Precision of Traditional Approaches for Lumbar Plexus Block

Impact and Management of Interindividual Anatomic Variability

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Background: Traditional methods for approaching the lumbar plexus from the posterior rely on finding the intersection of lines that are drawn based on surface landmarks. These methods may be inaccurate in many cases. The aim of this study was to determine the accuracy of these traditional approaches and determine if modifications could increase their accuracy.

Methods: The lumbar plexus region of 48 cadavers (78 ± 7 yr; 167 ± 6 cm; 60 ± 13 kg; men/women: 29/19) was dissected, and relevant anatomic structures were marked. Needle proximity curves were obtained by triangulation for the five traditional approaches and for vectors from the posterior superior iliac spine directed towards the lumbar spinous processes of L3 and towards L4.

Results: Proximity curves (mean ± SD) showed that except Pandin’s approach (13 ± 5 mm too medial), all others were too lateral: Winnie (17 ± 8 mm), Chayen (8 ± 5 mm), Capdevila (6 ± 4 mm), and Dekrey (17 ± 6 mm). Further, the curves had a narrow parabolic shape and thus a narrow margin of error. Both diagonal vectors had a significantly higher proximity to the lumbar plexus as compared with traditional approaches with a wide parabola, indicating more error tolerance. Using the vector posterior superior iliac spine-L3 with a length between 1/6–1/3 (= 16–22 mm) of the distance posterior superior iliac spine-L3, a proximity to the lumbar plexus < 5.0 ± 0.3 mm was reached.

Conclusion: Improvement of both the proximity and the margin of error is possible by using diagonal landmark vectors. Relying on the position of the posterior superior iliac spine eliminates the sex and sided differences and individual body size, which can be problematic if firm metric distances are used in determining the entry point.

TOTAL knee arthroplasty is one of the most commonly performed orthopedic procedures in elderly and obese patients. Peripheral nerve blocks offer potential advantages such as earlier hospital discharge and less postoperative pain, nausea, emesis, hypotension, and urinary retention.1–4 For sufficient intraoperative analgesia besides a sciatic nerve block, a block of the femoral and the obturator nerve is mandatory, which can either be achieved by either single nerve blocks or by a posterior lumbar plexus (psosas compartment) block. It has been recognized that the formerly termed “3-in-1 block” is rather a femoral nerve block and usually spares the obturator nerve, regardless of the use of catheter techniques.1,6,7 The obturator nerve has a cutaneous distribution at the mediodorsal aspect of the lower thigh in 43% of patients.8 Thus, the necessity of an obturator nerve block is a subject of debate in total knee arthroplasty.9 Intraoperative pain scores were lower and patient satisfaction was higher when using posterior lumbar plexus blocks as opposed to “3-in-1 blocks” during knee arthroscopy.9 In the postoperative setting, morphine consumption was significantly lower if an obturator block had been added to a femoral nerve block.10 However, even with the posterior lumbar plexus block, the obturator nerve is not consistently blocked.11 Thus, a number of slightly different approaches for posterior lumbar plexus block have been described (fig. 1) to improve the quality of blocks.12–16 In fact, with these new approaches the success rates did not increase. Instead new problems arose, such as retroperitoneal hematoma17 or accidental renal puncture18 caused by too lateral or cranial puncture. An injection of local anesthetics that is too medial increases the risk of their epidural spread,19,20 subarachnoid puncture,21 or even catheter placement.22

Traditional methods for determining the insertion site rely on surface landmarks; e.g., the spinous processes, iliac crests, and the posterior superior iliac spine (PSIS) from which “construction lines” are made to determine the point of needle entry.12–16 These construction lines intersect at one precise location, and the proximity of this intersection is not always a good reflection of the actual location of the lumbar plexus. Thus, small deviations in the needle insertion point from medial to lateral will result in large deviations between the needle tip and the actual plexus location. However, adopting a meaningful method that creates a line much closer to the axis...
of the nerve will allow for larger deviations along the course of that same line, without the tip of the needle ending up too far away from the plexus.

