ANESTHESIOLOGY

Transversus Abdominis Plane Block

A Narrative Review

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Since Rafi's[1] 2001 description, transversus abdominis plane blocks have become one of the most commonly performed truncal blocks.[2] They can be used to provide postoperative analgesia for open and laparoscopic abdominal surgery as well as inpatient and outpatient surgical procedures.[3] Transversus abdominis plane blocks remain a deceptively complex topic. For instance, not only can the transversus abdominis plane compartment be targeted using various approaches and techniques, but its size also requires a judicious dose of local anesthetic to ensure adequate postoperative pain control. More importantly, most approaches for transversus abdominis plane block only provide somatic (*i.e.*, abdominal wall) and not visceral analgesia. Thus, they may confer minimal benefits when compared with standard multimodal or thoracic epidural analgesia.

In this narrative review article, we discuss the anatomy, nomenclature, history, approaches/techniques, pharmacology, and complications of transversus abdominis plane blocks. We also review the evidence supporting their clinical use for common open and laparoscopic surgical procedures. Finally, we explore possible alternative truncal blocks as well as areas requiring further investigation.

Anatomy

The anterolateral abdominal wall encompasses four muscles: the rectus abdominis, external oblique, internal oblique, and transversus abdominis muscles. The transversus abdominis plane compartment is an anatomical plane that contains the T6–L1 thoracolumbar nerves and that can be found between the internal oblique and transversus abdominis muscles.[4] Anteriorly, the compartment is located between the transversus and rectus abdominis muscles.[5] Posterolaterally, as the

ABSTRACT

In this narrative review article, the authors discuss the anatomy, nomenclature, history, approaches (posterior *vs.* lateral vs. subcostal), techniques, pharmacology, indications, and complications of transversus abdominis plane blocks, as well as possible alternative truncal blocks.

Despite the scarcity of evidence and contradictory findings, certain clinical suggestions can nonetheless be made. Overall transversus abdominis plane blocks appear most beneficial in the setting of open appendectomy (posterior or lateral approach). Lateral transversus abdominis plane blocks are not suggested for laparoscopic hysterectomy, laparoscopic appendectomy, or open prostatectomy. However, transversus abdominis plane blocks could serve as an analgesic option for Cesarean delivery (posterior or lateral approach) and open colorectal section (subcostal or lateral approach) if there exist contraindications to intrathecal morphine and thoracic epidural analgesia, respectively.

Future investigation is required to compare posterior and subcostal transversus abdominis plane blocks in clinical settings. Furthermore, posterior transversus abdominis plane blocks should be investigated for surgical interventions in which their lateral counterparts have proven not to be beneficial (*e.g.*, laparoscopic hysterectomy/appendectomy, open prostatectomy). More importantly, because posterior transversus abdominis plane blocks can purportedly provide sympathetic blockade and visceral analgesia, they should be compared with thoracic epidural analgesia for open colorectal surgery. Finally, transversus abdominis plane blocks should be compared with newer truncal blocks (*e.g.*, erector spinae plane and quadratus lumborum blocks) with well-designed and adequately powered trials.

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rectus abdominis tapers to an end, the transversus abdominis plane compartment can be found between the internal oblique and transversus abdominis muscles.

Immediately after exiting from their respective intervertebral foramina, spinal nerves divide into anterior and posterior rami (fig. 1).[6] In turn, the anterior ramus gives off two main branches: the anterior and lateral cutaneous nerves. The anterior cutaneous branch (from the T6–T11 segments) gives rise to intercostal nerves, which supply the skin and muscles of the anterior abdominal wall.[4] The T6–T8 intercostal nerves initially travel between the innermost and internal intercostal muscles before entering the transversus abdominis plane compartment at the level of the costal margin.[4] In the transversus abdominis plane compartment, intercostal nerves display extensive interconnections and anastomosis to form the upper (cephalad) portion of the transversus abdominis plane plexus. The T9–T11 intercostal and T12 subcostal nerves penetrate the transversus abdominis plane compartment posterior to the midaxillary line.[7] They also interconnect
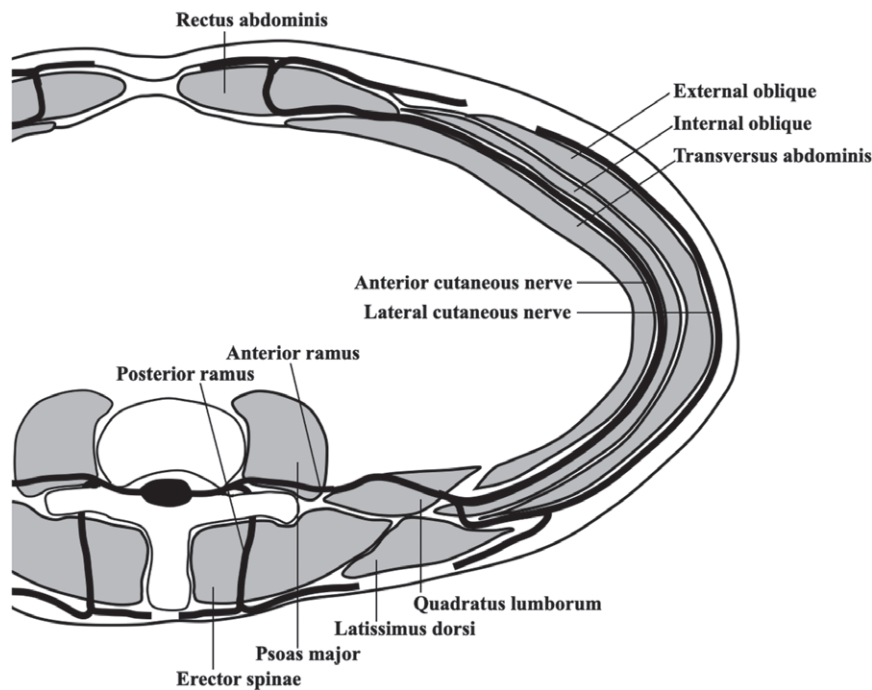

