45, 46). Similarly, the fifteen excluded studies, including those involving DLM (Appendix 5, Chapter 5), represent a diverse international range, covering thirteen countries: Australia, Canada, China, India, Italy, Japan, Jordan, South Afrika, South Korea, Switzerland, Turkey, the USA, and the UK.

MRI in the supine position remains the primary imaging modality for diagnosing neurologic lumbosacral radicular pain related to degenerative disc disease (47). Literature reviews confirm that MRI techniques for lumbar disc herniation are standardized across various regions (45, 46). The systematic review by Pojskic et al. commissioned by the WFNS Spine Committee, incorporated evidence from North America, Europe, Asia, and Latin America. The 2023 narrative review by Zhang et al. does not contain a formal inclusion list of studies but cited literature originating predominantly from the United States, United Kingdom, Netherlands, Japan, and Brazil. Despite this apparent global standardization, these conventional MRI protocols have significant inherent limitations.

However not investigated directly, the potentially inaccurate determination of lumbar spine levels in LSTV patients—often resulting form MRI scans that do not visualize the entire spine and a flawed counting process starting at the presumed L5 level, probably contributes to significant misdiagnoses in these patients, and appears to be a widespread international issue.

§8.5 Improving the accuracy of spinal level determination in patients with spinal anomalies

Chapter 2 outlines the diagnostic and treatment pitfalls encountered in patients with spinal anomalies. To address these, the study advocates for an evidence-based, standardized uniform approach to vertebral level determination. Central to this improvement is the necessity of enhanced communication between radiologists, neurologists, surgeons, and interventionalists. By improving intraprocedural imaging quality, establishing uniform counting protocols, and fostering multidisciplinary collaboration, clinicians can significantly reduce the risk of incorrect level interventions and optimize patient outcomes.

In Chapter 3 a high prevalence of discrepancies was reported between referral levels, MRI findings and the actual treatment levels. Chapter 4 further evaluated the real-world consequences of these misidentifications, which often lead to diagnostic uncertainty and suboptimal treatment. To mitigate these risks, interdisciplinary consultation is essential to reach a consensus on the target level, supported by high-resolution imaging that provides a clear view of the spinal anatomy.

The systematic review in Chapter 5 highlights the substantial variability in radio-diagnostic practices and level determination amongst medical specialists. Key recommendations include the early recognition of transitional vertebrae, the use of high-quality intraoperative imaging, collaboration between radiologists and interventionists and the systematic comparison of preoperative MRI or CT scans with procedural findings. Furthermore, full-spine imaging should be obtained whenever the vertebral count is in doubt.

Four studies addressed conventional level determination in patients with transitional vertebrae and provided accuracy statements (12, 30, 31, 48). Nakagawa et al. reported incorrect spinal numbering in 54% (38/71) of LSTV cases. Peker et al. analyzed 13 LSTV cases (9% of their cohort) and concluded that no single MRI parameter is reliable without comprehensive whole-spine counting. Discrepancies between spine surgeons and radiologists were observed in 10 of 293 cases in the study by Yan et al., while Yun et al. found minimal disagreement (1/100 cases), limited to Castellvi type I and II anomalies. Overall, studies incorporating full-spine imaging demonstrate high accuracy, whereas lumbar-focused approaches show substantially lower reliability.

Lian et al. recommended caudal counting from C2 to achieve accurate vertebral numbering in cases with transitional segments (33). This remains controversial in the presence of anatomical variations, necessitating careful evaluation with anteroposterior spinal radiographs (49). Despite the utility of Xray Ferguson views, rib-based counting, and CT scans for evaluating morphology,

the complexity of transitional anatomy (33) and limited sample sizes in current literature (49) leave the reliability of these methods uncertain.

The advanced methods (Chapter 5) such as ION systems and algorithm-based approaches, show promise in achieving near-perfect accuracy. However, their cost-effectiveness during interventional pain procedures requires further evaluation. Furthermore, if the current models are trained on standard anatomy (12 thoracic and 5 lumbar vertebrae), they may fail when encountering anomalies. Transitioning these emerging techniques to clinical practice will necessitate large-scale validation to ensure their efficacy and reliability.

Deep-learning models represent an emerging AI-based approach that increasingly supports clinical vertebral analysis, primarily using MRI and CT imaging (Appendix 5, Chapter 5). Recent studies (2024-26) currently focus more on vertebral localization, segmentation, and identification then on precise clinical level determination.

Understanding the origin of transitional vertebrae from human embryology and subsequent consequence in clinical practice.

The vertebral column develops through six embryonic stages (50) beginning with gastrulation and followed by somitogenesis, during which 42–44 pairs of somites form along the craniocaudal axis. It reorganizes and resegments to create the definitive spine, with sacral and coccygeal vertebrae developing last (51, 52). The segmentation clock is a molecular oscillator active in the cells in the posterior part of the perisomitic mesoderm and the period of oscillation matches the period of somite formation (53). The ratio between the speed of axis elongation and somitogenesis was proposed to play a critical role in controlling the size of the PSM and thus in defining the number of body segments (53). Hox10 controls the thoracic–lumbar transition; Hox11 controls the lumbosacral transition.(54, 55). The segmentation clock and Hox10/11 genes work together to establish vertebral identity: the clock sets the timing of somite formation, and the Hox clusters translate this timing into each segment's positional identity (56).

This thesis proposes that true lumbosacral transitional vertebrae (LSTV) and simple numerical vertebral variations arise from distinct embryological mechanisms, a distinction that has not been adequately addressed in clinical practice and the radiologic literature. Chapter 7 hypothesized that transitional morphology—such as sacralization or lumbarization—reflects a homeotic border shift driven by altered Hox10/Hox11 expression. Numerical variation (23 or 25 mobile vertebrae with normal morphology) results from differences in somite number or segmentation dynamics during early embryogenesis. The findings by recent studies (57-59) and this thesis (2, 8) supports these findings.

The discussion highlights that current clinical terminology and imaging protocols fail to account for this developmental distinction. Standard MRI workflows assume a fixed vertebral count and designate the

lowest lumbar vertebra as L5 (45-47), a practice that is unreliable in patients with either transitional anatomy or numerical variation (8, 12, 60). Level counting on MRI of the lumbar spine is unreliable , and this contributes directly to incorrect level diagnosis and intervention—an issue repeatedly emphasized in neurosurgical literature (18, 23, 61) and increasingly recognized in pain medicine.

Importantly, consideration should be given not only to the seven described combinations of thoracic and lumbar vertebrae in patients with LSTV (58, 59, 62-64), but also to the possibility of four, five, or six sacral segments (57). This broader anatomical variability reinforces the need to distinguish true transitional morphology from simple numerical variation, as each configuration affects vertebral labeling and nerve-root relationships differently.

The thesis integrates embryological insights with contemporary radiologic and clinical findings, demonstrating that transitional morphology and numerical variation alters nerve-root function, innervation patterns, and radiologic appearance (3-5, 65). Although both mechanisms disrupt conventional level identification, they probably do so in different ways. This distinction has not been sufficiently investigated and, as a result, has not been adequately incorporated into clinical decision-making or educational programs.

