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ORIGINAL ARTICLE

The key to success in blocking lateral cutaneous branches with re-modified thoracoabdominal nerves block through perichondrial approach: a newly discovered space between the endothoracic fascia, diaphragm, and costodiaphragmatic recess

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Abstract

Purpose This study aimed to determine whether the administration of a modified thoracoabdominal nerves block through perichondrial approach (M-TAPA) could result in the blockade of the lateral cutaneous branches. This study focused on a newly discovered anatomical space/plane adjacent to the M-TAPA plane, which we termed "space between the endothoracic fascia, diaphragm, and costodiaphragmatic recess: SEDIC."

Methods Thirteen sides of nine formalin-embalmed cadavers were macroscopically dissected to investigate the anatomical spaces related to the effects of M-TAPA. Furthermore, ten adult volunteers were administered 20 mL of 0.2% ropivacaine into the abdominal plane (corresponding to the M-TAPA plane) and the SEDIC, and a pinprick test was performed 1 h after the injection.

Results Cadaver macrodissection revealed the presence of the SEDIC adjacent to the M-TAPA plane. The SEDIC was completely spatially isolated from the M-TAPA plane by the presence of costal cartilage and/or tendinous structures. In the volunteer study, the administration of local anesthetics into the SEDIC effectively blocked the lateral cutaneous branches of T8–T12, in addition to the anterior branches.

Conclusion Our study revealed the presence of the SEDIC adjacent to the M-TAPA plane. Administration of local anesthetics into the SEDIC, named re-modified TAPA, may have the potential to enhance the analgesic effect in the abdominal region.

Keywords Abdomen · Lateral cutaneous branch · Modified thoracoabdominal nerves block through perichondrial approach

Introduction

The modified thoracoabdominal nerves block through perichondrial approach (M-TAPA), which was initially reported by Tulgar et al. in 2019 [1], involves the administration of a local anesthetic between the internal oblique and transversus abdominis muscles at the level of the 9th–10th costal cartilage. In recent studies, the M-TAPA has reportedly been used for perioperative analgesia not only in laparoscopic surgery [2–5] but also in open surgical procedures [6, 7]. However, the analgesic region achieved after M-TAPA administration remains a subject of controversy. There are two distinct research outcomes regarding the clinical efficacy of M-TAPA. Our previous volunteer study [8] and a few cadaver studies [9, 10] showed that M-TAPA primarily affected the anterior branches (ABs). In contrast, two

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observational studies focusing on the effectiveness of M-TAPA in patients undergoing gynecological surgeries have reported the occurrence of lateral cutaneous branch anesthesia from T4 to T12 or T6 to T12, albeit at a lower frequency compared to anterior branches [5, 7]. Furthermore, a clinical study investigating the application of M-TAPA in thoracic surgery has reported the blockade of the lateral cutaneous branches (LCBs) from T7 to T11 [11].

An important question arises: despite the anatomical fact that the administration site of local anesthetics during M-TAPA is located in the same plane as that of the transversus abdominis plane (TAP) block, why is it that only M-TAPA has the capability to block the LCBs extensively? Previous studies have demonstrated that blockade of the LCB of T12 can be achieved by administering local anesthetics through abdominal approaches, such as the posterior TAP block [12, 13] or the transversalis fascia plane block [14]. This is attributed to the fact that the subcostal (T12) nerve normally sends out its LCB very proximal in the TAP upon entering the abdominal cavity [14]. However, the administration site of M-TAPA block is distant from that of these blocks but it shares similarities with the subcostal TAP block [15, 16]. The notable difference between M-TAPA and the subcostal TAP block lies in the direction of needle insertion, where the needle for M-TAPA is directed towards the thoracic cavity in a cranial direction adjacent to the costal cartilage. This factor may potentially induce different responses in the behavior of local anesthetics administered through M-TAPA compared to those administered through the subcostal TAP block. The LCBs of T1–T11 bifurcate within the thoracic cavity, penetrating the intercostal and external oblique muscles. Therefore, we hypothesized that in order to block the LCBs above T12, local anesthetics injected by M-TAPA should directly infiltrate the adjacent spaces within the thoracic cavity.