Fig. 1. Transverse section of the lower abdominal wall (at the T12 level) demonstrating the course of a thoracolumbar nerve.

with each other and form the lower (caudad) portion of the transversus abdominis plane plexus. The latter runs along the deep circumflex iliac artery[4] and enters the rectus sheath at the lateral edge of the rectus abdominis muscle. Within the rectus sheath, the neural plexus runs along the deep inferior epigastric artery. The lower thoracic intercostal and subcostal nerves innervate the skin of the infra–umbilical area between the midline and midclavicular lines.

The lateral cutaneous branches of the T6–T11 spinal nerves depart from their respective anterior rami near the angle of the rib, or around the midaxillary line.[3,5,6] Thus, the lateral cutaneous branches arise before the main nerves penetrate the lateral transversus abdominis plane compartment (fig. 1). They supply the skin over the lateral abdominal wall between the costal margin and iliac crest.[5,6,8]

The L1 spinal nerve divides into iliohypogastric and ilioinguinal nerves. Both leave the transversus abdominis plane compartment anterior to the middle third of the iliac crest and lie ventral to the internal oblique muscle and medial to the anterosuperior iliac spine. These nerves supply the anterior abdomen at the level of the inguinal area and the medial thigh.[5,9]

Nomenclature of Transversus Abdominis Plane Blocks

The transversus abdominis plane compartment can be accessed using various approaches and techniques. For the purposes of this review article, the term *approach* refers to

the anatomical site *where* the transversus abdominis plane compartment is targeted. The term *technique* refers to *how* (*i.e.*, loss-of-resistance, ultrasound guidance, direct surgical vision) the compartment is identified for a given approach.

The nomenclature pertaining to approaches remains controversial.[10] For the sake of simplicity and clarity, the current review employs a modified version of the 2015 classification proposed by Hebbard.[11] The *subcostal* approach targets the transversus abdominis plane compartment in the anterior abdominal wall (beneath the costal margin as its name implies) anywhere between the xyphoid process[12] and the anterosuperior iliac spine (fig. 2).[13] The *lateral* approach targets the transversus abdominis plane compartment in the lateral abdominal wall between the midaxillary[14] and anterior axillary[15] lines (fig. 3). Finally, the *posterior* approach targets the transversus abdominis plane compartment at the level of the lumbar triangle of Petit[1] or the anterolateral aspect of the quadratus lumborum muscle (fig. 4).[16]

History of Transversus Abdominis Plane Blocks

Beyond simple academic interest, a discussion of the circuitous history of transversus abdominis plane blocks allows clinicians to understand the practical problems that led to the development of the different approaches. Furthermore, the chronology eloquently illustrates the possible continuum that exists between (posterior) transversus abdominis plane blocks and its more modern counterparts (*e.g.*, quadratus lumborum blocks).
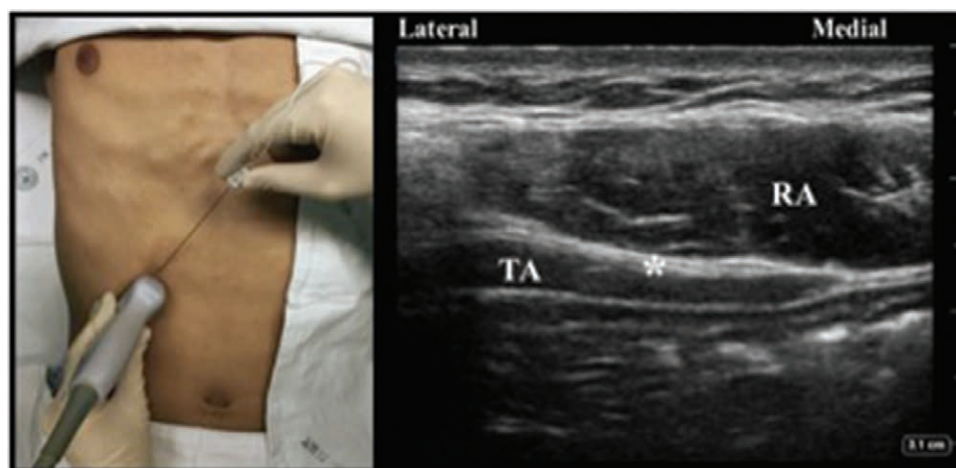
Fig. 2. Ultrasound probe position, needle puncture site, and sonographic image of the subcostal transversus abdominis plane block. Asterisk indicates needle target; RA, rectus abdominis muscle; TA, transversus abdominis muscle.
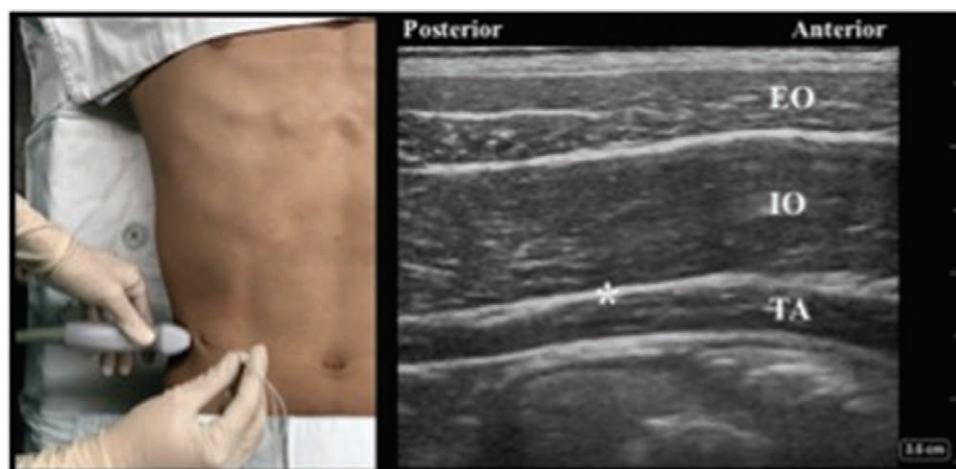