Animal studies, mainly in genetically modified mice, strongly support the genetic mechanisms. Human evidence is limited to anatomical and radiological observations of variants such as sacralization and lumbarization. No direct, convincing genetic link to Hox 10 or Hox 11 mutations has yet been demonstrated, likely due to genetic redundancy, regulatory complexity, variable expression, and limitations in clinical detection. Analyzing a collected population of over 400 patients with lumbar spine anomalies might clarify the proposal about the possible differences of the underlying mechanisms of distinct numerical anomalies and homeotic shifts of existing segments.

§8.6 Strengths and limitations

This thesis provides valuable insights into daily clinical management of patients with lumboradicular pain and spinal anomalies. By consistently directing attention to LSTV, clinicians identify it more often than expected. This demonstrates that awareness can be trained, and that structured education probably improves LSTV recognition.

Several limitations should be acknowledged. First and crucially, the lack of a gold standard for precise level determination within the spine complicates the diagnostic and therapeutic process, hindering the ability to establish the affected level with full certainty.

Secondly, a single-center study limits the generalizability of the findings. While similar diagnostic challenges have been reported internationally (13, 14), the true prevalence of LSTV in patients undergoing pain interventions may be underestimated due to restricted radiodiagnostic

protocols. Third, patient-reported outcome measures (PROMs) could not be included in this research. Patient selection was started in 2016; however, the PROMs infrastructure became only fully operational in 2020.

Fourth, patient selection was based on the nationwide Dutch Health Care Authority code system for 'lumboradicular pain'. Because referral sources—such as the distinction between neurology/neurosurgery and GPs/orthopedic surgery--significantly influence healthcare pathways, these systemic variations should be carefully considered when extrapolating these results to international contexts.

§8.7 General Conclusion

The management of patients with lumbosacral radicular pain in the presence of LSTV present a significant challenge in clinical practice, characterized by high rates of diagnostic discrepancy and procedural risk. This thesis demonstrates that LSTV is frequently overlooked in routine imaging, with reporting rates as low as 12% for X-rays and 4% for MRIs. These inaccuracies are probably not merely local or national issues but may reflect a current global practice rooted in standardized but limited imaging protocols.

The reliance on lumbar-only MRI and the conventional practice of counting cranially from a presumed L5 are insufficient for patients with anomalous lumbar anatomy. Our findings establish a clear correlation between total mobile vertebral counts and lumbar configurations: 24–25 mobile vertebrae often result in six lumbar vertebrae, while 23 correlate with four. Consequently, without full-spine imaging, the risk of misidentifying treatment levels remains high, leading to extended healthcare pathways and potential incorrect level interventions. Ultimately, mitigating these risks requires a shift from isolated specialist assessments toward integrated, multidisciplinary collaboration supported by universal counting protocols.

§8.8 Recommendations for clinical practice, further research and training & education

To advance the accuracy of level determination and strengthen collaboration among spinal specialists, future research should prioritize the following key areas to improve outcomes for patients with spinal anomalies:

1) For clinical practice:

- Improving diagnostics starts with a discussion on MRI-based assessment of lumboradicular pain in the presence of spinal anomalies. A survey-based study targeted at radiologists and spine specialists should be performed to pave the way toward a uniform gold standard for spinal level determination.

- Global healthcare pathway analysis should account for the structural differences between international healthcare systems and referral models (e.g., primary care-led vs. specialist-direct). Investigating how these diverse pathways influence diagnostic accuracy and care duration is essential to mitigate systemic bias and ensure that findings are generalizable across different international medical infrastructures.

2) For further research:

- Prospective clinical evaluation to analyze the impact of real-world consequences of spine anomalies should be performed by large-scale, prospective studies using PROMs. These studies should additionally focus on the clinical and economic consequences of incorrect-level interventions in pain medicine, a topic currently under-represented in the literature.

- Research should further aim to establish an international, evidence-based consensus on vertebral counting and level determination. This includes validating the necessity of full-spine imaging, sagittal and coronal, as a reference standard in suspected LSTV cases.

- Future algorithm based and AI-driven diagnostic tools should be trained on diverse datasets that include a real-world prevalence of anatomical variants (such as LSTV) rather than standard anatomy alone. This is essential to ensure the robustness and generalizability of automated vertebral level identification. These technologies must be rigorously validated for cost-effectiveness and seamless integration into clinical workflows.

3) For education and training:

Improvements of curricula and clinical training (NVA/VAVP) is recommended. Given the high rate of diagnostic discrepancies and the substantial variability in level determination—regardless of clinical experience— and to enhance patient safety and procedural precision, consideration should be given to incorporate LSTV recognition and uniform vertebral counting protocols into the core competency frameworks for pain medicine fellowships.

§8.9 References

1. Bart.J.F. Liebrand MD FIPP1 WvdWP, Selina.E.I. van der Wal MD PhD FIPP3, Kris.C.P. Vissers MD PhD FIPP3. Diagnostic and Treatment Pitfalls in a Patient with Lumbosacral Transitional Vertebrae: A Real-life Case Based Review. Pain Practice submission. 2025.
2. Liebrand B, van der Wal S, Slob M, Boon A, Henssen D, Zundert J, et al. Diagnostic Precision in Lumbar Radiculopathy: Impact of Transitional Vertebrae on Treatment Level Selection and Outcomes. Pain Med. 2025.
3. Chang HS, Nakagawa H. Altered function of lumbar nerve roots in patients with transitional lumbosacral vertebrae. Spine (Phila Pa 1976). 2004;29(15):1632-5; discussion 5.
4. Kim YH, Lee PB, Lee CJ, Lee SC, Kim YC, Huh J. Dermatome variation of lumbosacral nerve roots in patients with transitional lumbosacral vertebrae. Anesthesia and analgesia. 2008;106(4):1279-83.
5. Hinterdorfer P, Parsaei B, Stieglbauer K, Sonnberger M, Fischer J, Wurm G. Segmental innervation in lumbosacral transitional vertebrae (LSTV): a comparative clinical and intraoperative EMG study. Journal of Neurology, Neurosurgery & Psychiatry. 2010;81(7):734-41.
6. van der Windt DA, Simons E, Riphagen, II, Ammendolia C, Verhagen AP, Laslett M, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. Cochrane Database Syst Rev. 2010(2):Cd007431.
7. Al Nezari NH, Schneiders AG, Hendrick PA. Neurological examination of the peripheral nervous system to diagnose lumbar spinal disc herniation with suspected radiculopathy: a systematic review and meta-analysis. Spine J. 2013;13(6):657-74.
8. Liebrand B, Brakel K, Boon A, van der Weegen W, Wal SV, Vissers KC. Diagnostic treatment-level discrepancies in patients with lumbosacral radicular pain and lumbar spine anomalies. Reg Anesth Pain Med. 2021.
9. Farshad-Amacker NA, Lurie B, Herzog RJ, Farshad M. Interreader and intermodality reliability of standard anteroposterior radiograph and magnetic resonance imaging in detection and classification of lumbosacral transitional vertebra. Spine J. 2014;14(8):1470-5.
10. Kwak D, Ro DH, Kang DH. Automated Detection of Lumbosacral Transitional Vertebrae on Plain Lumbar Radiographs Using a Deep Learning Model. J Clin Med. 2025;14(21).
11. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210.
12. Nakagawa T, Hashimoto K, Tsubakino T, Hoshikawa T, Inawashiro T, Tanaka Y. Lumbosacral Transitional Vertebrae Cause Spinal Level Misconception in Surgeries for Degenerative Lumbar Spine Disorders. TOHOKU JOURNAL OF EXPERIMENTAL MEDICINE. 2017;242(3):223-8.
13. Thawait GK, Chhabra A, Carrino JA. Spine segmentation and enumeration and normal variants. Radiol Clin North Am. 2012;50(4):587-98.
14. Neelakantan S, Anandarajan R, Shyam K, Philip B. Multimodality imaging in Bertolotti's syndrome: an important cause of low back pain in young adults. BMJ Case Rep. 2016;2016.
15. Mayer JE, Dang RP, Duarte Prieto GF, Cho SK, Qureshi SA, Hecht AC. Analysis of the techniques for thoracic- and lumbar-level localization during posterior spine surgery and the occurrence of wrong-level surgery: results from a national survey. Spine J. 2014;14(5):741-8.