In this study, our initial objective was to identify the intrathoracic spaces that could potentially contribute to the clinical effectiveness of M-TAPA using formalin-embalmed cadavers. Subsequently, we assessed the continuity between these spaces and the M-TAPA plane. Our second objective was to evaluate the correlation between the thoracic cavity spaces and the blockade of both ABs and LCBs by administering local anesthetics to healthy volunteers.

Methods

Cadaver dissection

This cadaveric study was approved by the Institutional Ethics Committee of Juntendo University Medical School (approval number: 20-304). In this study, nine formalin-embalmed cadavers (four men and five women) were used to conduct anatomical dissections on a cumulative total of 13 sides (four on the left and nine on the right). All dissections were conducted collaboratively by an anesthesiologist (Y.O.) and an experienced anatomist (H.A.). After the skin was removed from the cadaver, a midline incision was made in abdomen to remove the intra-abdominal organs. Subsequently, parallel incisions along the ribs within each intercostal space were made, cutting through the intercostal muscles parallel to the ribs, while extending the incisions beyond the costal arch to the abdomen. Each incision site was observed to explore the intrathoracic spaces adjacent to the M-TAPA plane. Additionally, a rectangular dissection encompassing the ribs was performed to facilitate a more detailed anatomical evaluation, including the course of the intercostal nerves at each intercostal level.

Volunteers

The volunteer study consisted of two phases: the first phase focused on verifying the right-side block effect for efficacy assessment, and the second phase examined the left-side block effect to investigate potential asymmetry. Ethical approval for each phase of the volunteer study was granted by the Institutional Ethics Committee of Keiyu Hospital (approval numbers: K2023016 and K2023022 for the first and second phases, respectively). Each study phase was registered as a separate trial in the UMIN Clinical Trials Registry (URL: https://www.umin.ac.jp; UMIN 000051264 and 000053141 for the first and second phases, respectively). For the first phase of study, a convenience sample of healthy adult volunteers of both sexes with an American Society of Anesthesiologists Physical Status I was enrolled between June 5 and September 14, 2023. The exclusion criteria were as follows: (1) age < 20 or > 50 years, (2) history of allergy to local anesthetics, (3) neurological disorders affecting the corresponding region, (4) use of opioids or steroids, and (5) pregnancy. Prior to participation, the participants received a comprehensive explanation of the procedure and subsequently provided written informed consent. For the second phase of the study, participants from the first phase were included between December 20, 2023, and February 28, 2024, after receiving thorough explanation of the trial and providing written informed consent.

Local anesthetic administrations

In each phase of the study, participants were allocated, using a sealed-envelope method, to receive the administration of local anesthetics either in the abdominal plane or thoracic plane as the initial procedure. All injections were administered by a single anesthesiologist (Y.O.) under continuous ultrasound guidance. The participants were positioned in the supine position. A 4–15 MHz linear probe (PX, Fujifilm

Sonosite, Tokyo, Japan) was placed parallel to the 10th costal space on the costal arch to visualize the junction of the diaphragm and the transverse abdominis muscle. Following aseptic preparation of the injection area, 1% lidocaine was used to anesthetize the skin. A needle (22-G × 70 mm, Stimuplex Ultra 360, B. Braun, Tokyo, Japan) was inserted in-plane through the skin. The needle tip was advanced either into the plane between the internal oblique and transversus abdominis muscles for the abdominal plane injection or into the plane between the diaphragm and intercostal muscles for the thoracic plane injection. After confirming negative blood aspiration, 20 mL of 0.2% ropivacaine was administered for each injection. The second block was carried out at least seven days after the first block to facilitate a complete recovery from the previous block. In the second block, we administered the injection into the plane that was not allocated during the initial procedure.