Fig. 3. Ultrasound probe position, needle puncture site, and sonographic image of the lateral transversus abdominis plane block. Asterisk indicates needle target; EO, external oblique muscle; IO, internal oblique muscle; TA, transversus abdominis muscle.

The first description of transversus abdominis plane block is generally credited to Rafi, who, in 2001, advocated the performance of abdominal field block at the level of the lumbar triangle of Petit. Rafi suggested using a blunt needle and a single pop sensation to identify the intermuscular plane between the internal oblique and transversus abdominis muscles, a compartment purported to contain the 7th to 11th intercostal nerves, the subcostal nerve, as well as the ilioinguinal and iliohypogastric nerves.[1] In 2006, O'Donnell[17] introduced the term *transversus abdominis plane block* into the literature. He also modified Rafi's original description by advocating a double pop technique to identify the planes between fascial extensions of the external oblique muscle and the internal oblique muscle (first pop),[18] and between the internal oblique and transversus abdominis muscles (second pop).[17]

The next technical development occurred in 2007: because the triangle of Petit can be difficult to identify in obese patients (because of its increased depth) and elderly subjects (because of a loss in muscle mass), Hebbard *et al.*[14] advocated the use of ultrasound guidance to identify the different intermuscular planes. Hebbard *et al.*[14] also favored a puncture site on the midaxillary line (instead of the triangle of Petit) to facilitate visualization of the abdominal wall. The technique proposed by Hebbard *et al.*[14] was indeed easy to master, as experience with only 16 blocks was required

Fig. 4. Ultrasound probe position, needle puncture site, and sonographic image of the posterior transversus abdominis plane block. Asterisk indicates needle target; EO, external oblique muscle; IO, internal oblique muscle; LD, latissimus dorsi muscle; QL, quadratus lumborum muscle; TA, transversus abdominis muscle.

to achieve 90% proficiency.[19] Unfortunately, clinical experience[12,20] and cadaveric investigation[21] soon revealed that lateral transversus abdominis plane blocks cover mainly the T10 to L1 dermatomes, thereby confining their usefulness to lower abdominal surgery.

Dissatisfaction with the lateral approach spearheaded the search for better alternatives. Two (opposite) schools of thought arose. In one camp, propelled by Hebbard's subsequent 2008 report,[12] operators started experimenting with an ultrasound-guided subcostal approach for transversus abdominis plane blocks. With this method, the initial needle insertion begins near the xyphoid process and the local anesthetic is deposited between the rectus abdominis and transversus abdominis muscles. Subsequently, the needle is directed inferolaterally along the costal margin toward the anterosuperior iliac spine with incremental local anesthetic injection to distend the transversus abdominis plane compartment.[12] A 2010 confirmatory study by Lee *et al.*[22] demonstrated that, compared with its lateral counterpart, the new subcostal approach anesthetized an increased number of dermatomes (4 *vs.* 3) and yielded a higher peak of sensory blockade (T8 *vs.* T10).

In contrast, proponents of the ultrasound-guided posterior approach advocated displacing the puncture site posterior to the midaxillary line to target the anterolateral border of the quadratus lumborum muscle. The earliest description of posterior transversus abdominis plane blocks can be traced back to a 2011 study by Carney *et al.*[16] In it, the authors credited a personal communication with Dr. Rafael Blanco for the concept. In Carney *et al.*'s study, volunteers underwent ultrasound-guided posterior transversus abdominis plane blocks: local anesthetic and contrast solution were deposited at the intersection of the oblique/transversus abdominis muscles and the quadratus lumborum muscle, superficial to the transversalis

fascia. On subsequent magnetic resonance imaging, contrast spread reached the T6–T10 paravertebral spaces.[16] These findings seem to suggest that the mechanism of action of the posterior approach could be dual: blockade of the thoracolumbar nerves in the transversus abdominis plane compartment and local anesthetic spread around the quadratus lumborum muscle to the paravertebral space. Interestingly, the injection site posterior to the midaxillary line was not only reminiscent of Rafi's[1] original description but also of the lateral (*i.e.*, type 1) quadratus lumborum block described by Blanco.[23] This has prompted some authors to ponder whether the posterior transversus abdominis plane block is in fact a mislabeled quadratus lumborum block.[24] Such a parallel appears logical but remains unproven, as preliminary studies revealed that, contrarily to posterior transversus abdominis plane blocks,[16] local anesthetic injected in the setting of lateral quadratus lumborum blocks does not spread to the paravertebral spaces.[25,26]

In summary, the landmark-guided posterior approach constitutes the original method for transversus abdominis plane block. Over the last decade, technical difficulty and the search for more extensive (upper) abdominal wall anesthesia led to the subsequent development of ultrasound-guided lateral and subcostal approaches, respectively. In recent years, things seem to have come full circle with the (re)discovery of the (ultrasound-guided) posterior approach. The latter may share some similarities with the lateral quadratus lumborum block.