The aim of this study was to evaluate the traditional surface landmarks regarding their precision to predict the lumbar plexus position. Further, optimizing these traditional landmarks was attempted, and diagonal construction lines were tested regarding their suitability and error tolerance in predicting the actual location of the lumbar plexus.

**Materials and Methods**

The lumbar plexus region of 48 human cadavers (78 ± 7 yr; 167 ± 6 cm; 60 ± 13kg; body mass index 21.4 ± 4.2; men/women 29/19) was dissected, and relevant internal landmarks were marked. The cadavers had been fixed with a mix of 5 parts ethanol, 3 parts glycerin, 4 parts water, and 3 parts formalin. All cadavers were the legal property of the Institute of Anatomy of the Medical Faculty of Dresden, and approval of the Institutional Review Board of the Medical Faculty of Dresden exists.

Digital images, including a centimeter scale, were taken and were mapped offline. In each cadaver the intercrestal line was taken as x-axis, and a craniocaudal line through the center of the vertebral column was taken as y-axis. Mapping of all relevant structures in a frontal plane enabled the calculation of the vicinity of a virtual needle perpendicularly advanced from traditional insertion points towards the lumbar plexus. Coordinates (x- and y-axis) were calculated for the upper and lower border of the lumbar vertebral bodies L3–L5, spinous processes L3–L5, lateral and medial borders of the major psoas muscle at the mid-levels of L3–L5, as well as for the PSIS.

**Trigonometric Mapping of the Lumbar Plexus**

The trigonometric procedure is briefly described. (For detailed explanation of the mathematic models, see appendix, Supplemental Digital Content 1, which contains an in-depth description, http://links.lww.com/ALN/A536.) In addition to generating mathematical models for the individual lumbar plexus position in each subject (fig. 2), data of all subjects were gathered in one virtual map of the lumbar plexus region containing the average positions of the relevant anatomic structures. Subsequently, the distance between the needle inserted at any given point (traditional landmarks, optimized traditional landmarks, or new landmarks) and the lumbar plexus was calculated.

**Optimizing Traditional Landmarks**

In all subjects, spots on the body surface being located on the horizontal construction lines for the traditional entry points (e.g., the parallel line 10 mm cephalad to the intercrestal line for Capdevila’s approach; 12 cross 2 in fig. 1) were analyzed in 2- to 5-mm steps from the midline onwards laterally for their proximity to the individual course of the lumbar plexus. In this manner all spots on horizontal construction lines defined by the five original describers 12–16 (fig. 1) were screened for their proximity to the lumbar plexus. Needle approach curves were obtained for each traditional technique. In all cases, polynomic regression analysis was performed (Excel, Microsoft, Berlin, Germany). Subsequently, minima of the obtained polynomial curves were calculated by algebraic standard procedure. Cubic polynomial models fitted considerably better with the data obtained from the cadavers than quadratic models in terms of \( R^2 \) and their ability to predict the true highest proximity of needle and nerve (represented by the curve minima).
Mapping the PSIS Region and Diagonal Vectors

In addition to the construction line-derived mapping (one-dimensional; only lateral position is variable on the predefined craniocaudal levels\textsuperscript{12–16}), the whole area around the PSIS was two-dimensionally mapped (both lateral position and craniocaudal level are variable) in millimeter steps for its proximity to the lumbar plexus. The screened rectangle extended from 8 to 16 mm medially, and from 10 to 22 mm cranially of the PSIS. This was chosen for practical reasons: Within the area of 8 mm medially and 10 mm cranially from the PSIS, iliac bone will regularly impede successful puncture. The mediocranial boundary of the rectangle was defined with respect to the ascending bottom of the proximity groove shown in the three-dimensional proximity graph (fig. 3). Increasing distance from the PSIS is associated with a rising ground of the groove, reflecting the respectively increasing degree of interindividual variation and thus lower predictability when using direct metric measures. The mediocranial direction of this proximity groove gave the idea of a vector ideally being located above the groove in a long common course with the lumbar plexus. Thus, the two vectors from the PSIS directed towards the spinous processes of L3 and L4 (fig. 4) were respectively screened for the length producing the highest proximity to the lumbar plexus.