16. Mody MG, Nourbakhsh A, Stahl DL, Gibbs M, Alfawareh M, Garges KJ. The prevalence of wrong level surgery among spine surgeons. Spine (Phila Pa 1976). 2008;33(2):194-8.
17. Groff MW, Heller JE, Potts EA, Mummaneni PV, Shaffrey CI, Smith JS. A survey-based study of wrong-level lumbar spine surgery: the scope of the problem and current practices in place to help avoid these errors. World Neurosurg. 2013;79(3-4):585-92.
18. Naqvi AZ, Magill H, Anjarwalla N. Intraoperative practices to prevent wrong-level spine surgery: a survey among 105 spine surgeons in the United Kingdom. Patient Saf Surg. 2022;16(1):6.
19. Epstein N. A perspective on wrong level, wrong side, and wrong site spine surgery. Surg Neurol Int. 2021;12:286.
20. George KJ. Wrong site spine surgery in the U.K.: a review of current practice. Br J Neurosurg. 2023;37(5):1131-4.
21. Albano S, Brown NJ, Pennington Z, Nguyen A, Hsu TI, Pham MH, et al. Risks Associated with Surgical Management of Lumbosacral Transitional Vertebrae: Systematic Review of Surgical Considerations and Illustrative Case. World Neurosurg. 2024;186:e54-e64.
22. Algie CM, Mahar RK, Wasiak J, Batty L, Gruen RL, Mahar PD. Interventions for reducing wrong-site surgery and invasive clinical procedures. Cochrane Database Syst Rev. 2015;2015(3):Cd009404.
23. Srivatsa S, Vira S, Schils J, Shook S, Gill A, Krishnaney AA. Reducing Wrong-level Spinal Surgeries Through Root Cause Analyses: A 10-year Longitudinal Analysis of a Single Tertiary Institution's Iterative Policy Improvements. Spine (Phila Pa 1976). 2021;46(11):E648-e54.
24. Devine J, Chutkan N, Norvell DC, Dettori JR. Avoiding wrong site surgery: a systematic review. Spine (Phila Pa 1976). 2010;35(9 Suppl):S28-36.
25. MG M, A N, DL S, M G, M A, KJ G. The prevalence of wrong level surgery among spine surgeons. Spine. 2008;33(2):194-8.
26. Vitale M, Minkara A, Matsumoto H, Albert T, Anderson R, Angevine P, et al. Building Consensus: Development of Best Practice Guidelines on Wrong Level Surgery in Spinal Deformity. Spine Deform. 2018;6(2):121-9.
27. Grimm BD, Laxer EB, Blessinger BJ, Rhyne AL, Darden BV. Wrong-Level Spine Surgery. JBJS reviews. 2014;2(3).
28. Lee SH, Kim JS, Jeong YC, Kwak DK, Chun JH, Lee HM. Patient safety in spine surgery: regarding the wrong-site surgery. Asian Spine J. 2013;7(1):63-71.
29. B. Liebrand MD FIPP1, 9, L. Braunhofer2, W. van der Weegen PhD3, K.C.P. Vissers MD PhD FIPP4, J.W.M. Van Goethem MD PhD5, Jan Van Zundert MD PhD FIPP1,7,8, M.W. van den Boogaart MD6, S.E.I. van der Wal MD PhD FIPP4. Accuracy in Spinal Level Determination, Including Transitional Vertebrae: An ASReview supported Systematic Review. Accepted for publication. European Spine Journal. 2026.
30. Peker E, Hursoy N, Akkaya H, Unal S, Gulpinar B, Arikan B, et al. Evaluation of spinal-paraspinal parameters to determine segmentation of the vertebrae. POLISH JOURNAL OF RADIOLOGY. 2019;84:E470-E7.
31. Yun S, Park S, Park J, Huh J, Shin Y, Yun J. Spinal Enumeration by Morphologic Analysis of Spinal Variants: Comparison to Counting in a Cranial-To-Caudal Manner. KOREAN JOURNAL OF RADIOLOGY. 2018;19(6):1140-6.
32. YZ Y, QP L, CC W, XX P, ZX S, SQ C, et al. Rate of presence of 11 thoracic vertebrae and 6 lumbar vertebrae in asymptomatic Chinese adult volunteers. Journal of orthopaedic surgery and research. 2018;13(1):124.
33. Lian J, Levine N, Cho W. A review of lumbosacral transitional vertebrae and associated vertebral numeration. Eur Spine J. 2018;27(5):995-1004.

34. Nakajima A, Usui A, Hosokai Y, Kawasumi Y, Abiko K, Funayama M, et al. The prevalence of morphological changes in the thoracolumbar spine on whole-spine computed tomographic images. Insights Imaging. 2014;5(1):77-83.
35. Shah M, Halalmeh DR, Sandio A, Tubbs RS, Moisi MD. Anatomical Variations That Can Lead to Spine Surgery at the Wrong Level: Part III Lumbosacral Spine. Cureus. 2020;12(7):e9433.
36. Tee JW, Rutges J, Marion T, Street J, Paquette S, Ailon T, et al. Factors predictive of topographical accuracy in spine level localization. J Spine Surg. 2017;3(1):23-30.
37. Vaishnav A, Merrill R, Sandhu H, McAnany S, Iyer S, Gang C, et al. A Review of Techniques, Time Demand, Radiation Exposure, and Outcomes of Skin-anchored Intraoperative 3D Navigation in Minimally Invasive Lumbar Spinal Surgery. SPINE. 2020;45(8):E465-E76.
38. Manbachi A, De Silva T, Uneri A, Jacobson M, Goerres J, Ketcha M, et al. Clinical Translation of the LevelCheck Decision Support Algorithm for Target Localization in Spine Surgery. Ann Biomed Eng. 2018;46(10):1548-57.
39. De Silva T, Lo S, Aygun N, Aghion D, Boah A, Petteys R, et al. Utility of the LevelCheck Algorithm for Decision Support in Vertebral Localization. SPINE. 2016;41(20):E1249-E56.
40. Lo SF, Otake Y, Puvanesarajah V, Wang AS, Uneri A, De Silva T, et al. Automatic localization of target vertebrae in spine surgery: clinical evaluation of the LevelCheck registration algorithm. Spine (Phila Pa 1976). 2015;40(8):E476-83.
41. Otake Y, Schafer S, Stayman J, Zbijewski W, Kleinszig G, Graumann R, et al. Automatic Localization of Target Vertebrae in Spine Surgery using Fast CT-to-Fluoroscopy (3D-2D) Image Registration2012 2012.
42. Burström G, Persson O, Edström E, Elmi-Terander A. Augmented reality navigation in spine surgery: a systematic review. Acta Neurochir (Wien). 2021;163(3):843-52.
43. Andrade-Andrade P, Acevedo-González JC. Radiologic Insights: Diagnosing Lumbosacral Transitional Vertebrae. Systematic Review of the Literature. Pain Pract. 2026;26(3):e70138.
44. Robin Smithuis RdotRhiL, the Netherlands. . Lumbar Disc Herniation and other causes of nerve compression: Educational site of the Radiological Society of the Netherlands; 2014 [updated 2014-12-14. Available from: https://radiologyassistant.nl/neuroradiology/spine/lumbar-disc-herniation#mri-protocol.
45. Pojskic M, Bisson E, Oertel J, Takami T, Zygourakis C, Costa F. Lumbar disc herniation: Epidemiology, clinical and radiologic diagnosis WFNS spine committee recommendations. World Neurosurg X. 2024;22:100279.
46. Zhang AS, Xu A, Ansari K, Hardacker K, Anderson G, Alsoof D, et al. Lumbar Disc Herniation: Diagnosis and Management. Am J Med. 2023;136(7):645-51.
47. Farshad-Amacker NA, Farshad M, Winklehner A, Andreisek G. MR imaging of degenerative disc disease. Eur J Radiol. 2015;84(9):1768-76.
48. Yan YZ, Li QP, Wu CC, Pan XX, Shao ZX, Chen SQ, et al. Rate of presence of 11 thoracic vertebrae and 6 lumbar vertebrae in asymptomatic Chinese adult volunteers. J Orthop Surg Res. 2018;13(1):124.
49. Fang H, Wang J, Kiwale JC, Cui M, Zeng X, Yang C, et al. Prevalence, diagnosis, and clinical significance of lumbosacral transitional vertebrae: A systematic review and narrative analysis. Brain Spine. 2025;5:105628.
50. Dias MS. Normal and abnormal development of the spine. Neurosurg Clin N Am. 2007;18(3):415-29.
51. Sadler TW. Langman's Medial Embryology. Fifteenth Edition ed: Wolters Kluwer; 2024.
52. KL Moore TP, MG Torchia. The Developing Human, Cl,inically Oriented Embryology. 11th ed: Elsevier; 2020.