Approaches and Techniques for Transversus Abdominis Plane Blocks

Optimal Approach for Transversus Abdominis Plane Blocks

Before 2014, no randomized trial had compared the subcostal, lateral, and posterior approaches head-to-head in

clinical settings, and much of the knowledge was inferred from cadaveric[27] and volunteer[16,22] investigations as well as meta-analyses.[28] For instance, in a cadaveric study (n = 13), Milan et al.[27] injected 40 ml of dye under direct vision in the subcostal, lateral and posterior transversus abdominis plane compartments. These authors then traced the area of dye spread onto clear plastic, which was then photographed. Milan et al.[27] found that the spread was greatest for the subcostal approach (85 cm²) followed by its posterior (78 cm²) and lateral (59 cm²) counterparts, with statistical significance reached for the difference between subcostal and lateral approaches. These findings echoed the results of a 2010 volunteer study by Lee et al.,[22] who reported a higher number of dermatomes (4 vs. 3) anesthetized with the subcostal compared to the lateral approach.

Based on preliminary studies, the pattern of spread also seems to differ between approaches. In a volunteer study, Carney et al.[16] observed (with magnetic resonance imaging) that levobupivacaine-gadolinium injected with the lateral and subcostal approaches remained in the transversus abdominis plane compartment. In contrast, the mixture reached the quadratus lumborum muscle and T5–L1 paravertebral spaces with the posterior approach. Subsequently, in a 2013 meta-analysis, Abdallah et al.[28] reported that, compared with placebo, the posterior approach results in decreased pain and breakthrough opioid consumption during the first 48 h after lower abdominal surgery. Such benefits do not seem to occur with the lateral approach.[28] Abdallah et al.[28] speculated that the improved pain control seen with posterior transversus abdominis plane blocks stems from paravertebral local anesthetic spread, which results in sympathetic block and, consequently, improved visceral analgesia.

Since 2014, six randomized controlled trials have compared the different approaches for transversus abdominis plane blocks in the setting of laparoscopic cholecystectomy[29–32] Cesarean delivery[33] and laparoscopic gynecologic surgery.[34] Overall, these randomized controlled trials confirmed the knowledge derived from previous volunteer and cadaveric studies. For instance, in four trials, compared with their subcostal counterparts, lateral transversus abdominis plane blocks expectedly resulted in higher pain scores during the first 24 h after laparoscopic cholecystectomy.[29–32] Furthermore, lateral transversus abdominis plane blocks anesthetized fewer dermatomes[34] and also proved inferior to posterior transversus abdominis plane blocks for Cesarean delivery due to increased pain scores at rest (during the first 24 h), shorter analgesic duration and decreased patient satisfaction.[33]

In summary, based on the current knowledge, we suggest using the subcostal and posterior approaches instead of the lateral approach. Future randomized investigation is required to compare subcostal and posterior transversus abdominis plane blocks. In recent years, to circumvent the shortcomings associated with the lateral approach, some operators have advocated combining the latter with the subcostal approach thereby creating a multiple quadrant injection method.[35–37] Although this strategy results in more widespread dermatomal anesthesia than the targeted lateral approach,[36] we suggest caution with local anesthetic dosing, especially in subsets of patients at risk for local anesthetic systemic toxicity (e.g., elderly, children, individuals with low muscle masses). One possible strategy consists in retaining conventional volumes of local anesthetic but using more dilute concentrations (e.g., bupivacaine 0.2%) with epinephrine.

Optimal Technique for Transversus Abdominis Plane Blocks

The transversus abdominis plane compartment can be located with landmarks or ultrasound guidance. Alternately, it can also be identified intraoperatively by surgeons.

To date, the landmark-guided technique has been used exclusively for the posterior approach.[1,8,17] Although still employed by some authors,[38] it can be fraught with technical challenges. The landmark-guided technique requires two fundamental steps: identification of the lumbar triangle of Petit and recognition of the intermuscular plane between the internal oblique and transversus abdominis muscles with tactile pops. Unfortunately, the triangle of Petit can be difficult to palpate in obese patients,[1,39] and its position varies significantly between individuals.[7,40] Furthermore, in 17.5% of patients, it can be absent because the external oblique overrides the latissimus dorsi muscle.[41] To complicate matters further, the technical endpoint (pop sensation) remains debated. Although some experts advocate the search of two distinct pops,[17] others use only a single pop, as the initial crossing of fascial extensions of the external oblique muscle (theoretically the first pop) may be too subtle to be felt.[38] In fact, in 36 patients undergoing bilateral transversus abdominis plane blocks, McDermott et al.[42] reported that the double pop endpoint resulted in correct needle position in only 24% of cases (as assessed by ultrasound guidance). Alarmingly, in 18% of the time, the needle tip inadvertently breached the peritoneum.[42] Thus, despite the lack of randomized controlled trials comparing landmark and ultrasound techniques, the potential for visceral injury[43] has led many authors to favor the use of ultrasound guidance for transversus abdominis plane blocks.[42,44,45]

