

Magnetic Resonance Imaging Analysis of the Spread of Local Anesthetic Solution after Ultrasound-guided Lateral Thoracic Paravertebral Blockade

A Volunteer Study

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ABSTRACT

Background: This study was designed to examine the spread of local anesthetic (LA) *via* magnetic resonance imaging after a standardized ultrasound-guided thoracic paravertebral blockade.

Methods: Ten volunteers were enrolled in the study. We performed ultrasound-guided single-shot paravertebral blocks with 20 ml mepivacaine 1% at the thoracic six level at both sides on two consecutive days. After each paravertebral blockade, a magnetic resonance imaging investigation was performed to investigate the three-dimensional spread of the

What We Already Know about This Topic

- Thoracic paravertebral blockade has become increasingly popular, but is associated with an unpredictable spread of somatic sensory blockade

What This Article Tells Us That Is New

- In a volunteer study, magnetic resonance imaging and sensory testing were used to compare the spread of 20 ml of local anesthetic injectate with the extent of sensory block
- The spread of local anesthetic encompassed about four vertebral levels, greater caudal than rostral, which differed significantly from the greater extent of sensory block, which was highly variable

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LA. In addition, sensory spread of blockade was evaluated *via* pinprick testing.

Results: The median (interquartile range) cranial and caudal distribution of the LA relative to the thoracic six puncture level was 1.0 (2.5) and 3.0 (0.75) [=4.0 vertebral levels] for the left and 0.5 (1.0) and 3.0 (0.75) [=3.5 vertebral levels] for the right side. Accordingly, the LA distributed more caudally than cranially. The median (interquartile range) number of sensory dermatomes which were affected by the thoracic paravertebral blockade was 9.8 (6.5) for the left and 10.7 (8.8) for the right side. The sensory distribution of thoracic paravertebral blockade was significantly larger compared with the spread of LA.

Conclusions: Although the spread of LA was reproducible, the anesthetic effect was unpredictable, even with a standardized ultrasound-guided technique in volunteers. While it can be assumed that approximately 4 vertebral levels are covered by 20 ml LA, the somatic distribution of the thoracic paravertebral blockade remains unpredictable. In a significant percentage, the LA distributes into the epidural space, prevertebral, or to the contralateral side.

THORACIC paravertebral blockade (TPVB) is a regional anesthetic technique where local anesthetic (LA) is administered inside the thoracic paravertebral space (TPVS), which is formed between the superior

costotransverse ligament, the parietal pleura, and the structures of the vertebral column. It is a widely used regional anesthetic technique with a large number of clinical indications.^{1,2} The major drawback of TPVB is the unpredictable extent of somatic blockade, which is described for pure anatomical landmark-based methods,³ “loss-of-resistance,”⁴ and “pressure-measurement”⁵ techniques. In addition, the spread of LA solution inside the TPVS is mostly unknown.

Recently our study group developed a standardized ultrasound-guided technique for TPVB, where LA is administered between the internal intercostal membrane (the lateral continuation of the superior costotransverse ligament), the pleura, and the transverse process.⁶ This technique was defined as the lateral TPVB and shows a sufficient clinical effect, but the exact spread of LA remains unclear. Nevertheless, knowledge regarding the spread of LA is a major prerequisite for a safe and effective use of all regional anesthetic methods in clinical practice.

Magnetic resonance imaging (MRI) is a useful technique for the detection of the three-dimensional spread of LA following regional blocks. The clarification of mechanism of perivascular inguinal femoral nerve blockade is one example for the effectiveness of MRI in this context.⁷ We therefore designed a prospective study in volunteers to examine the spread of LA *via* MRI investigation in correlation with the extent of somatic block after a standardized ultrasound-guided TPVB. As the TPVS is described wider on the left than on the right side,⁸ we performed TPVB on both sides in each volunteer on two different days to compare the distribution of LA solution and subsequent sensory effects between both sides.

Materials and Methods

The study was approved by the Ethics Committee of the Medical University of Vienna, Austria (EK 730/2011), and by the Austrian Agency for Health and Food Safety (EudraCT 2011-00-3656-39). Trial registration was performed *via* the German Clinical Trials Register (DRKS 00003323).

Screening Visit

Ten healthy, male volunteers aged between 18 and 45 yr were enrolled in the study. Prior to inclusion in the study, we informed them about the nature, scope, and the procedures of the study and about the particular study-related risks.