53. Bénazéraf B, Pourquié O. Formation and segmentation of the vertebrate body axis. Annu Rev Cell Dev Biol. 2013;29:1-26.
54. Carapuço M, Nóvoa A, Bobola N, Mallo M. Hox genes specify vertebral types in the presomitic mesoderm. Genes Dev. 2005;19(18):2116-21.
55. Wellik DM, Capecchi MR. Hox10 and Hox11 genes are required to globally pattern the mammalian skeleton. Science. 2003;301(5631):363-7.
56. Deschamps J, Duboule D. Embryonic timing, axial stem cells, chromatin dynamics, and the Hox clock. Genes Dev. 2017;31(14):1406-16.
57. Krenn VA, Fornai C, Webb NM, Woodert MA, Prosch H, Haeusler M. The morphological consequences of segmentation anomalies in the human sacrum. Am J Biol Anthropol. 2022;177(4):690-707.
58. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, et al. The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul). 2020;15(1):103-10.
59. Chiu CK, Chin TF, Chung WH, Chan CYW, Kwan MK. Variations in the Number of Vertebrae, Prevalence of Lumbosacral Transitional Vertebra and Prevalence of Cervical Rib Among Surgical Patients With Adolescent Idiopathic Scoliosis: An Analysis of 998 Radiographs. Spine (Phila Pa 1976). 2024;49(1):64-70.
60. Tokgoz N, Ucar M, Erdogan AB, Kilic K, Ozcan C. Are spinal or paraspinal anatomic markers helpful for vertebral numbering and diagnosing lumbosacral transitional vertebrae? Korean J Radiol. 2014;15(2):258-66.
61. Saito R, Fujibayashi S, Shimizu T, Murata K, Otsuki B, Onishi E, et al. Wrong-level spine surgery: A multicenter retrospective study. J Orthop Sci. 2023.
62. Tins BJ, Balain B. Incidence of numerical variants and transitional lumbosacral vertebrae on whole-spine MRI. Insights Imaging. 2016;7(2):199-203.
63. Tatara Y, Niimura T, Sekiya T, Mihara H. Changes in Lumbosacral Anatomy and Vertebral Numbering in Patients with Thoracolumbar and/or Lumbosacral Transitional Vertebrae. JB JS Open Access. 2021;6(3).
64. Gonzales-Portillo GS, Rizvi O, Avila MJ, Dumont TM. The prevalence of 11 ribs and its potential implications in spine surgery. Clin Neurol Neurosurg. 2021;203:106544.
65. Nam Y, Yang JH, Chang D-G, Suh SW. Discordance Between Anatomical Nerve Root Compression and Functional Radiculopathy in Patients with Lumbosacral Transitional Vertebrae. Journal of Clinical Medicine. 2026;15(10):3809.



Chapter 9

Summary and Samenvatting

Summary

Low back pain is one of the leading causes of disability worldwide. A substantial proportion of patients develop lumbosacral radicular pain and, when conservative treatment like physiotherapy or medication fails, are referred for specialist diagnostics. Interventional pain procedures in the pain management department are frequently the next treatment method. During these treatments discrepancies in determining the correct spinal level frequently arise in patients with lumbosacral transitional vertebrae (LSTV). These congenital anatomical variants, present in approximately 10% of the population, may result in four or six lumbar vertebrae instate of the standard five. LSTV remain often undetected due to limitations in standard MRI protocols, increasing the risk of incorrect level identification and treatment. This thesis investigates the nature and extent of these discrepancies, their clinical consequences, and the accuracy of existing level-determination methods.

After an introduction on LSTV and its' clinical context in the first chapter of this thesis, **Chapter 2** presents a case-based review showing that differences in diagnostic approaches, varieties in fluoroscopic techniques, and limitations of MRI protocols frequently lead to ambiguous identification of the symptomatic level. The article demonstrates that no standardized, evidence-based method exists for level determination in the presence of anatomical variants. Improved communication between radiologists, neurologists, surgeons, and interventional pain specialists, along with higher quality intraprocedural imaging and standardized counting protocols, is essential to prevent wrong-level interventions.

Chapter 3 describes a retrospective study of 114 patients with an anomalous number of lumbar vertebrae in which discrepancies between referral, MRI, and treatment levels were examined. These discrepancies were common: 40% between referral and treatment, and 46% between MRI and treatment. Interobserver agreement between radiologist and pain specialist was fair for classifying transitional vertebrae and substantial for vertebral counting.

Chapter 4 explores the clinical consequences of incorrect level identification in a cohort of 214 patients. Unclear level determination, for instance the nomination of possible two affected levels in an MRI report, was associated with more consultations, more interventional procedures, increased imaging, longer treatment trajectories, and more frequent referrals to other hospitals. Furthermore, this research demonstrated that discrepancies between MRI and treatment levels significantly increased the likelihood of incorrect level interventions.

Chapter 5 presents a systematic review evaluating the accuracy of conventional and advanced methods for spinal level determination. Conventional techniques (fluoroscopy, MRI, CT, ultrasound) showed variable accuracy and never achieved 100% accuracy in the presence of LSTV's. Advanced methods, including intraoperative navigation and algorithm-based approaches,

frequently reached near-perfect accuracy but remain costly and insufficiently validated for routine clinical use. Artificial intelligence methods have achieved near-perfect accuracy but are not yet applicable to routine clinical use.