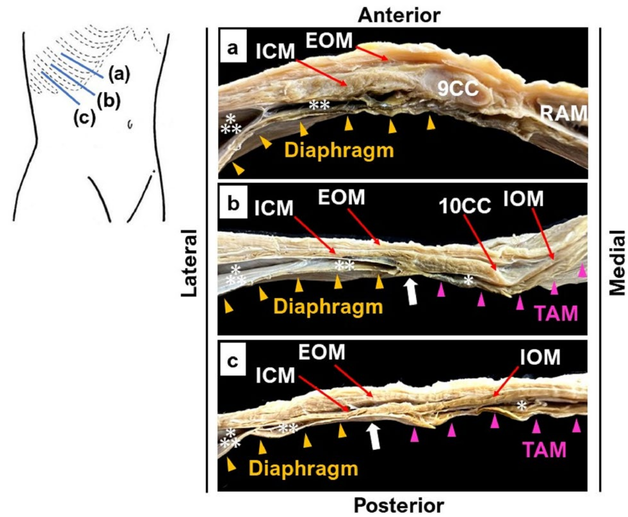

Fig. 1 Macroscopic cross-sectional images of anatomical specimens at the levels of the 8th (**a**), 9th (**b**), and 10th (**c**) intercostal spaces. The orange and pink arrowheads show the diaphragm and transversus abdominis muscle, respectively. The white arrows show the border between the diaphragm and transversus abdominis muscle. The asterisk shows the M-TAPA plane. The double asterisk indicates the SEDIC. The triple asterisk indicates the costodiaphragmatic recess. *9CC* 9th costal cartilage, *10CC* 10th costal cartilage, *EOM* external oblique muscle, *ICM* intercostal muscle, *IOM* internal oblique muscle, *M-TAPA* modified thoracoabdominal nerves block through perichondrial approach, *PP* parietal pleura, *RAM* rectus abdominis muscle, *SEDIC* the space between the endothoracic fascia, diaphragm, and parietal pleura, *TAM* transverse abdominis muscle

Sensory-level assessment

After receiving the block, the participants remained in a supine position for one hour and then underwent a pinprick test. The pinprick test was conducted by an investigator (S.H.), who employed a three-point numerical scale (0 = no pain, 1 = decreased pain, and 2 = normal pain) to assess the participants' responses. Values of 0 or 1 indicated an effective outcome.

Results

Cadaveric study

In this study, nine formalin-embalmed cadavers (five women and four men, mean age of 83.6 years) were used, and permission to anatomically dissect a cumulative total of 13 sides (four on the left and nine on the right) was obtained. In all specimens, the presence of a unique space/plane within the thoracic cavity, adjacent to the M-TAPA plane and extending between the 6th and 11th intercostal spaces, was observed. The observed intrathoracic space/plane adjacent to M-TAPA plane can be characterized as a non-uniform space, ranging in length from approximately 10 to 40 mm in the sagittal direction, delimited by the endothoracic fascia, diaphragm, and parietal pleura (Figs. 1, 2). Owing to the absence of a previous anatomical name, we termed it "space between the endothoracic fascia, diaphragm, and parietal pleura: SEDIC." An intervening weak connective tissue is found in the SEDIC. In cases where the costal cartilage is sufficiently large, the diaphragm and the transverse abdominis muscle attach to the costal cartilage, resulting in complete disconnection from both the SEDIC and the M-TAPA plane. In four specimens, the size of the 10th costal cartilage was small, and the transversus abdominis muscle and diaphragm were attached to the intercostal muscles via a tendinous fibrous tissue (Fig. 1b). Spatial separation between the SEDIC and the M-TAPA plane was observed in the four specimens. In the 10th intercostal space, where the costal cartilage was absent, tendinous fibrous tissue was responsible for connecting the intercostal and internal oblique muscles, as well as the diaphragm and transversus abdominis muscles (Fig. 1c). As shown in Fig. 2a more comprehensive anatomical dissection revealed a complete isolation of the SEDIC and the M-TAPA plane by this tendinous structure, elucidating the penetration of the AB of the 10th spinal nerve through the tendinous structure into the abdominal cavity. Figure 3 provides a schematic illustration of the relationship between the M-TAPA plane and the SEDIC at the 9th and 10th intercostal levels, accompanied by an ultrasonographic image at the 10th intercostal level.

First-phase volunteer study

To assess the efficacy of local anesthetic injection into the SEDIC, the first phase of the volunteer study was conducted solely on the right side. Ten participants (five males and five females) were successfully recruited and completed the study.