Exclusion criteria were defined as follows:

- Anatomical abnormalities of the thoracic spine identified by physical examination
- Spontaneous pneumothorax in the medical history
- Body mass index ≥ 30 kg/m²
- Claustrophobia
- Metal implants (pacemaker and others)
- Use of nonsteroidal anti-inflammatory drugs during the last 2 weeks

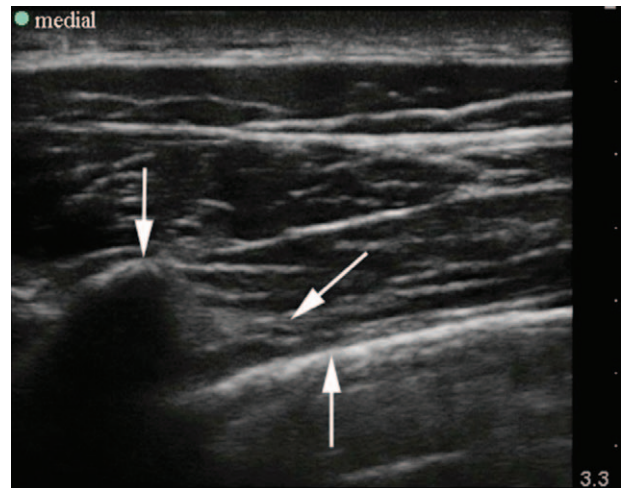


Fig. 1. Cross-sectional ultrasound image of the right thoracic paravertebral space (downward oriented arrow = transverse process, upward oriented arrow = pleura, oblique arrow = internal intercostal membrane; left = medial).

- Known allergy or hypersensitivity against mepivacaine or other amino-amide LAs
- Participation in another clinical study within the last 4 weeks prior to study
- Coagulopathies in the medical history
- Abnormalities in electrocardiography that are considered clinically relevant such as atrioventricular block or bradycardia

After signing the informed consent, each volunteer underwent a general physical examination, including patient history and drawing of blood for the laboratory (red and white blood count, and standard blood coagulation parameters). In addition, an electrocardiogram as well as determination of blood pressure and heart rate was performed. If all inclusion criteria were met, a bilateral cross-sectional ultrasound examination of the TPVS at the thoracic six (T6) level was performed to confirm a clear identification of the ultrasound landmarks (fig. 1):

- Transverse process T6
- Internal intercostal membrane
- Parietal pleura

The T6 level was determined by counting the spinous processes from the seventh cervical vertebra (vertebra prominens) in a distal direction. The screening visit took place within 3 weeks before study day 1.

Ultrasound-guided Paravertebral Blockade and MRI Investigation

On the morning of study day 1, the volunteers were admitted to the clinical research ward. A venous access was inserted into an antecubital vein and standard cardiorespiratory monitoring was established (electrocardiogram, noninvasive blood pressure, and SpO₂).

The ultrasound-guided injection of LA inside the TPVS was performed under direct ultrasound guidance using a transportable ultrasound system (SonoSite M-Turbo, SonoSite Inc., Bothell, WA) with a 50-mm 7–15 MHz linear ultrasound transducer in a lateral position with the scheduled blocking area above. The TPVS was visualized as recently described by our group at the level of T6 between the transverse process, the internal intercostal membrane, and the pleura. The puncture area and the ultrasound probe were prepared in a sterile manner, and a skin wheal was performed with 2 ml mepivacaine 1% (BBraun Melsungen AG, 34209 Melsungen, Germany). Then, the puncture was performed with a 21-G, 80-mm Facette tip needle and an injection line (Stimuplex D Plus, 0.71 × 80 mm, 22G × 3 1/8," BBraun Melsungen AG) realizing an “out-of-plane” ultrasound-guided technique as described in a recent study. The cable of the needle was not used for stimulation purposes. Once the tip of the needle was placed inside the TPVS, 20 ml mepivacaine 1% was administered after negative aspiration under direct ultrasound imaging.

After the injection of LA inside the TPVS, an MRI was performed using a 3-Tesla unit, long spine coil, covering the whole spine. T2-weighted sequences were performed in sagittal and coronal planes. Axial T2-weighted sequences with fat suppression were added in the region of the fluid accumulation. Axial T1-weighted sequences in this region were performed to identify or exclude hemorrhagic components. Slice thickness was 3 mm. During MRI investigation, the volunteers were monitored *via* the MRI Bluetooth monitoring system (SpO₂, electrocardiogram). The distribution pattern of LA inside the TPVS was evaluated by analyses of the T2-weighted, fluid-sensitive images (fig. 2). Starting at the T6 puncture level, the axial T2-weighted sequences were analyzed in a cranial and caudal direction to evaluate the cranio-caudal spread of LA. Any distribution of LA outside the TPVS (dorsal to the internal intercostal membrane, pleural, epidural, prevertebral, and contralateral) was analyzed. All images were investigated by the same radiologist.