Chapter 6 describes a study on level identification accuracy in the lumbar spine by pain specialists and demonstrates that even experienced specialists struggle with level identification in patients with LSTV. Incorrect level identification occurred in 43% of LSTV cases, compared with 8% in standard lumbar anatomy.

Chapter 7 outlines the embryonic origins of transitional vertebrae and discusses their implications for clinical practice. True LSTV involve real structural changes at the lumbosacral junction, while numerical vertebral variations are simple count differences without transitional anatomy. Spines with 25 or 23 vertebrae might represent numerical anomalies when no transitional morphology is present. Lumbarization and sacralization should be strictly defined in the literature and related to the sacral and lumbar counts.

In the general discussion of **Chapter 8** I conclude that concludes that transitional vertebrae in the lumbar spine constitute a significant source of diagnostic disagreement due to limitations and differences in clinical approaches to these patients. Improvement is achievable through multidisciplinary collaboration, full-spine imaging, uniformed counting protocols, and future AI models trained on anatomical variation.

Samenvatting

Lage rugpijn is wereldwijd één van de belangrijkste oorzaken van verlies van kwaliteit van leven. Een aanzienlijk deel van deze potentiële patiënten ontwikkelt lumbosacrale radiculaire pijn. Indien conservatieve behandeling zoals fysiotherapie en medicatie onvoldoende effect heeft, worden zij doorverwezen voor verdere specialistische diagnostiek en behandeling. Vaak worden dan invasieve pijnbehandelingen ingezet. Tijdens deze behandelingen ontstaan er bij pijnspecialisten bij patiënten met lumbosacrale overgangswervels onzekerheden over het juiste te behandelen niveau van de wervelkolom. Deze onzekerheid ontstaat door de aanwezigheid van overgangswervels. Dit zijn aangeboren varianten van de wervelkolom waardoor er vier of zes lendenwervels aanwezig zijn in plaats van de standaard vijf lumbale wervels. Bij circa 10% van de bevolking komen overgangswervels voor. Deze blijven vaak onopgemerkt door beperkingen in de standaard MRI-protocollen en het ontbreken van een gouden standaard. Hierdoor ontstaat een verhoogd risico op de bepaling van een incorrect wervel niveau met als gevolg een inadequate behandeling met minder resultaat. Dit proefschrift onderzoekt de aard en omvang van deze verschillen in de diagnose en het behandelniveau bij patiënten met overgangswervels, de klinische gevolgen hiervan alsmede de nauwkeurigheid van bestaande methodieken voor niveaubepaling in de wervelkolom.

Na een algemene inleiding over lumbosacrale overgangswervels wordt in **hoofdstuk 2** een case-based review beschreven waarin wordt aangetoond dat verschillen in diagnostische benaderingen, variatie van doorlichtingstechnieken en beperkingen van MRI-protocollen regelmatig leiden tot discrepanties in het juiste behandelniveau. In dit artikel wordt verder aangetoond dat een gestandaardiseerde en bewezen effectieve methode voor niveaubepaling bij anatomische varianten ontbreekt. Verbeterde communicatie tussen radiologen, neurologen, chirurgen en pijnspecialisten, evenals hogere beeldkwaliteit en uniforme telprotocollen, zijn essentieel om de discrepanties in het juiste behandelniveau te voorkomen.

In **hoofdstuk 3** wordt een retrospectieve studie gepresenteerd waarin bij 114 patiënten met een afwijkend aantal lumbale wervels aanzienlijke verschillen werden gevonden tussen verwijsniveau van de neuroloog, MRI-niveau en behandeld niveau door de pijnspecialist. In 40% van de gevallen verschilden dossier-, verwijs- en behandelniveau, en in 46% kwam het MRI-niveau niet overeen met het behandelde niveau. De onderlinge betrouwbaarheid tussen radioloog en pijnspecialist voor het bepalen van het aantal lendenwervels was redelijk, maar voor het classificeren van de overgangswervels matig.

Hoofdstuk 4 onderzoekt de klinische gevolgen van de discrepanties van niveaubepaling in een cohort van 214 patiënten. Onduidelijke beschrijving van het juiste niveau, door benoeming van bijvoorbeeld twee niveaus in een MRI-verslag, leidde tot meer consulten, meer interventies, meer beeldvorming, langere behandeltrajecten en vaker verwijzing naar andere ziekenhuizen

bij patiënten met lumbosacrale overgangswervels. Verschillen tussen MRI- en behandelniveau verhoogden significant de kans op interventies op een incorrect onjuist niveau.

Hoofdstuk 5 presenteert een systematische review naar de nauwkeurigheid van conventionele en geavanceerde methoden voor niveaubepaling. Conventionele technieken, zoals doorlichting echo CT en MRI, tonen wisselende nauwkeurigheid en bereiken nooit 100% nauwkeurigheid bij patiënten met overgangswervels. Geavanceerde methoden zoals intra-operatieve navigatie en algoritme-gebaseerde technieken benaderen wel perfecte nauwkeurigheid, maar zijn kostbaar en onvoldoende gevalideerd. Artificiële intelligentie is nog niet geschikt om niveaubepalingen te doen in de wervelkolom.

Hoofdstuk 6 beschrijft een onderzoek naar niveaubepaling in de lendenwervels door pijnspecialisten en toont aan dat zelfs ervaren pijnspecialisten moeite hebben met niveaubepaling bij patiënten met overgangswervels: in 43% van de gevallen werd een onjuist niveau gekozen, tegenover 8% bij normale anatomie.

Hoofdstuk 7 beschrijft de embryonale oorsprong van overgangswervels en bespreekt de gevolgen hiervan voor de klinische praktijk. Een echte lumbosacrale overgangswervel gaat gepaard met structurele veranderingen bij de lumbosacrale overgang, terwijl numerieke wervelvariaties enkel verschillen in aantal wervels zijn, zonder overgangsanatomie. Wervelkolommen met 23 of 25 vrij bewegende wervels zijn alleen numerieke afwijkingen wanneer er geen overgangsanatomie aanwezig is. Lumbalisatie en sacralisatie dienen in de literatuur strikt gedefinieerd te worden en gerelateerd te zijn aan het aantal sacrale en lumbale wervels.

In een algemene discussie in **Hoofdstuk 8** concludeert dat overgangswervels in de lage rug een belangrijke bron van diagnostische onenigheid vormen door beperkingen en verschillen in benaderingswijze van deze patiënten. Verbetering is mogelijk door multidisciplinaire samenwerking, volledige wervelkolombeeldvorming, gestandaardiseerde telprotocollen en toekomstige AI-modellen die getraind zijn op anatomische variatie.



Chapter 10

Research Data Management

§ 10.1 Ethics and privacy

10.1.1 Medical and ethical approval

- This thesis is based on the results of research that did not involve animals or human participants.
- The recognized Medical Ethics Review Committee 'METC Máxima MC' has given approval to conduct these studies. The file numbers are N25.035; N18.166; N25.035 for the studies in Chapters 2, 3 ,4 and 6 (N18.166 chapters 3 and 4). The studies in Chapter 5 and 7 did not involve patient material.