To date, no randomized, controlled trial has investigated the optimal technique for ultrasound-guided transversus abdominis plane blocks in clinical settings. However, preliminary cadaveric studies suggest that, for the lateral approach, a minimal volume of 15 ml is required[46] and, for the subcostal approach, a multiple-injection technique (along the costal margin) provides more extensive coverage than its single injection counterpart.[47]

In 2010, West et al.[48] and Araco et al.[49] described for the first time the intraoperative performance of transversus abdominis plane blocks by surgeons. Since these initial

reports, multiple instances of surgical transversus abdominis plane blocks have been published. In fact, the number of permutations of transversus abdominis plane blocks is much greater with surgical than with (anesthesiologist–driven) percutaneous methods. For instance, like anesthesiologists, surgeons can target all three (subcostal, lateral, and posterior) transversus abdominis plane compartments[48,50] in the setting of open (laparotomy)[48] or laparoscopic[51] incisions. However, they can also perform transversus abdominis plane blocks by going through the abdominal wall[48,50,51] or through the peritoneum.[52,53] Furthermore, unlike anesthesiologists, they can identify the transversus abdominis plane compartment using conventional tactile feel,[48] intraoperative ultrasound,[54] or direct vision with actual dissection of the oblique muscles[49] or peritoneum.[55] Unfortunately, no trial has elucidated the optimal technique for surgical transversus abdominis plane blocks.

To date, four randomized controlled trials (Jadad scores of at least 3) have compared surgeon- and anesthesiologist-performed transversus abdominis plane blocks.[56–59] In three studies investigating subcostal transversus abdominis plane blocks performed for laparoscopic cholecystectomy,[56] and lateral transversus abdominis plane blocks performed for Cesarean delivery[58] or laparoscopic colorectal surgery,[57] surgical and anesthesiologist-driven transversus abdominis plane blocks provided similar postoperative analgesia and breakthrough opioid consumption. However the surgical technique resulted in a 60 to 80% decrease in performance time.[56,58] In contrast, in one trial investigating minimally invasive colorectal surgery, surgical lateral transversus abdominis plane blocks resulted in similar pain scores but 17.2-mg-lower intravenous morphine consumption at 48 h than their anesthesiologist–performed counterparts.[59]

In summary, based on the current knowledge, we suggest foregoing landmark guidance in favor of ultrasound for the performance transversus abdominis plane blocks. Surgical transversus abdominis plane blocks constitute an interesting alternative to their anesthesiologist-performed counterparts, as they result in comparable analgesia but require a shorter performance time. Further investigation is required to elucidate the optimal technique for ultrasound as well as surgical transversus abdominis plane blocks.

Pharmacology of Transversus Abdominis Plane Blocks

Transversus abdominis plane blocks display rapid first phase absorption kinetics,[60–63] and can lead to elevated plasmatic concentrations of total and unbound fractions of local anesthetic. Compared with other truncal blocks (*e.g.*, rectus sheath block), transversus abdominis plane blocks may result in a 50% shorter time to maximum serum concentration. The latter most likely stems from the large, highly vascularized absorptive surface area.[62,64] Furthermore, accidental intramuscular injection (inside the internal oblique or transversus abdominis muscle) could lead to even faster local anesthetic uptake.[65] All these factors may predispose to local anesthetic systemic toxicity.[66,67]

Pharmacokinetics of Single Dose of Local Anesthetic

Multiple trials have assessed local anesthetic plasmatic concentrations after boluses of ropivacaine,[36,60–63,68–74] levobupivacaine,[75–78] and bupivacaine.[79,80] The reported mean time to maximum serum concentration ranged from 10 to 35 min. However delayed absorption can occasionally occur with a time to maximum serum concentration as high as 240 min.[79] With increasing local anesthetic doses, a clear dose–dependent trend in maximum plasma concentration emerges. However the time to maximum serum concentration remains constant.[80]

Although local anesthetic plasmatic levels often exceed known toxic thresholds in many cases, only a minority of patients seems to display signs of local anesthetic toxicity. This could be explained by the fact that, in many trials, patients were under general anesthesia at the time of maximum plasma concentration. Interestingly, many reported cases of local anesthetic toxicity originate from two trials performed in obstetrical patients undergoing Cesarean delivery.[69,80] This strengthens the argument that the calculation of local anesthetic dosing should perhaps be based on lean rather than real (*i.e.*, pregnant) body weight.[66,69] Conversely, elevated plasma levels have been reported in patients receiving doses that would traditionally be considered safe (*e.g.*, 2.1 mg/kg of ropivacaine).[68] Therefore the discrepancy between local anesthetic dosage and (toxic) plasma levels underscores the complex interaction between bound and unbound local anesthetic concentrations.[68,80]

The impact of epinephrine (up to 5 μg/ml) on local anesthetic systemic absorption for transversus abdominis plane block has been addressed in two studies. These trials demonstrated 35% maximum plasma concentration decreases and time to maximum serum concentration prolongations ranging from 18.5 to 44 min with the addition of epinephrine to the local anesthetic mix.[62,75]

Pharmacokinetics of Continuous Infusion of Local Anesthetic

To date, only two trials have investigated local anesthetic pharmacokinetics in the setting of continuous transversus abdominis plane blocks.[81,82] In these studies, the time to maximum serum concentration for the infusion occurred at 48 h and 72 h for the subcostal and posterior approach, respectively. However, the unbound maximum plasma concentration peaked earlier (within 24 h) and remained steady thereafter.