Statistical Analyses

All data within the text and the tables are given as mean ± SD. To enable proper visibility within the proximity curves, SEM is here given as the measure of variability. For comparison of the original approaches with their optimization and with the new diagonal vectors, respectively, two-tailed, paired \( t \) tests were performed and the 95\% CIs are depicted. Sex-related effects were checked with a two-tailed, unpaired \( t \) test. Statistical significance was accepted at \( P < 0.05 \). Linear regression analysis was performed to assess the effect of age and sex on the cross-sectional diameter of the major psoas muscle. All statistical comparisons were done with SPSS for Windows version 15.0 (SPSS, Chicago, IL).

Polynomial fit procedures were performed to find insertion points on the skin at the predefined craniocaudal levels,\textsuperscript{12–16} showing closest proximity to the nerve as represented at the respective curve minima.

Results

Anatomic coordinates relevant for a lumbar plexus block can be taken from table 1. Proximity curves of the traditional approaches showed that except Pandin’s approach, (13 ± 5 mm too medial) all others were too lateral (fig. 5A–E): Winnie (17 ± 8 mm), Chayen (8 ± 5 mm), Capdevila (6 ± 4 mm), and Dekrey (17 ± 6 mm). The curves further had a narrow parabolic shape, and thus narrow error margins. Changing the insertion points for each of the traditional landmarks to the very spots of nearest proximity within the respective approximation curves (fig. 5) resulted in significant higher accuracy of needle placement (fig.
6). A proximity map of the region mediocranially of the PSIS is given in figure 3, offering direct approaches to the lumbar plexus. The vectors PSIS–L3 (fig. 7) and PSIS–L4 (fig. 8) had a significantly higher proximity to the lumbar plexus versus traditional approaches with a wide parabola, indicating high error tolerance. Using the vector PSIS–L3 with a length between 1/6–1/3 (H11005 16–22 mm) of the distance PSIS–L3, a proximity to the lumbar plexus H11021 5.0 H11006 0.3 mm was reached. The vector PSIS–L4 with a length between 1/10–1/4 (H11005 7–15 mm) of the distance PSIS–L4 approached the lumbar plexus H11021 5 H11006 0.4 mm. As compared with the original approaches, the PSIS–based diagonal vectors had significantly closer proximities (fig. 9).

While the diameters of the psoas muscle on the measured vertebral levels did not differ with regard to the right or left side, on the right side the complete muscle was shifted significantly laterally by 3 H11006 5 mm (P 0.01–0.05). Correspondingly, the lateral position of the PSIS was found on the left side at 49 H11006 9 mm, as opposed to the right side with 54 H11006 10 mm (P 0.028) without significant differences in the craniocaudal position. Further, the insertion sites of Pandin, Dekrey, and Chayen showed significant side dependence. Pandin correlated better (P < 0.001) on the left side (3 mm closer), while Dekrey (2 mm closer) and Chayen (3 mm closer) had better (P < 0.05) results on the right side. The accesses based on the PSIS landmark by Winnie and