If the regional anesthetic technique and the subsequent MRI examination were performed without any

complications (definitions see following section), the particular volunteers were scheduled for the same procedure on the contralateral side on the subsequent day (study day 2).

Evaluation of Sensory Blockade

Sensory block was assessed by pinprick testing with 22-G short bevel needles in comparison with the contralateral dermatomes. The tip of the needle was applied with a force adequate to indent the skin without puncturing it, and this produced a consistent painful sensation when applied to nonblocked areas. The blocked area was tested from the T6 dermatome at the anterior axillary line in a cranial and then in a caudal direction. If required, the C2–5 dermatomes were tested at the neck. Each individual dermatome on the blocked side was compared with the contralateral side. All assessments were performed by one investigator (D.M.).

Assessments were quantified from 100% (full sensory feeling) to 0% (no sensory feeling) in proportions of 10%. Sensory scores were evaluated at the following time points: Prior block → 30 min after block (after MRI investigation) → 60 min after block → 120 min after block → 24 h after the block for days 1 and 2 and during 1 week (final examinations). Successful blockade in a specific dermatome was defined when pinprick testing was positive (≤10%).

Onset and duration of TPVB were not evaluated, as this study was designed to investigate the spread of LA within the TPVS. The expansion of the TPVB was investigated meticulously to compare it with the LA spread in the TPVS.

Randomization

The sequence of the puncture side was performed according to a computerized random protocol. The contralateral TBVS was blocked on the second study day.

Observation after Injection of LA Inside the TPVS

The volunteers were observed and monitored (SpO₂, electrocardiogram, and noninvasive blood pressure) 3 h after performance of TPVB and discharged after that time. An emergency telephone number was provided in cases of any medical problems.

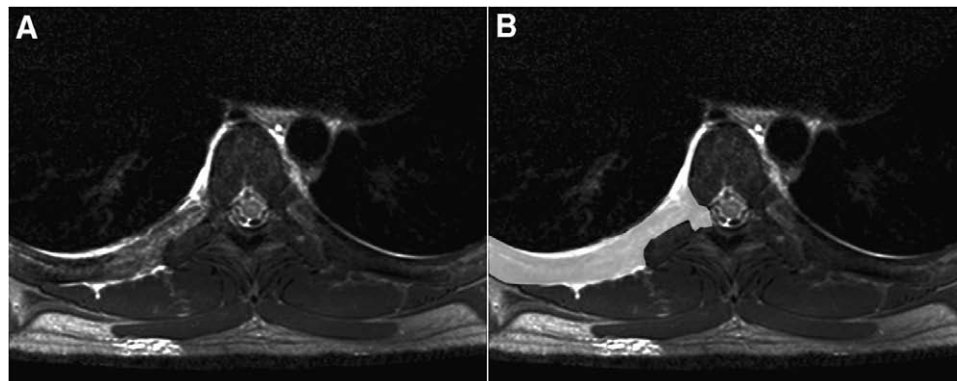


Fig. 2. (A) T2-weighted fluid sensitive magnetic resonance imaging image at the thoracic six level, where local anesthetic can be detected inside the right paravertebral space. (B) Local anesthetic outlined.

Management of Side Effects

Decrease in heart rate and blood pressure $\geq 30\%$ from initial values was treated with 0.01 mg/kg glycopyrrolate and repetitive doses of 2 mg etilefrine, respectively.

Follow-up Investigation

At 1 week after the second study day, all volunteers underwent an investigation of the puncture sites to exclude puncture-related infection or hematoma.

Statistical Analysis

The cranio-caudal spread of LA was recorded and described for each of the volunteers. Due to the paired and not-normally distributed nature of the data, we used a two-tailed Wilcoxon matched-pairs test to compare the cranio-caudal spread of LA and the sensory distribution between the left and the right side, and to compare the cranial *versus* the caudal spread of LA at the same side. Pearson correlation coefficient was used to correlate the spread of LA with the sensory distribution of TPVB and to correlate the spread of LA of MRI and sensory distribution between the right and left sides. Data are presented as median (interquartile range). A $P < 0.05$ was considered as statistically significant. SPSS 17.0.1 was used as statistical software (IBM Inc., Armonk, NY).