Optimal Local Anesthetic Agent

To date, one randomized controlled trial (published in English) has investigated the optimal local anesthetic for transversus abdominis plane blocks. In 2016, Sinha *et al.*[83] compared bupivacaine 0.25% and ropivacaine 0.375% for transversus abdominis plane blocks in patients undergoing

laparoscopic cholecystectomy. Although the ropivacaine group displayed lower pain scores during the first postoperative hour, both drugs were equivalent in terms of the 24-h cumulative analgesic requirement.[83]

Optimal Local Anesthetic Dose

When it comes to the selection of an optimal local anesthetic dose for transversus abdominis plane blocks, little definitive information is available. A recent meta-analysis compared high dose (greater than 50 mg of bupivacaine equivalents) with low dose (less than or equal to 50 mg of bupivacaine equivalents) of long-acting local anesthetic and found no intergroup differences in terms of analgesia, 6-h or 24-h opioid consumption, time to first analgesic request, and patient satisfaction.[84] To date, very few dose-finding studies have investigated the ED50 for transversus abdominis plane blocks. This dearth of evidence may be attributed to the difficulty in carrying out such studies in light of the significant interindividual variability in analgesic effect. In one trial, the ED50 for ropivacaine in adults was 2.7 mg/kg, a dose for which toxicity has been previously reported.[85] In children, the ED50 of levobupivacaine was found to be 0.22 mg/kg,[86] and the EC50 of bupivacaine, 0.08239%.[87]

Local anesthetic dose constitutes the mathematical product of concentration and volume. In the literature, multiple trials have compared different local anesthetic concentrations (using constant volumes). Overall, these studies revealed minimal differences between low (0.125 to 0.25%) and high (0.5 to 0.75%) concentrations of bupivacaine, levobupivacaine, and ropivacaine in terms of postoperative pain and rescue analgesic consumption.[88–94] In terms of volume, large injectates (15 to 30 ml per side in adults; 0.1 to 1 ml/kg per side in children) are commonly used to ensure adequate local anesthetic spread for transversus abdominis plane blocks.[78,79,84,95] Although the minimal effective volume remains unknown, a trend toward superior analgesia was demonstrated with at least 15 ml per side in a meta-analysis conducted by Abdallah *et al.*[96] These findings concord with those of a subsequent cadaveric study, which reported that, compared with lower volumes, 15 ml can provide more extensive cephalo-caudal spread.[46] Finally, the overall local anesthetic dose seems to matter more than either concentration or volume alone, as differences in volumes carry minimal analgesic impact in the setting of a constant local anesthetic dose.[78,97,98]

Optimal Local Anesthetic Infusion Strategy

In the literature, two trials have compared continuous local anesthetic infusion with intermittent local anesthetic boluses (without a background infusion). In the first study, compared with a continuous infusion (8 ml/h of ropivacaine 0.2%), 20-ml aliquots every 8 h proved to be more economical because of lower local anesthetic daily requirement.[99] Furthermore, the intermittent bolus-group maintained similar block coverage on postoperative days 1 and 2, whereas its continuous infusion counterpart displayed a regression of two dermatomal segments.[99] A second trial simultaneously applied both strategies in volunteers[100]; one side received a continuous infusion of ropivacaine 0.2% at 8 ml/h, whereas the other side received intermittent boluses (24 ml of ropivacaine 0.2% every 3 h). The primary outcome, block extension at 6 h, was similar in both groups; however, there was a significant difference at various time points between 0 and 5 h favoring intermittent boluses.

Optimal Adjuvants

In the literature, several adjuvants (*i.e.*, dexamethasone, alpha-2 agonists, magnesium, opioids, liposomal formulation) have been investigated to prolong the duration of transversus abdominis plane blocks.

Dexamethasone is commonly used for peripheral nerve blocks.[101] A 2018 meta-analysis concluded that, compared with saline, perineural dexamethasone (4 to 8 mg) can increase the duration of transversus abdominis plane blocks by almost 3 h while reducing breakthrough analgesic consumption and postoperative nausea and vomiting.[102] To date, the optimal dose and mode of administration (intravenous *vs.* perineural) have not been investigated for transversus abdominis plane blocks.

Alpha-2 agonists (*i.e.*, clonidine and dexmedetomidine) have also been used as adjuvants for transversus abdominis plane blocks. Clonidine has been investigated in the setting of transversus abdominis plane blocks performed for Cesarean delivery. Compared with plain bupivacaine, analgesia was prolonged by 10 h with the simple addition of clonidine (1 ug/kg per side); however, sedation occurred in almost one third of patients.[103] In the case of dexmedetomidine, studied doses include both weight-based regimens (*i.e.*, 0.5 to 1 μg/kg per side) and fixed dosing (*i.e.*, 100 μg per side). A 2018 meta-analysis reported significant reductions in pain scores at rest and on movement with the addition of dexmedetomidine for transversus abdominis plane blocks.[104] However, dexmedetomidine may result in increased sedation during the first postoperative hour as well as a lower heart rate during the first 4 h.[105] Future trials are required to investigate the optimal dose and route of administration (intravenous *vs.* perineural) of dexmedetomidine.

Since 2016, four randomized controlled trials have looked at the role of perineural magnesium for transversus abdominis plane blocks. Compared with control, doses between 0.15 and 0.5 g (per side) provide lower postoperative pain scores (for up to 12 h), longer analgesic duration, and lower morphine consumption.[106–109] Future trials are required to investigate the optimal dose and mode of administration (intravenous *vs.* perineural) of magnesium for transversus abdominis plane blocks.