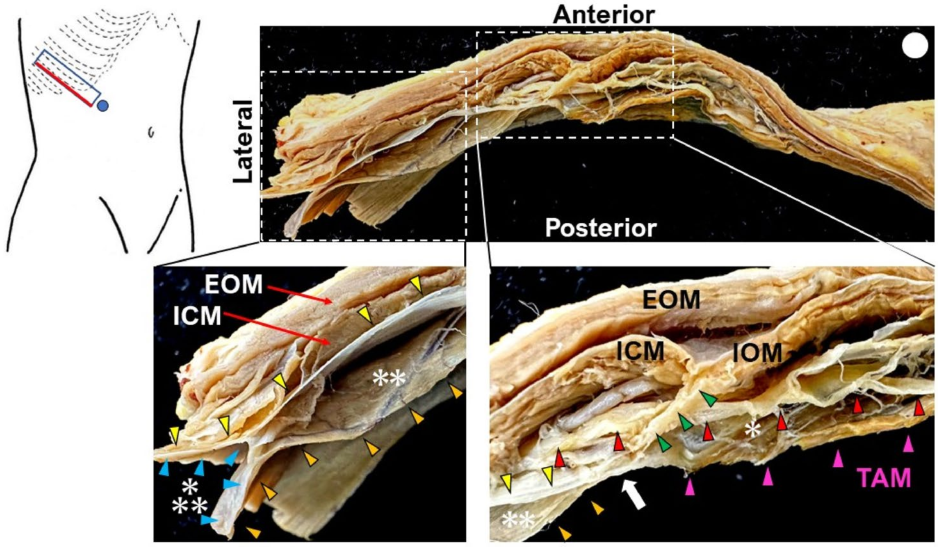

Fig. 2 Anatomical photograph of a rectangular section containing the 10th rib, as viewed from the indicated direction (shown in red). The white arrow shows the border between the diaphragm and transversus abdominis muscle. Blue arrowheads indicate the parietal pleura. Green arrowheads show the tendinous structure. Red arrowheads indicate the anterior branch of the 10th spinal nerve. Orange arrowheads indicate the diaphragm. Yellow arrowheads indicate the endothoracic fascia. The asterisk indicates the M-TAPA plane. The double asterisk indicates the SEDIC. The triple asterisk indicates the costodiaphragmatic recess. *EOM* external oblique muscle, *ICM* intercostal muscle, *IOM* internal oblique muscle, *M-TAPA* modified thoracoabdominal nerves block through perichondrial approach, *SEDIC* the space between the endothoracic fascia, diaphragm, and parietal pleura, *TAM* transverse abdominis muscle