Results

Pertinent patient data are presented in table 1. The specific ultrasound landmarks (transverse process, pleura, and internal intercostal membrane) could be identified in all volunteers (fig. 1). Subsequently, the ultrasound-guided TPVBs were performed successfully in all volunteers on both sides.

Figure 2 illustrates one case of an MRI image of the axial distribution of LA inside the right TPVS at the level of T6. MRI analysis and sensory evaluation of both sides are presented in figures 3 and 4.

The median (interquartile range) cranial and caudal distribution of LA relative to the T6 puncture level was 1.0 (2.5) and 3.0 (0.75) vertebral levels for the left and 0.5 (1.0) and 3.0 (0.75) vertebral levels for the right side. No significant

Table 1. Pertinent Patient Data

Volunteer	Age, yr	Height, cm	Weight, kg	BMI, kg/m ²
1	31	174	68	23
2	31	182	87	26
3	33	172	86	29
4	24	189	84	24
5	25	190	80	22
6	29	194	102	27
7	24	189	94	26
8	22	182	83	25
9	23	189	67	19
10	22	175	75	25

BMI = body mass index.

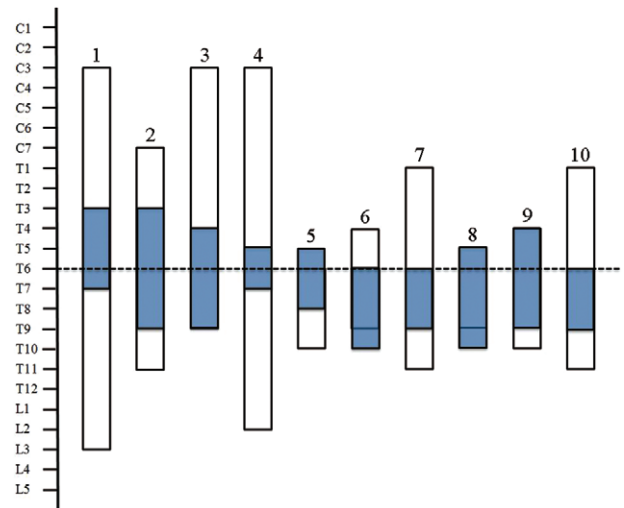


Fig. 3. Analysis of the spread of local anesthetic solution (full boxes) and sensory evaluation (open boxes) of left thoracic paravertebral blocks. Numbers indicate the consecutive study cases.

difference could be detected between the left and the right spread of LA, whereas the LA distributed significantly more in a caudal compared with a cranial direction on the right side ($P \leq 0.01$), but was not statistically significant on the left side ($P = 0.06$). The median (interquartile range) number of dermatomes, where LA was detected *via* MRI, was 4.0 (2.0) for the left side and 3.5 (1.0) for the right side ($P = 0.46$).

The median (interquartile range) number of sensory dermatomes that were affected by the TPVB was 9.8 (6.5) for the left and 10.7 (8.8) for the right side ($P = 0.25$). The sensory distribution of TPVB was significantly larger compared with the spread of LA ($P \leq 0.01$ for both sides), without positive correlations between MRI analysis and sensory

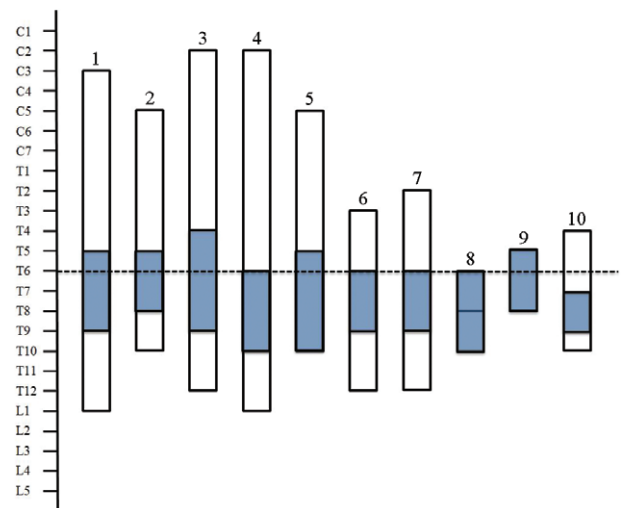


Fig. 4. Analysis of the spread of local anesthetic solution (full boxes) and sensory evaluation (open boxes) of right thoracic paravertebral blocks. Numbers indicate the consecutive study cases.

blockade (Pearson correlation coefficient -0.29 for the left and $+0.49$ for the right side). Pearson correlation coefficients between the right and left sides were -0.05 for MRI distribution and $+0.74$ for sensory distribution.