<table>
<thead>
<tr>
<th>X/Y Axis</th>
<th>Anatomic Structure</th>
<th>Mean (mm)</th>
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<tbody>
<tr>
<td>Y</td>
<td>Upper edge vertebral body L3</td>
<td>52 ± 14</td>
</tr>
<tr>
<td>Y</td>
<td>Spinous process L3</td>
<td>40 ± 14</td>
</tr>
<tr>
<td>Y</td>
<td>Lower edge vertebral body L3</td>
<td>28 ± 14</td>
</tr>
<tr>
<td>Y</td>
<td>Upper edge vertebral body L4</td>
<td>17 ± 14</td>
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<tr>
<td>Y</td>
<td>Spinous process L4</td>
<td>4 ± 13</td>
</tr>
<tr>
<td>Y</td>
<td>Lower edge vertebral body L4</td>
<td>−9 ± 13</td>
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<tr>
<td>Y</td>
<td>Upper edge vertebral body L5</td>
<td>−19 ± 12</td>
</tr>
<tr>
<td>Y</td>
<td>Chayen’s puncture level</td>
<td>−26 ± 13</td>
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<tr>
<td>Y</td>
<td>Spinous process L5</td>
<td>−32 ± 11</td>
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<td>Lower edge vertebral body L5</td>
<td>−43 ± 15</td>
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<td>Posterior superior iliac spine</td>
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<td>Lateral margin of psoas L4 mid</td>
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<td>X</td>
<td>Diameter of psoas muscle L4</td>
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<td>Diameter of psoas muscle L5</td>
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<td>Distance: Posterior superior iliac spine to spinous process of L4</td>
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<tr>
<td>Distance: Posterior superior iliac spine to spinous process of L3</td>
<td>95 ± 16</td>
<td></td>
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</table>

Obtained anatomic coordinates (mean ± SD [mm]) in a coordinate system with the intercrestal line representing the x-axis and the vertebral column standing for the y-axis. Positive Y values represent structures above the intercrestal line; negative values below it. X values give the lateral deviation from the center of the vertebral column (median line).

Fig. 5. Proximity curves of the traditional approaches to the lumbar plexus (in craniocaudal order). (A) Dekrey13 (B) Capdevila12 (C) Winnie16 (D) Chayen15 and (E) Pandin14 insinuating perpendicular needle advancement (mean ± SEM). The lateral distance of the insertion site from the center of the vertebral column (x-axis) is given in millimeters or in proportions of the horizontal distance of the posterior superior iliac spine (PSIS) (as originally published). White marks indicate the proximity obtained by original access. Xmin gives the calculated lateral entry position with the closest proximity of the needle tip to the lumbar plexus.
Capdevila as well as the diagonal vectors all showed no side dependence.

A significant \( P < 0.001 \) correlation between age and cross-sectional diameter of the psoas muscle was found. Regression analysis revealed a loss of muscle diameter by 0.4 mm per year \( (R^2 = 0.19) \) in our cohort.

Sex differences were found, indicating higher psoas diameters by 5 ± 6 mm in men \( (P = 0.03) \) associated with a lateral shifting of the muscles’ lateral margin by 5 ± 6 mm \( (P < 0.01) \). Further, in relation to the inter-crestal line, the lower edge of the fifth lumbar vertebral body was found to be 9 mm more caudally in men \( (\text{women/men} = 37 ± 22 \text{ mm}/46 ± 10 \text{ mm}) \), but with a higher variability in women.

**Discussion**

Traditional insertion points for lumbar plexus block rely on surface landmarks and lines derived from them.
which lie nearly perpendicular to the course of the lumbar plexus.\textsuperscript{12–16} Small deviations in the needle insertion point from medial to lateral will result in large deviations between the needle tip and the actual plexus.

The current analysis demonstrates that traditional surface landmarks\textsuperscript{12–16} place the entry points for a lumbar plexus block significantly away from the average location of the course of the lumbar plexus (fig. 5). The method described by Capdevila\textsuperscript{12} is the least problematic, but still places the entry point, on average, 6 mm lateral to the course of the nerve. Such landmarks prone to deviation may increase patients’ risk by repetitive attempts and prolong block performance time, which is usually 4–12 min.\textsuperscript{23} In addition, the narrow shape of the curves of the traditional approaches in figure 5 indicates that small variations of the insertion point result in higher distances of the needle from the average location of the nerve, and thus have a narrow margin of error. Best medial or lateral modifications for improving the accuracy of traditional entry points are represented by the respective minima of the curves in figure 5, A–E.