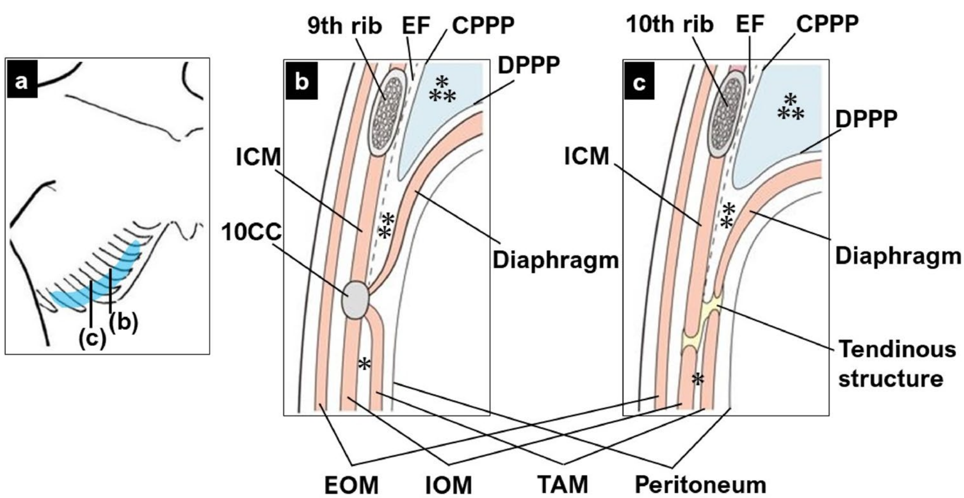

Fig. 3 Schematic representation of the relationship between the M-TAPA plane and SEDIC. **a** Schematic illustration showing the extent of the SEDIC (blue). Lines (b) and (c) represent the respective positions indicated by schemas (b) and (c). **b**, **c** Schematic illustration of a sagittal view at the 9th (b) and 10th (c) intercostal levels. The asterisk indicates the M-TAPA plane. The double asterisk indicates the SEDIC. The triple asterisk indicates the costodiaphragmatic recess. *10CC* 10th costal cartilage, *CPPP* costal part of the parietal pleura, *DPPP* diaphragmatic part of the parietal pleura, *EF* endothoracic fascia, *EOM* external oblique muscle, *ICM* intercostal muscle, *IOM* internal oblique muscle, *M-TAPA* modified thoracoabdominal nerves block through perichondrial approach, *PP* parietal pleura, *RAM* rectus abdominis muscle, *SEDIC* the space between the endothoracic fascia, diaphragm, and parietal pleura, *TAM* transverse abdominis muscle

The characteristics of the participants are presented in Table 1. Figure 4 shows the transducer orientation and ultrasonographic image of thoracic plane (SEDIC) and abdominal plane injections. Each participant reported areas of anesthesia demarcated by corresponding areas of normal sensation. Figure 5 shows the area of sensory block one hour after right intrathoracic and abdominal plane injections. Figure 6 presents the percentage distribution of blocked dermatomes, represented using bar

Table 1 Participant characteristics.

Sex (M/F)	5 (50%)/5 (50%)
Age (year)	37 (7) [25–47]
Height (cm)	166 (9) [150–179]
Weight (kg)	60 (13) [40–80]
Body mass index (kg/m^2)	21.6 (3.6) [17.5–28.7]

Data are shown as *n* (%) or mean (*SD*) [range]