10.1.2 Privacy measures (i.e. pseudonymization / anonymization)

- According to Dutch legislation, data collection from electronic patient files was performed by the principal investigator (PI) and writer of this thesis (BL) with a treatment relationship with the patients.
- The privacy of the participants in these studies was warranted by the use of anonymization for chapter 2 and pseudonymization for the chapters 3 4 and 6.
- The pseudonymization key was stored on a secured network drive that was only accessible to members of the project (BL and WW (co-supervisor)) who needed access to it because of their role within the project. The pseudonymization key was stored in Anna Hospital Geldrop and is separately from the research data which was stored on a secured network drive that was only accessible to members of the project (BL, SW (co-supervisor), KV (supervisor)in the Radboud UMC.
- The privacy of the participants in these studies was warranted by the use Castor EDC Castor EDC is a web-based Electronic Data Capture (EDC) system used for the secure collection, management, and validation of research data in clinical studies. Only the patients' demographic data were stored in the database. These data were then exported to SPSS files for further analysis.

10.1.3 Informed consent

For the case-based review informed consent to use the anonymized data was obtained from the patient. For the studies with pseudonymized data (chapter 3,4, and 6) informed consent was not required according to the Medical Ethics Review Committee 'METC Máxima MC'.

§10.2 Data Collection and storage

10.2.1 Data collection

- The primary patient selection was performed by two certified pain physicians with treatment relationships (the PI had a relationship with all patients). All patients were consecutively identified under fluoroscopic guidance during their routine interventional pain procedures. Demographic, medical, and other relevant variables were extracted from the hospital's electronic patient records (Xcare Nexis EPD) and entered into a study-specific data collection system (Castor Electronic Data Capture).
- Chapter 2 was a case-based review with anonymized patients' demographics.
- Data for chapters 3, 4, and 6 was extracted from Castor EDC and exported to SBSS for further analysis.
- Data for chapter 5 (a systematic review) and 7 (a narrative review) was obtained from the literature.

10.2.2 Data storage

- Data from Chapter 2 were anonymized and stored on a secure network drive at Anna Hospital.
- Patient data and documentation from Chapters 3, 4, and 6 were pseudoanonymized and stored on a secure network drive at Anna Hospital and in Castor EDC and are accessible only to project members working in the hospital.
- Processed data and documentation are archived in a Research Documentation Collection (RDC) within the Radboud Data Repository.
- Data from Chapters 5 and 7 were stored and analyzed on the department server and are accessible only to project members working at Radboudumc.
- These secure storage solutions safeguard the availability, integrity, and confidentiality of the data.
- No paper-based data were used.

§10.3 Data sharing according to the FAIR principles

10.3.1 Published Chapters

- Chapters 3,4, and 6 are published.
- Chapters 2 and 5 have been submitted for publication and are currently under review.
- Chapter 7 has been submitted.

10.3.2 Datasets available for reuse in a data repository

- All datasets are stored with restricted access in the Anna Hospital and Radboud UMC.
- Requests for access and reuse for data in the Anna Hospital will be checked by Bart Liebrand and Walter van der Weegen.
- Requests for access and reuse for data in the Radboud UMC will be checked by data managers/data stewards of the department Ilona van den Brink or Jackie van Gemert.
- All data included in this thesis were newly generated for the purposes of the studies.
- All data from published chapters are available for inspection and reuse. Data from unpublished chapters will become available for inspection and reuse after publication.

10.3.4 Overview published and archived datasets

Chapter	RDR - DAC	RDR - RDC	RDR - DSC	DATA REPOSITORY	Hospital
2	-	-	-	"C:\Users\z516248\OneDrive - Radboudumc\z516248\LSTV"	Radboud UMC
3	-	-	-	w.vander.weegen@anna.nl bart.liebrand@mumc.nl	Anna Hospital
4	-	-	-	w.vander.weegen@anna.nl bart.liebrand@mumc.nl	Anna Hospital
5	-	-	-	"C:\Users\z516248\OneDrive - Radboudumc\z516248\LSTV"	Radboud UMC
6	+	-	-	Ilona.vandenBrink@radboudumc.nl	Radboud UMC
7	+	-	-	Ilona.vandenBrink@radboudumc.nl	Radboud UMC



Chapter 11

Dankwoord

Mijn dankwoord wil ik graag beginnen bij de Raad van Bestuur van het Anna Ziekenhuis te Geldrop, de vakgroep Anesthesiologie en Pijnbestrijding en bij mijn voorganger dr. W. Halim, door mij toe te laten tot deze vakgroep. Hiermee ontstond de mogelijkheid om de patiënten met overgangswervels te zien en de lange reis van deze PhD aan te vangen.

In het Radboud UMC sprak ik met Kris Vissers over het onderwerp. Hij stelde terecht de klinische relevantie van het onderwerp ter discussie. Maar een beetje anders of raar en bijzonder interessant of relevant liggen soms verassend dicht bij elkaar en kreeg ik toch een Go. Selina van der Wal, die ik kende van het FIPP-traject in 2017, en Walter van der Weegen, uit het Anna (copromotor van Willy Halim), voegden wij toe aan het team. In de laatste twee jaar vergezelde Jan Van Zundert (MUMC) dit, naar mijn mening, absolute sterrenteam.

Kris, bij deze dank ik jou voor jouw zijn als gids tijdens deze uitdagende reis. Je was er voor mij op wetenschappelijke, vakinhoudelijke, schrijf technische en persoonlijke manier en dat ik heb als heel bijzonder ervaren.

Selina, dankjewel voor al jouw adviezen en samenwerking tijdens en buiten werktijd. Jouw soms strenge en strakke adviezen waren heel welkom en een belangrijke bijdrage. Genoten heb ik van jouw eigen nuance over deze adviezen.

Walter, dankjewel dat jij voor mij de ideale buurman was in het Anna. Ik kon altijd aankloppen, je gaf mij altijd goede wetenschappelijk en soms vaderlijke adviezen. Ik heb genoten van de vele kopjes koffie en de lunches in de Ontmoeting.

Jan, dankjewel voor de ondersteuning bij de publicaties, informele gesprekjes en de adviezen over de grote lijnen in de artikelen en dit boekje. Gelijk hebben is inderdaad niet hetzelfde als gelijk krijgen in het wonderlijke land van de wetenschap. “Daterbij”.

Tijdens de reis was Prof. dr. van Crevel mijn mentor. Reinout dank voor onze jaargesprekken en algemene adviezen over wetenschappelijk onderzoek en het schrijven van artikelen en het boekje.

Er was ook nog een ander sterrenteam die mij hebben ondersteund in dit traject: team Poli Pijnbestrijding in het Anna. Beste Anita, Chantal, Theo, Maria, Vera, Oscar, Tosca, Patricia, Anne, Lisa, Maaike en Stein en Jorien. Dank voor jullie luisterend oor en begrip voor dit traject. Ik mis onze fijne samenwerking nog steeds. Speciaal dank voor Satria die als collega pijnspecialist zes jaar in de spreekkamer naast die van mij zat. We hadden een intense klinische samenwerking en soms dito persoonlijke gesprekken.