Finally, two randomized controlled trials conducted by Hutchins *et al.* have investigated the benefits of liposomal bupivacaine.[110,111] Compared with bupivacaine with epinephrine, liposomal bupivacaine (130 mg) resulted in improved analgesia during the study period (72 h) as well as decreased opioid consumption and postoperative nausea or vomiting. To date, no trial has prospectively compared liposomal bupivacaine and continuous transversus abdominis plane blocks.

In summary, based on the current knowledge, we suggest the use of dilute concentrations of local anesthetic (*e.g.*, bupivacaine 0.2 to 0.25% or ropivacaine 0.2 to 0.25%) and injectate volumes of at least 15 ml (per side) for single–injection transversus abdominis plane blocks. For perineural transversus abdominis plane catheters, intermittent boluses (every 8 h) may provide more extensive blockade and higher cost efficiency than continuous local anesthetic infusion. Adjuvants such as dexamethasone, dexmedetomidine, and magnesium can increase the duration of transversus abdominis plane blocks. However, future investigation is required to elucidate their optimal dosing, mode of administration (intravenous *vs.* perineural), and combination. Furthermore, buprenorphine has been reported to prolong peripheral nerve blocks[112] and thus should also be investigated for transversus abdominis plane blocks in terms of efficacy as well as attendant emetic risk. Finally, patients undergoing transversus abdominis plane blocks remain at risk for local anesthetic systemic toxicity. In addition to careful local anesthetic dosing (based on lean weight), the operator should consider adding epinephrine to the local anesthetic mix, and providing patient monitoring for a period exceeding the time to maximum serum concentration (*e.g.*, 40 min).

Clinical Indications for Transversus Abdominis Plane Blocks

In the literature, transversus abdominis plane blocks have been used for a multitude of surgical interventions.[3] The current review article focuses on the most common ones (*i.e.*, Cesarean delivery, laparoscopic cholecystectomy, hysterectomy, colorectal resection, appendectomy, inguinal hernia repair, prostatectomy, and bariatric surgery). To highlight the contemporary evidence, we base our suggestions on systematic reviews or meta-analysis published in 2018 or 2019. In the absence of such recent reviews, we derive our conclusions from the cumulative findings of randomized controlled trials. However, only trials published in PubMed-indexed journals were retained for analysis. This precautionary step was undertaken to minimize the impact of weaker studies published in lower tiered journals. Furthermore, particular attention (discussion) was paid to the control arm of randomized controlled trials, as the validation of transversus abdominis plane blocks (or any block) requires that control subjects receive optimal standard treatment (*e.g.*, thoracic epidural and multimodal analgesia for open and laparoscopic abdominal surgery, respectively). For the purposes of the current review, the term *multimodal analgesia* was defined as the use of at least two nonopioid analgesic agents (*e.g.*, acetaminophen, nonsteroidal antiinflammatory drug, gabapentinoids, ketamine, local anesthetic wound infiltration)[113] in addition to *pro re nata* oral or parenteral opioids.

Cesarean Delivery

Cesarean delivery constitutes the ideal surgical setting to investigate transversus abdominis plane blocks because the conventional Pfannenstiel incision lies in a territory readily anesthetized by the commonly performed lateral approach. Furthermore, because Cesarean section involves uterine incision but not excision, postoperative visceral trauma and pain may (arguably) be less pronounced. To date, Cesarean delivery constitutes the most studied surgery for transversus abdominis plane blocks.[114–133] Unfortunately, the most recent systematic review article investigating the efficacy of transversus abdominis plane blocks for Cesarean section dates back to 2016[134] and thus did not include more recent trials.

Starting with the first trial investigating transversus abdominis plane blocks for Cesarean delivery (2008),[114] multiple randomized controlled trials have concluded that the addition of posterior or lateral transversus abdominis plane blocks to a pharmacologic regimen encompassing acetaminophen, nonsteroidal antiinflammatory drugs and parenteral opioids results in significant analgesic and opioid-sparing benefits.[115,118,120,121,130,132] However subsequent trials revealed that the efficacy of transversus abdominis plane blocks rivals at best that of wound infiltration[126–128,131] and is inferior to that of intrathecal morphine (100 to 200 μg).[117,122] Because the latter is commonly used to provide analgesia for Cesarean delivery, the issue became whether the addition of transversus abdominis plane blocks to multimodal regimens that include long-acting neuraxial opioids would result in supplemental analgesic benefits. Six randomized controlled trials have investigated the question.[116,119,123–125,129] Except for one study,[129] all trials (and the 2016 meta-analysis) concluded that posterior or lateral transversus abdominis plane blocks confer minimal advantages for Cesarean delivery in the setting of conventional doses of intrathecal morphine (*i.e.*, 100 to 250 μg).[116,119,123–125,134]

In summary, based on the current knowledge, we do not suggest the use of posterior or lateral transversus abdominis plane blocks for Cesarean delivery when long-acting intrathecal opioids are incorporated to the multimodal analgesic regimen. However, both approaches remain valuable analgesic options in patients who cannot receive intrathecal morphine or who undergo Cesarean section under general anesthesia.[135,136]

Laparoscopic Cholecystectomy

Laparoscopic cholecystectomy constitutes the second most studied surgery for transversus abdominis plane blocks.[15,29–31,50,88,137–144] The most recent meta-analysis investigating the efficacy of transversus abdominis plane blocks for laparoscopic cholecystectomy dates back to 2016.[145]