F female, *M* male, *SD*, standard deviation

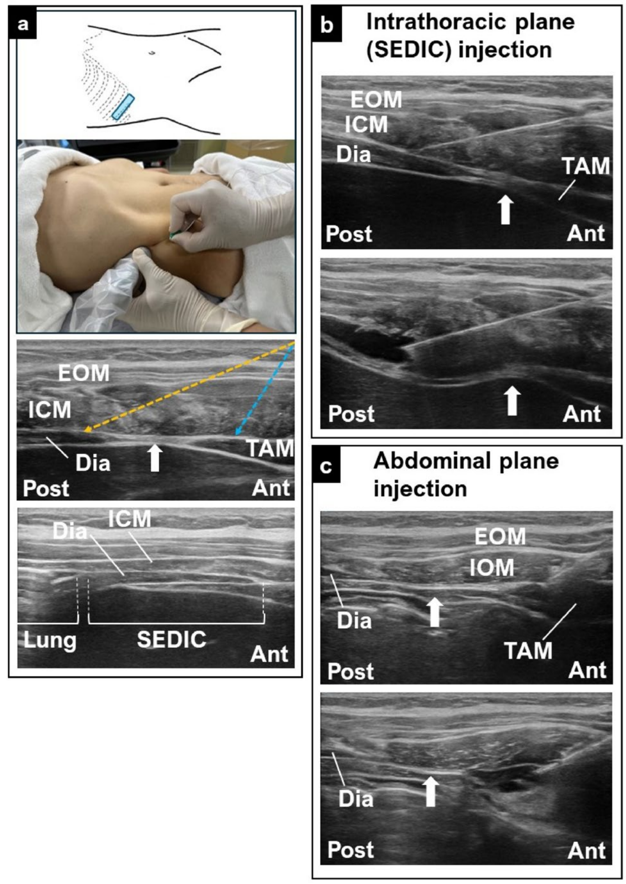

Fig. 4 Transducer orientation and ultrasonographic image of thoracic plane (SEDIC) and abdominal plane injections. **a** Transducer orientation placed on the 10th intercostal space (upper panel) and the corresponding ultrasonographic image (middle panel). The orange and blue dotted arrows indicate the needle positions for the intrathoracic plane (SEDIC) and abdominal plane injections, respectively. The white arrow indicates the border between the diaphragm and transversus abdominis muscle. The lower panel displays the ultrasonographic image during maximum inspiration, showing the expansion of the lungs and anticipated spread of the SEDIC. **b** The ultrasonographic photographs showing the needle position of the intrathoracic plane (SEDIC) injection (upper panel) and image after local anesthetic administration (lower panel). The white arrow indicates the border between the diaphragm and transversus abdominis muscle. Local anesthetic spread into the abdominal plane was not observed. **c** The ultrasonographic photographs showing the needle position of the abdominal plane injection (upper panel) and image after local anesthetic administration (lower panel). The white arrow indicates the border between the diaphragm and transversus abdominis muscle. Local anesthetic spread into the intrathoracic plane (SEDIC) was not observed. *Ant* anterior, *Dia* diaphragm, *EOM* external oblique muscle, *ICM* intercostal muscle, *Post* posterior, *SEDIC* the space between the endothoracic fascia, diaphragm, and parietal pleura, *TAM* transverse abdominis muscle

graphs. Upon injection into the abdominal plane, all participants exhibited a sensory block of the ABs centered around the mid-abdomen, with three of them (participants 3, 4, and 9) experiencing sensory loss in a part of the lateral abdomen innervated by the LCB of T12. Upon injection into the thoracic plane, both the anterior and lateral cutaneous branches were extensively blocked in nine participants, and the largest extent of the lateral cutaneous branch block was from T8 to T12. Participant 5 was only able to obtain a block of the AB of T10, regardless of the type of injection. Notably, no severe complications were observed in any of the participants.

Second-phase volunteer study

The second phase of the volunteer study was conducted on the participants who completed phase one to examine the presence of left–right asymmetry of the block effect. While consent was obtained from all participants who completed the first phase of the study, one individual was excluded from the second phase due to pregnancy. For the second phase, the administration of local anesthetics was confined to the left side, and the resultant outcomes are presented in Figs. 5, 6 alongside the data obtained in the first phase. In the abdominal plane injection on the left side, there was no observed disparity in block effect range in the ABs compared to the right side. In the left intrathoracic plane injection, four out of the nine participants exhibited a broad blockade not only in the AB region but also in the LCBs. However, in three participants, the LCB block was confined to a very narrow range, and in two participants, no LCB block was detected. Furthermore, in the case of these five participants, the range of blockade in the AB region achieved with intrathoracic injection was found to be smaller than that achieved with abdominal plane injection. Notably, no severe complications were observed in any of the participants.

Discussion

In this study, our anatomical analysis discovered the intrathoracic space/plane, the SEDIC, which is presumed to have an influence on the block effectiveness of the LCBs in the M-TAPA. In addition, our volunteer study revealed the necessity of administering local anesthetics directly into the SEDIC for achieving anesthesia of the LCBs in the abdomen.