Verder ben ik dankbaar voor de samenwerking in de verschillende onderzoeken met dr. Koen van Brakel, dr. Marjan Slob en dr. Arthur Boon, specialisten in het Anna. Jullie verhoogden de kwaliteit van de onderzoeken en maakten de publicaties mede mogelijk. Dit geldt ook voor drs. Mark van den Boogaart (MUMC) en dr. Dylan Hensen (Universitätsklinikum Leipzich). In het bijzonder geldt dit voor Prof. dr. Johan Van Goethem (Senkang General Hospital Singapore) met zijn zeer scherpe wetenschappelijke en vakinhoudelijke adviezen. Alles moet zo eenvoudig mogelijk worden gemaakt, maar niet eenvoudiger (Albert Einstein) was door jou voor mij een wijze les.

Verder ben ik dank verschuldigd aan Ingrid ter Hoeven (bibliothecaris Anna Ziekenhuis), Remy van Alebeek en Rinus Verdonschot (Library Unviversity Maastricht) die onmisbare ondersteuning hebben verleend bij de systematische review van de literatuur. Dank aan Mariella Kuijpers en Corine Hermans, ondersteuning van de Radiologie in het Anna. Zij hebben de vele onderzoek foto's bewerkt en anoniem gemaakt, zodat deze bruikbaar waren voor publicatie.

Tijdens de wetenschappelijke onderzoeken zijn er ook studenten en co-assistenten geweest die het promotieproject deels hebben ondersteund. Nena Kenadu, Kaley Bons en Lisa Braunhoff hebben met hun wetenschappelijke stages pilotstudies uitgevoerd en daarmee de klinische relevantie van het onderzoek onderschreven. Lisa heeft tot het einde (3 jaar) meegedaan in de systematische review. Dank daarvoor. Iris Sleegers, Ella Deinum, Eline Fischer, Loïs Aitatus dank voor de ondersteuning bij de studie tijdens het NVA Pijncongres 2025. Mede dankzij de statistische inbreng van Sander van Kuijk, werd ook hier de klinische relevantie van dit proefschrift onderschreven.

Verder ben ik mijn collega's van de pijngeneeskunde in het MUMC dankbaar voor de ontvangst van mij vanaf mijn start in het MUMC. Nicole, Brigitte, Reinoud, Els, Micha, Esther en José, ik heb mij meteen thuis gevoeld en heb door de ruimte die ik van jullie heb gekregen, dit proefschrift af kunnen ronden.

Mijn kinderen, Lara en Noor, waren geen onderdeel van, hielpen mij met mijn Engels in de formulering in de eerste artikelen en stonden verder aan de zijlijn vermakelijk hoofdschuddend en soms een beetje verontwaardigd naar hun vader te kijken. Hun grapjes motiveerden mij.

Lieve Madelon, last but the best! Ik heb het afgerond na 7 jaar. Je hebt dit traject voor mij aangenamer en makkelijker gemaakt. Dankjewel voor alle liefdevolle onvoorwaardelijke steun sinds ons begin, elke dag weer!



Chapter 12

Curriculum Vitae

Bart Johan Frederik Liebrand werd op 23 juni 1970 geboren te Haaksbergen, Nederland. In 1988 haalde hij zijn vwo-diploma aan Lyceum de Grundel in Hengelo (ov). Aansluitend begon hij aan de studie Geneeskunde aan de Rijksuniversiteit Groningen. Na een stage in traumachirurgie in het Westeinde Ziekenhuis behaalde hij zijn masters en koos hij voor een brede klinische basis in de acute geneeskunde: van spoedeisende hulp en chirurgie tot intensive care en anesthesiologie in het LUMC en het Rijnland Ziekenhuis. Deze jaren vormden zijn klinische blik en vermogen onder druk te handelen.

In 2000 startte hij de specialisatie tot Anesthesioloog. Na het behalen van deze opleiding in 2005, werkte hij als Anesthesioloog in Alkmaar (2005) en bij de Ziekenhuisgroep Twente (2005-2010). Hij ontwikkelde daar expertise in regionale (echogeleide) anesthesie, perioperatieve zorg en intensive care. Interesses in organisatie en kwaliteit leidden hier tot een rol als voorzitter van de medische staf, met aanvullende opleidingen in ziekenhuismanagement (Universiteit van Tilburg) en zorgfinanciën (KNMG).

Vanaf 2011 verschoof de focus weer naar de patiënt en startte hij een fellowship in de pijngeneeskunde en leerde interventionele pijnprocedures. In 2017 behaalde hij het Fellow of Interventional Pain Practice (FIPP) examen. Bart werkte in Lelystad (2010), de Gelre Ziekenhuizen (2011-2014), het Elkerliek (2015), ZorgSaam (2015) en vanaf 2016 in het Anna Ziekenhuis. Hier bouwde hij aan een moderne pijngeneeskunde praktijk en werkte intensief samen met orthopedie, neurologie neurochirurgie en revalidatie. Deze intercollegiale samenwerking voor de patiënt leverde hem in 2024 de patiënten prijs op van PA!N Alliantie Nederland. Sinds 2025 is hij werkzaam als anesthesioloog-pijnspecialist in het MUMC+, zijn aandachtsgebieden zijn neuromodulatie, oncologie, wervelkolom gerelateerde pijn, aangezichtspijn.

Parallel aan de klinische carrière was er interesse in de wetenschap. Met het promotietraject over lumbosacrale overgangswervels werd gezocht naar uitdagingen om antwoorden te vinden op klinisch relevante vragen met directe impact op de patiëntenzorg. Dit onderzoek richtte zich op anatomische variatie, diagnostische nauwkeurigheid en de consequenties daarvan voor interventionele pijnbehandelingen. Dit resulteerde in internationale publicaties, presentaties op congressen en leerzame samenwerkingen met toonaangevende onderzoekers. Om zijn wetenschappelijke kunde verder te ondersteunen start hij in november 2026 met de Global Clinical Scholars Research Training program aan de Harvard Medical School.

Naast het klinische en wetenschappelijke werk was er inzet op het gebied van onderwijs en kwaliteitsverbetering. Hij begeleidde verpleegkundigen en arts-assistenten, leidde implementatieprojecten zoals perioperatieve complicatieregistratie en was actief in commissies voor veiligheid, orgaandonatie, reanimatie en acute zorg.

Buiten het ziekenhuis bestaat zijn vrijetijdsbesteding uit sociale activiteiten met familie en vrienden, sporten en natuur: zeilen, schaatsen, wielrennen, trail-running, lezen, koken en tuinieren.



Chapter 13

Portfolio

Department: Department of Anesthesiology, Pain and Palliative Medicine
PhD period: 01**/04/2019 – 01/06/2026**
PhD Supervisor(s): **Prof. dr. K.C.P. Vissers, Prof. dr. J.H.M. Van Zundert**
PhD Co-supervisor(s): **Dr. W. van der Weegen, Dr. S.E.I. van der Wal**

Training activities	**Hours**
Courses	
• Graduate School specific introductory course (RIHS, link)# (year 1)	12
• Good clinical practice course, clinical investigation (year 1)	16
• End note workshop (year 1)	16
• Scientific Integrity course (link) (year 2)	16
• How to wright a scientific medical paper (year 2)	16
• Pubmed workshop, basic (year 2)	32
• Statistics for clinical research (year 2)	16
• Pubmed workshop, advanced (year 3)	16
• Statistics for clinical research (year 3)	16
• How to wright a scientific medical paper (year 3)	16
• Training Good clinical practice (year 4)	16
• Study group RAPID: cervical RF ablation, international study (year 5)	160
• Study group RAPID: cervical RF ablation, international study (year 6)	160
• Course speed reading & strategic reading RU (year 6)	8
• Course in neuromodulation by Medtronic with lectures about public speaking, bias assessment and scientific integrity (year 7)	64
	(580)
Seminars	
• Radboud Research Rounds (link) (year 1)	6
• Handleiding medisch wetenschappelijk onderzoek (year 1)	56
• Regional Consultation in Pain Medicine (year 2)	3
• Meeting and lecture Knowledge Platform Orthopedic Surgery St. Anna Hospital (year 2)	16
• Medical Statistics at a glance (year 2)	56
• Regional Consultation in Pain Medicine (year 3)	3
• Regional Consultation in Pain Medicine (year 4)	3
• Regional Consultation in Pain Medicine (year 5)	3
• Regional Consultation in Pain Medicine (year 5)	3
• Regional Consultation in Pain Medicine (year 5)	3
	(155)