LA was detected in six cases outside the TPVS: prevertebral for both sides in volunteer no. 3; posterior to the internal intercostal membrane in volunteers no. 4 and no. 5 on the left side, and in volunteer no. 8 on the right side; a contralateral distribution in volunteer no. 5 for the right-sided TPVB. An epidural distribution of LA was detected in five cases ($=25\%$; in volunteers no. 4, no. 9, and no. 10 on the left side and in volunteers no. 1 and no. 9 on the right side). Thus, a spread of LA outside the TPVS was detected in eight of 20 cases (40%), whereas a detection of LA posterior to the internal intercostal membrane ($3/20$ cases = 15%) could be puncture related.

Volunteer no. 4 required hemodynamic therapy after blockade on the left side, and volunteer no. 2 required hemodynamic therapy after blockade on the right side. Both volunteers returned to initial hemodynamic values after 0.8 mg glycopyrrolate and 4 mg etilefrine. No case of pneumothorax (detected clinically and *via* MRI), infection, or hematoma was detected.

Discussion

This study is the first analysis of the spread of LA after standardized ultrasound-guided TPVB *via* MRI. After ultrasound-guided injection of 20 ml mepivacaine 1% , a mainly caudal distribution of LA relative to the puncture site at the T6 level was observed with an average cranio-caudal spread to four vertebral levels. In 40% of the cases, a spread of LA outside the TPVS was detected. A highly significant difference between the MRI investigation and the sensory evaluation of the TPVB was identified. Thereby in most of the cases, the extent of sensory effects exceeds the apparent distribution as observed *via* MRI. No side differences were observed regarding spread of LA solution and sensory block.

In-depth anatomical knowledge is required to understand the mechanism of TPVB. It is described as a wedge-shaped space that lies on either side of the vertebral column. The anterolateral boundary is formed by the parietal pleura, and the medial boundary is formed by the posterolateral aspect of the vertebral body, the intervertebral disc, the intervertebral foramen, and its contents. The superior costotransverse ligament and its lateral continuation, the internal intercostal membrane, extend from the lower border of the transverse process above to the upper border of the transverse process below and form the posterior wall of the TPVS. The apex of the TPVS is continuous, with the intercostal space lateral to the tips of the transverse processes. The TPVS contains the intercostal spinal nerves, the spinal dorsal rami, the rami communicants, the sympathetic chain, intercostal vessels, and fatty tissue. The TPVS communicates with the intercostal space in a lateral direction, the epidural space *via* the intervertebral foramina, and the contralateral TPVS *via* the prevertebral and epidural space. The cranial extension of the

TPVS is not exactly defined, but the observation of Horner syndrome following paravertebral blockade is an indicator of involvement up to the cervical region. The caudal boundary of the TPVS is formed by the origin of the psoas major muscle.¹

The knowledge of the spread of LA during regional anesthesia techniques is an important issue for the clarification of particular block mechanisms, and the findings are useful for the daily clinical practice. An example for successful use of advanced imaging techniques is the 3-in-1 blockade, where MRI showed the spread of LA, allowing clarification of the block mechanisms.⁷

Despite the good clinical effect of the ultrasound-guided approach to the lateral TPVS,⁶ the information regarding the three-dimensional spread of LA is limited. The direct observation of the anterior movement of the pleura with ultrasound caused by injected LA during TPVB is highly relevant to predict the success of the block. In other words, if the tip of the needle is placed below the internal intercostal membrane (the lateral continuation of the superior costotransverse ligament) and an anterior movement of the pleura is visualized during injection of LA, the block can be considered technically correctly performed.

However, an exact prediction of the somatic distribution is not possible, even with our standardized technique. This study shows a high percentage of cases where the LA was detected outside the TPVS, and a considerable mismatch between cranio-caudal spread of LA and somatic block.

We observed a mean cranio-caudal distribution of LA during TPVB of four levels with a significantly more caudal than cranial spread. Former studies have investigated the spread of LA during TPVB clinically or in cadavers. Table 2 summarizes the relevant publications in that field. In particular, the large variability of somatic blockade needs to be highlighted. Interestingly, the individual sensory effect between left and right sides showed a notable correlation (Pearson correlation coefficient $+0.74$), which supports the large interindividual sensory effect of TPVB.