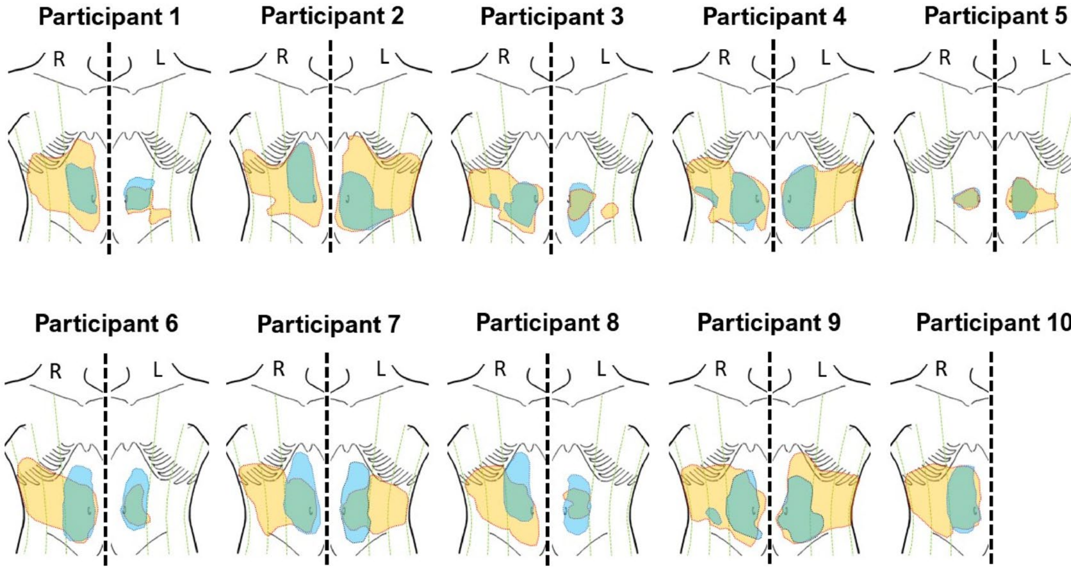

Fig. 5 Results of the pinprick test in the volunteer injection study. Blue areas show sensory loss after abdominal plane injection. Orange areas shows sensory loss after intrathoracic plane injection. The green dotted lines represent the midclavicular, anterior axillary, and posterior axillary lines. *L* left, *R* right

	Abdominal plane injection				Intrathoracic plane (SEDIC) injection			
	Right		Left		Right		Left	
	ABs	LCBs	ABs	LCBs	ABs	LCBs	ABs	LCBs
T6	30%(3/10)	0%(0/10)	0%(0/9)	0%(0/9)	20%(2/10)	0%(0/10)	22%(2/9)	0%(0/9)
T7	30%(3/10)	0%(0/10)	11%(1/9)	0%(0/9)	20%(2/10)	0%(0/10)	22%(2/9)	0%(0/9)
T8	60%(6/10)	0%(0/10)	44%(4/9)	0%(0/9)	40%(4/10)	40%(4/10)	22%(2/9)	0%(0/9)
T9	80%(8/10)	0%(0/10)	89%(8/9)	0%(0/9)	80%(8/10)	70%(7/10)	78%(7/9)	33%(3/9)
T10	100%(10/10)	0%(0/10)	100%(9/9)	0%(0/9)	100%(10/10)	90%(9/10)	100%(9/9)	56%(5/9)
T11	80%(8/10)	0%(0/10)	78%(7/9)	0%(0/9)	90%(2/10)	90%(9/10)	78%(7/9)	56%(5/9)
T12	40%(4/10)	30%(3/10)	56%(5/9)	11%(1/9)	70%(2/10)	90%(9/10)	33%(3/9)	67%(6/9)

Fig. 6 Bar graph showing the percentage of each individual sensory dermatome that was blocked. *ABs* anterior branches, *LCBs* lateral cutaneous branches, *SEDIC* the space between the endothoracic fascia, diaphragm, and parietal pleura

The SEDIC is an anatomical space/plane surrounded by the endothoracic fascia, diaphragm, and parietal pleura, exhibiting the presence of weak connective tissue on the inside. In terms of anatomy, the SEDIC can be understood as the extrapleural space situated in the caudolateral aspect of the thoracic cavity. In this region, the costal part of the parietal pleura folds back and transitions into the diaphragmatic part of the parietal pleura, forming the cranial end of the SEDIC. Although the SEDIC itself may not directly participate in vital activities, local anesthetic spread to the SEDIC could potentially facilitate the blockage of LCBs, preceding their penetration of the intercostal muscle. Our detailed anatomical examination revealed that the SEDIC and M-TAPA plane are spatially completely separated by either costal cartilage or a tendinous structure. The findings suggested a low probability of local anesthetics administered with M-TAPA spontaneously spreading into the SEDIC.

Subsequently, we examined the differences in anesthetic effects arising from the variances in the administration site between the abdominal plane (corresponding to the M-TAPA plane) and the intrathoracic plane (SEDIC). However, in cadavers, identifying the thin diaphragm using ultrasonography proved to be challenging, making it difficult to correctly position the needle tip. Additionally, in surgical patients, the use of analgesics and the surgical intervention itself may potentially affect the assessment of block effects. Therefore, we decided to administer the injections to healthy adult volunteers. Clinically, analgesic intervention for the LCB region in abdominal surgery is predominantly required on the right side, attributed to the anatomical position of organs, such as the gallbladder, liver, and appendix. Hence, in the first phase of our volunteer study, we evaluated the effectiveness of the procedure specifically in the right LCB area. Additionally, considering the results of our cadaveric study, we determined the administration level of local anesthetics to be at the 10th intercostal space. The 10th intercostal space is distinguished by the absence of costal cartilage and the presence of a tendinous structure instead, which separates the M-TAPA plane from the SEDIC and allows the passage of ABs of the 10th spinal nerve. Therefore, if it is assumed that the local anesthetics administered to the M-TAPA plane spontaneously spread into the SEDIC, this region becomes the most likely candidate for the entry point. Moreover, the lack of costal cartilage is an important factor as it facilitates easy needle access to the SEDIC. In the first phase of the volunteer study, the administration of local anesthetics into the right intrathoracic plane resulted in a significant loss of sensation, not only in the mid-abdomen but also in the lateral abdomen, observed in nine out of 10 participants. In contrast, sensory loss in the LCB region after local anesthetic injection into the right abdominal plane was observed in a mere three participants, and it was restricted exclusively to a partial aspect of T12. These findings suggest that, to achieve blockade of LCBs above T12, it is necessary to administer local anesthetics directly into the SEDIC.