Besides optimizing traditional surface landmarks, we were seeking a meaningful method that creates a line much closer to the axis of the nerve, and which will allow for larger deviations along the course of that same line without the needle tip ending up far away from the plexus. Figures 7 and 8 are depicting new PSIS-related approaches with constructing lines that fulfill these criteria. They are more in line with the average location of the nerve (fig. 4), and thus will have a higher margin for deviations from the individually best insertion point.

By needle advancement off the perpendicular direction as necessary in Winnie’s approach,\textsuperscript{16} a high needle tip deviation results from minimal changes of the advancement angle, thus increasing the risk of puncture complications, \textit{e.g.}, renal or neuraxial puncture. In this regard, the present dataset underestimates the proximity of Winnie’s approach due to the insinuation of perpendicular needle advancement in the two-dimensional model in the frontal plane. However, the large width of the needle approach curve (fig. 5C) and therefore the problem of Winnie’s technique remains: Small medial or lateral deviations in the entry point result in large deviations from the needle tip from the lumbar plexus, even if the approach curve would be slightly shifted medially during medial needle advancement off the perpendicular direction.

Fixed metric surface landmarks as suggested by Parkinson,\textsuperscript{13} Pandin,\textsuperscript{14} and Chayen\textsuperscript{15} may not fit to the individual patient and are, likewise, prone to deviation from perpendicular needle direction and thus result in too medial advancement.\textsuperscript{22} An approach that is too caudal for lumbar plexus block\textsuperscript{14} in addition may fail to block the femoral nerve because of its variable exit off the major psoas muscle.\textsuperscript{24} The hypothesis of problematic fixed metric landmarks is supported by the observed side differences in the calculated needle proximity within our dataset when using these metric accesses\textsuperscript{13–15} rather than in the PSIS-oriented traditional\textsuperscript{12,16} and diagonal approaches. Side differences in the anatomical shape of the hip have been shown in electromagnetic three-dimensional studies, indicating a greater lateral sacral mass on the right side.\textsuperscript{25} These observations are in accordance with the present data and may be explained by the notion that the right lower limb of right-handed individuals has a greater role in propulsion.\textsuperscript{26} Despite a majority of right-handed specimens being assumed in our study, definite data on the distribution of right- and left-handed specimens were not available.

Because its position being in general too medial (fig. 5E), Pandin’s approach\textsuperscript{14} is closer to the lumbar plexus on the left side, where the PSIS and the major psoas muscle are located more medially than on the right side. By contrast, Dekrey’s\textsuperscript{13} (fig. 5A) and Chayen’s\textsuperscript{15} (fig. 5D) approaches, generally located too laterally, therefore fit better on the right side, where the major psoas muscle and the PSIS are shifted laterally. The significant sex difference in the Y level of the lower edge of the vertebral body of L5 in relation to the intercrestal line (women/men \(-37 \pm 22\text{ mm}/-46 \pm 10\text{ mm}\)) indicates a broader pelvis in women.\textsuperscript{25} Considering this sex-related variabilty, accesses to the lumbar plexus relying on the intercrestal line\textsuperscript{12,16} hypothetically are prone to deviations from the target structure. In the present dataset, however, no sex differences could be shown for either accesses. This may be because of the fact that both Winnie’s\textsuperscript{16} and Capdevila’s\textsuperscript{12} insertion sites are, in addition, related to the PSIS in the lateral axis, which may in parts compensate for the craniocaudal variability.

Too medial an injection of local anesthetics favors their epidural spread\textsuperscript{19,27} Access that is too high and too lateral bears the risk of renal puncture. PSIS area mapping (fig. 3) was the first step in seeking more precise approaches to the lumbar plexus. The PSIS approximation map (fig. 3) starts medially and cephalad of the PSIS, considering that pelvic bone may impair perpendicular needle advancement. Figure 3 gives a first assumption of the lumbar plexus course which then inspired the idea of diagonal vectors. However, it does not consider the transverse process of L5.