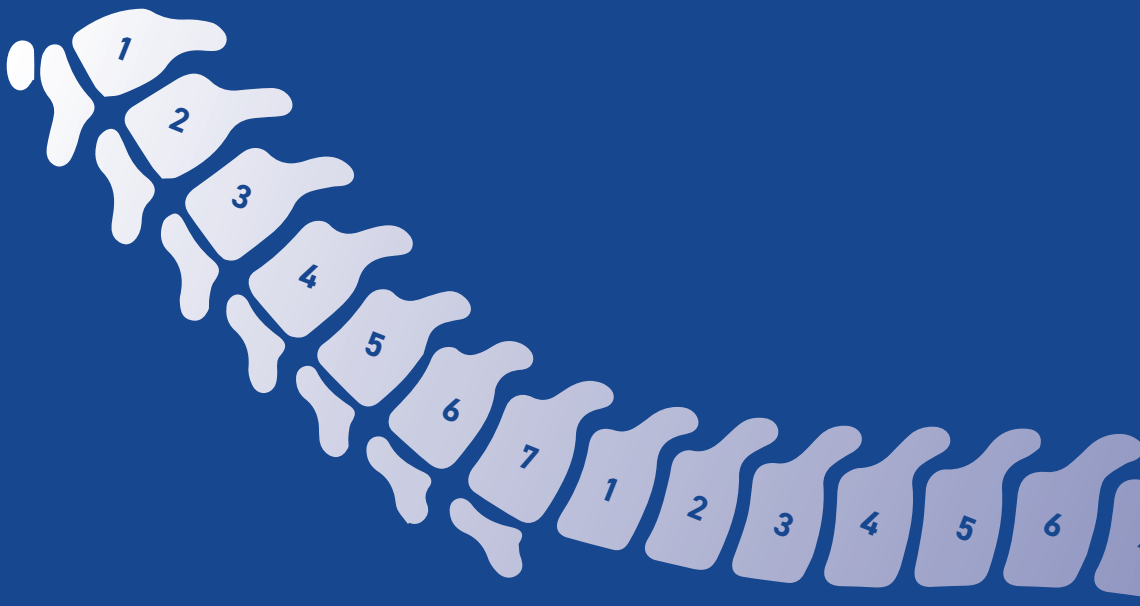
Conferences

• Dutch Anesthesiology congress (year 1)	16
• Dutch-Belgium Pain congress (year 1)	8
• PGA Ney York, lectures and courses in interventional pain medicine (year 1)	32
• Dutch Anesthesiology congress (year 2)	16
• Dutch-Belgium Pain congress (year2)	8
• International congress Invasive Pain Medicine (year 2)	24
• Webinars in pain medicine (online) (year 2)	2
• Dutch Anesthesiology congress (year 3)	16
• Dutch-Belgium Pain congress (year3)	8
• International congress Invasive Pain Medicine (year 3)	24
• Symposium ultrasound in Pain medicine (year 3)	8
• International congress with LSTV as a topic (Neuro- or Orthopedic 1Surgery) (year 3)	24
• Reading: Discovering Statistics Using SPSS-Andy Field, first part (year3)	40
• Symposium for Statistics (year 3)	8
• Dutch Anesthesiology congress (year 4)	16
• Dutch-Belgium Pain congress (year 4)	8
• International congress Invasive Pain Medicine EFIC, Dublin (year 4)	24
• Reading: Discovering Statistics Using SPSS-Andy Field, first part (yearn4)	80
• Dutch Anesthesiology congress (year 5)	16
• Dutch-Belgium Pain congress (year 5)	8
• International congress Invasive Pain Medicine EFIC, Budapest (year 5)	24
• Dutch Anesthesiology congress (year 6)	16
• Dutch-Belgium Pain congress (year 6)	8
• IASP 2024 Wereld Pijn Congres Amsterdam (year 6)	40
• PAIN Alliance The Netherlands: Winner patient price best initiative development multidisciplinary care (year 6)	8
• Dutch-Belgium Pain congress (year 7)	8
• PA!N Alliance The Netherlands (year7)	8
	(498)

Teaching activities	
Lecturing &	
Supervision of internships / other	
• Lecture Symposium Pain in the Head and Neck Area (year 1)	8
• Internship medical student in science: accurateness of Fluoroscopy Guided Invasive Pain Management in Patients with Lumbosacral Transitional Vertebra (year 1)	45
• Supervision of Indonesian Pain specialists in interventional pain medicine (year 1)	20
• Lecture Symposium Pain in the Head and Neck Area (year 2)	12
• Internship medical student in science: clinical relevance of LSTV in pain medicine	45
• Supervision of Indonesian Pain specialists in interventional pain medicine (year 2)	20
• Lecture Symposium Pain in the Head and Neck Area (year3)	12
• Lecture: Consequences of a lumbosacral transitional vertebrae in invasive pain medicine. National Pain Congress (year 3)	8
• Internship medical student in science: writing the systematic review on interventional pain management in patients with LSTV (year 3)	45
• Lecture: A multi center retrospective research. Patients with lumbosacral transitional vertebrae diagnosed with lumboradicular pain what level? International Pain Congress (year 3)	8
• Supervision of Indonesian Pain specialist in interventional pain medicine (year 3)	20
• Lecture: How to overcome the difficulties in treating patients with lumbosacral transitional vertebrae. International pain Congress (year 4)	8
	8
• Lecture: The probable solution for treating patients with lumbosacral transitional vertebrae (year4 4)	8
• Supervision of Indonesian Pain specialist in interventional pain medicine (year 4)	20
• Internship medical student in science: systematic review about the accuracy of level determinations during spine procedures (year 4-5-6)	135
• Education and training of fellows in pain medicine (year 7)	120
• Coach medicine bachelor student to develop study: Real-Life level Identification accuracy study in patients with lumbosacral transitional vertebrae (year 7)	20
	(562)
Total	1795

Abbreviations:

TV	Transitional vertebrae
TLTV	Thoracolumbar transitional vertebra
LSTV	Lumbosacral transitional vertebrae
MV	Mobile vertebrae
LV	Lumbar vertebrae
ION	Intraoperative navigation
DLM	Deep-Learning Methods
FIPP	Fellow of international pain practice
PI	Principal investigator
LS	Lumbar spine
WL	Wrong level
CLD	Correct level determination
WLD	Wrong level determination
ALD	Ambiguous level determination
sd	Standard deviation
ns	non-significant
MRI	Magnetic resonance imaging
CT	Computed Tomography
US	Ultrasound
X-ray	Radiograph





Radboudumc
university medical center

Radboud University