In the second phase of the volunteer study, local anesthetic was administered to the participants of the first phase study, specifically targeting the left side, to evaluate the presence or absence of asymmetry. No significant difference was observed in the analgesic range following the administration of local anesthetics into the left abdominal plane compared to the right side. Interestingly, local anesthetic injection into the left intrathoracic plane resulted in no or very limited loss of sensation in the LCB region in five out of nine participants. Additionally, among those five participants, the sensory loss in the AB region exhibited a remarkably narrow extent. These results suggested individual variation as well as left–right asymmetry in the spread of local anesthetics administered into the SEDIC. The presence of the liver and heart typically results in left–right asymmetry in the position of the diaphragm, which may potentially impact diaphragm attachment to the ribs, consequently influencing the spread of local anesthetics. Participant five exhibited extremely limited effectiveness with local anesthetic injection into both the abdominal and intrathoracic plane, regardless of whether the right or left side was targeted. In our experience, we occasionally encounter patients, similar to Participant 5, who experience an extremely low analgesic effect following M-TAPA in clinical practice. This observation implies the possibility of significant interindividual variation in the spread of local anesthetics.

This study had several limitations, including the use of formalin-embalmed cadavers, which might have a different tissue integrity compared with that of living patients. Additionally, it should be noted that this study was a proof-of-concept pilot study involving a small number of volunteer participants. In the volunteer study, local anesthetic was administered in the 10th intercostal space, and the participants were observed in a supine position. The distribution of local anesthetics may vary depending on body positions such as the head-down position, potentially resulting in a more extensive sensory blockade. Investigating the differential effects and diffusion patterns of the injectate based on various injection sites and body positions would provide valuable insights.

This study represents the first investigation reporting the discovery of the SEDIC, an intrathoracic space/plane that is spatially isolated and adjacent to the M-TAPA plane. Moreover, this study provides evidence that direct administration of local anesthetics into the SEDIC is required to effectively block LCBs in addition to ABs. Due to the proximity between the SEDIC and the M-TAPA plane, there is the possibility that the needle may reach the SEDIC during M-TAPA, particularly when the needle tip is positioned below the 10th costal cartilage. These two injections, although seemingly similar, are fundamentally distinct, and we refer to the administration of local anesthetics into the SEDIC as re-modified TAPA (RM-TAPA). This finding suggests the presence of a potential duality within the previously executed block under the name M-TAPA, encompassing two distinct blocks, M-TAPA and RM-TAPA. Local anesthetic administration into the SEDIC could be achieved by making a slight cranial advancement of the needle during the M-TAPA procedure. However, this modification carries the potential risk of puncture of the diaphragm and/or damage to the ABs running beneath the costal cartilage. The RM-TAPA may have the potential to enhance analgesic effects by blocking both ABs and LCBs, particularly in the right abdominal region. Identifying the precise anatomical features of the SEDIC and elucidating the factors contributing to asymmetrical block effects represent critical objectives for future research.

Conclusion

To achieve a wide blockade of the LCBs in M-TAPA, it is essential to administer local anesthetics directly to the adjacent intrathoracic plane, the SEDIC. We have named this procedure RM-TAPA. RM-TAPA may provide effective abdominal pain relief, particularly in the right abdominal region.

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Data availability The data supporting the results reported in our paper can be provided on reasonable personal request to the corresponding author.

Declarations

Conflict of interest The authors declare no conflicts of interest.

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