While computed tomography offers the advantage of visualizing the spread of injected radiographic contrast media with precision, MRI remains the best method for detecting the spread of water-based injectate other than contrast media and does not rely on the use of ionizing radiation. This study may therefore be the best available investigation regarding the spread of LA within the TPVS during TPVB. To date, no study describes the correlation between the spread of LA and the extent of somatic block during TPVB because the spread of LA is described in cadavers and the extent of somatic blocks is described in patients with the blocks performed by landmark-based techniques. However, it is important to highlight the large variability of cranio-caudal distribution in previous studies, which is also observed in our study. We detected a variability of the spread of LA in MRI between two and six levels. TPVB is associated with a considerable variability even with our standardized ultrasound-guided

Table 2. Relevant Publications Where the Distribution of Fluid or Extent of Blockade after Thoracic Paravertebral Blockade Was Investigated

Publication	Study Population	Technique	Volume of LA/Dye	Distribution of Dye	Mean Extent of Somatic Block (Range)
Eason <i>et al.</i> ¹⁴	Cadavers	Landmark based	15 ml	4 intercostal segments	...
Cheema <i>et al.</i> ¹⁵	Patients	Landmark based	15 ml	...	5 (1–9)
Richardson <i>et al.</i> ¹⁶	Patients	Landmark based	0.3 ml/kg	...	Cranial: 1.4 (0–4) Caudal: 2.8 (0–7)
Cowie <i>et al.</i> ¹⁷	Cadavers	Ultrasound guided	20 ml	4.5 intercostal segments	

LA = local anesthetic.

technique performed by one experienced anesthesiologist in young normal-weight volunteers. This has to be considered in daily clinical practice, where variability may be even increased due to a more heterogenic patient population as investigated in this study. The variability of spread of LA in the TPVS seems to be caused by individual anatomical circumstances, rather than by the technique used to perform TPVB.

The significant difference between MRI distribution of LA and somatic blockade cannot be simply explained by our data. One possible hypothesis regarding this observation was recently published by Lundblad *et al.*,⁹ who described similar findings for ultrasound-guided caudal blockade in children. The authors assumed a secondary spread following the primary visualization of caudally administered LA.⁹ We found evidence of epidural spread of LA *via* MRI at the time of MRI investigation in 25% of TPVB. A secondary epidural spread with possibly subsequent contralateral sensory effects is a reasonable explanation for the larger extent of somatic block compared with the spread of LA, which is in accordance with the literature.^{10–12} Our findings regarding the epidural spread of LA is also in accordance with cadaver studies, where proportions of paravertebral administered fluid have been detected in the epidural space.¹³ However, MRI is a static method of visualization; therefore, we assume a dynamic redistribution of LA which cannot be detected *via* MRI. Another possible explanation of the discrepancy between the spread of LA and the extent of somatic block is a secondary vertical spread of LA inside the TPVS, which could not be detected *via* immediate post-puncture MRI. The spread of LA within the TPVS might have been underestimated by the use of MRI; fat and water have similar signal intensities, making exact determination of the extent of LA spread difficult to determine.

Limitations of the Study

This study is performed in volunteers and therefore the evidence of block success is lacking. A study design where MRIs are performed after TPVB is not possible in daily clinical practice. Although MRI is the accepted standard for exact visualization of anatomical details from all three axes, it is a non-dynamic method of investigation and, therefore, only conclusions regarding the spread of LA *at the time of MRI investigation* can be drawn.

The investigation of T2-weighted MRI to assess the spread of a water-based solution is influenced by the individual radiologist. Thus, slightly different results regarding the cranio-caudal spread of LA which are dependent on the investigators' experience cannot be excluded.

We observed in one study case a contralateral spread of LA. Specific statements regarding the implications on contralateral sensory blockade are not possible with pinprick testing. Anyway, we suppose that the volume of contralateral LA is insufficient for a detectable sensory effect. We observed in five cases an epidural spread of LA, and similar to the contralateral distribution of LA, we were not able to quantify the implications on contralateral sensory effect.

Conclusion

The somatic extent of TPVB is unpredictable, even with a standardized technique performed by one experienced anesthesiologist in young healthy volunteers. While it can be assumed that approximately four vertebral levels are covered by 20 ml LA, the somatic distribution of the TPVB remains unpredictable. In a significant number of cases, the LA distributes into the epidural space, prevertebral, or to the contralateral side.

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