The idea of evaluating diagonal landmark vectors was derived from the PSIS mapping and the derived needle approach groove (fig. 3). Vectors directed from the PSIS to the spinous process of L3 (fig. 7) and L4 (fig. 8) were taken because of their relatively parallel course with the axis of the lumbar plexus (fig. 4). These vectors intersecting the course of the lumbar plexus in an obtuse angle result in wide needle approach curve indicating a minimum effect of variations in the entry point on needle tip proximity to the mean nerve location, as opposed
to the traditional approaches (fig. 5). Vectors in the direction PSIS-L5 and PSIS-L2 were not considered for several reasons: The first one is located almost horizontally, insinuating the same problems as the traditionally used landmarks. The PSIS-L2 vector may be prone to age-related variations such as lowered height of vertebral bodies or intervertebral discs. Further, this vector intersects the lumbar plexus rather cephalad (fig. 4), so that failure of obturator block may occur. Keeping in mind Broadbent’s findings29 that anesthetists frequently fail to identify the intended vertebral level by using the intercrestal line for orientation, the higher the vertebral level aimed at, the higher the probability of error. On the other hand, the fact that both PSIS-related diagonal approaches have a long close course to the lumbar plexus, around 1/5 of the distance of PSIS-spinous process to L3 or to L4, “Broadbent’s error” may not reduce the success of reaching the lumbar plexus even when L3 and L4 are mixed up by the anesthetist.

Practical implications for block performance derived from this study include identification of the iliac crests. Spinosus process of L4 will be found 4 ± 13 mm cephalad of the intercrestal line, and the spinous process of L3 ± 14 mm, respectively (table 1). PSIS may be found 40 ± 11 mm below the intercrestal line in a lateral distance of 52 ± 14 mm from the midline. A line between the PSIS and the spinous process of L3 should be drawn (fig. 4). The entry point for lumbar plexus block is at 1/5 of the PSIS-L3 distance counted from the PSIS (fig. 7). In case of erring by one vertebral level aiming at L3 and reaching L4, nevertheless taking 1/5 of the distance from the PSIS to the identified spinous process (actually L4) would, likewise, produce a close proximity (fig. 8). From the current data all distances on a vector from the PSIS to L5 will produce bony contact throughout, either with the iliac bone or the sacrum.

By means of this new vector localization technique, using a line drawn between the PSIS and L3 or L4, if the needle contacts bone, the entry point can be moved further cephalad and medially along the line without deviating too far from the course of the nerve or changing the axis of needle advancement after skin penetration from perpendicular to the skin’s surface in all planes.

The mean age of the cadavers was 10 yr older than patients from recent literature on lumbar plexus block in total knee arthroplasty,7,12,23,27,29 and own regression analysis revealed that major psoas muscle diameter in typical total knee arthroplasty patients can be expected to be 4 mm broader, without having considered artifacts caused by fixation, as described, and shrinking. Fixation artifacts in the present setting may not be completely ruled out. However, in the present analysis all techniques for identifying entry points to the lumbar plexus12-16 were challenged within the same model. Thus, comparisons between the different techniques are still valid and of relevance.

Broadening of the major psoas muscle in younger individuals because of the solid vertebral column may merely be achieved laterally, as indicated by the sex difference in major psoas muscle thickness and lateral extent. The lumbar plexus may not shift laterally to the same extent because of fixation of nerve roots within the intervertebral spaces. The assumption made in the present model that the lumbar plexus was located at the medial third border of the major psoas muscle was driven by own observations in line with previous literature,1,2,24 thus being sufficient for model generation.

From the studied specimens, traditional landmarks should be considered to be adapted as reported to bring the needle tip closer to the average course of the lumbar plexus. In this regard, relying on the position of the PSIS eliminates the sex and sided differences, as well as individual body size, that can be problematic if firm metric distances from the midline are used in determining the entry point. In addition, using the PSIS-based entry points places the course of the needle to the lumbar plexus, where neuraxial spread is less likely.

Improvement of both the proximity of traditional accesses and increasing error tolerance of needle advancement by diagonal landmark vectors was possible within our anatomic model. Clinical use in terms of safety and case of access, however, must be evaluated in a relevant cohort of patients.

References

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