Over the last 10 yr, multiple trials have investigated the benefits of lateral transversus abdominis plane blocks in the setting of laparoscopic cholecystectomy with mixed results. Whereas initial trials by El Dalawlatly *et al.*[15] and Ra *et al.*[88] concluded that transversus abdominis plane blocks outperform intravenous morphine, a subsequent study detected no differences between the two analgesic strategies.[144] Furthermore, compared with local anesthetic infiltration of laparoscopic ports, lateral transversus abdominis plane blocks provide only marginal benefits in terms of postoperative pain scores[142] and analgesic duration.[137] In fact, in the context of a multimodal analgesic regimen that included acetaminophen and ibuprofen (as well as patient-controlled intravenous opioids), Petersen *et al.*[138] demonstrated that the benefits of transversus abdominis plane blocks are confined to a small (8 mm on a 0 to 100 mm scale) reduction in pain while coughing and a 2.5-mg decrease in opioid requirement only during the first two postoperative hours.

The contemporary evidence suggests that the subcostal approach consistently outperforms its lateral counterpart in the setting of laparoscopic cholecystectomy.[29–31] Therefore, from a methodologic standpoint, a critical analysis of potential benefits of transversus abdominis plane blocks for laparoscopic cholecystectomy should focus exclusively on the subcostal approach. In the literature, seven randomized controlled trials have compared subcostal transversus abdominis plane blocks with placebo (saline) or no treatment.[29–31,50,139,141,143] Except for one study that only detected a shorter extubation time with transversus abdominis plane blocks,[139] the six other trials unequivocally suggest that subcostal transversus abdominis plane blocks outperform the standard analgesic treatment[29–31,141,143] as well as periportal local anesthetic infiltration[50] with benefits extending up to 24 h postoperatively.[29,141] However, these findings should be interpreted with caution because in none of the six trials did the control group employ a multimodal analgesic regimen that included acetaminophen, nonsteroidal antiinflammatory drugs, and periportal local anesthetic infiltration.[146] Thus, it remains unclear whether, similarly to Cesarean delivery, the benefits of (subcostal) transversus abdominis plane blocks could be negated by multimodal analgesia.

In summary, based on the current knowledge, we suggest further investigation to determine whether (subcostal) transversus abdominis plane blocks provide clinical benefits in the context of a multimodal analgesic regimen that incorporates acetaminophen, nonsteroidal antiinflammatory drugs, and periportal local anesthetic infiltration. We suggest the subcostal approach (instead of its lateral counterpart) if operators elect to perform transversus abdominis plane blocks for laparoscopic cholecystectomy.

Hysterectomy

Transversus abdominis plane blocks have been extensively studied in the context of open[147–159] and laparoscopic hysterectomy.[160–169] In 2018, a meta-analysis authored by Zhou *et al.*[170] examined the benefits of transversus abdominis plane blocks for open and laparoscopic hysterectomy. Zhou *et al.*[170] concluded that, compared with placebo or no block, posterior/lateral transversus abdominis plane blocks result in reduced 24-hr morphine consumption, decreased pain scores at rest and on movement, lower incidences of nausea or vomiting, and increased analgesic duration after open hysterectomy. In contrast, transversus abdominis plane blocks seem to confer minimal benefits after laparoscopic hysterectomy.[170] The following year, Bacal *et al.*[171] decided to carry out a similar meta-analysis. However they limited the scope of investigation to benign disease. Similarly to Zhou *et al.*,[170] Bacal *et al.*[171] concluded that, compared with placebo or no block, posterior or lateral transversus abdominis plane blocks result in decreased early (2 h) and late (24 h) postoperative pain scores as well as a 10-mg lower morphine consumption at 24 h in patients undergoing open hysterectomy. Again, the benefits for laparoscopic hysterectomy seem marginal at best, as lateral transversus abdominis plane blocks can only decrease early postoperative pain.[171]

From a comparative standpoint, most published trials have used acetaminophen or nonsteroidal antiinflammatory drugs or periportal local anesthetic infiltration in the control group. However, none has employed a multimodal regimen that includes gabapentinoids,[172] ketamine, and possibly intrathecal opioids.[173] Thus, future investigation is required to determine whether the benefits of transversus abdominis plane blocks (for open hysterectomy) would survive the implementation of such a multimodal analgesic regimen.

In summary, based on the current knowledge, we do not suggest the use of lateral transversus abdominis plane blocks for laparoscopic hysterectomy. Future trials are needed to determine the benefits of posterior transversus abdominis plane blocks for the latter. Although the current evidence supports the use of posterior and lateral transversus abdominis plane blocks for open hysterectomy, the authors suggest further investigation to determine whether these benefits would still be present in the context of a multimodal analgesic regimen that includes gabapentinoids, ketamine, or intrathecal opioids.

Colorectal Surgery

Transversus abdominis plane blocks have been extensively studied in the settings of open[53,174,175] and laparoscopic colorectal surgery.[176–182] Although a recent meta-analysis has summarized the benefits of transversus abdominis plane blocks for colorectal surgery,[183] the inclusion of both open and laparoscopic procedures constitutes a methodologic limitation, as the two types of interventions display inherently different patterns of postoperative pain and thus should be analyzed separately.

In 2018, Oh *et al.*[184] restricted the scope of their review article to laparoscopic colorectal surgery to investigate the potential benefits of transversus abdominis plane blocks. These authors reported that (lateral) transversus abdominis

plane blocks decrease early and late dynamic pain on movement after laparoscopic colorectal surgery compared with placebo or no treatment, despite similar pain at rest and breakthrough opioid consumption. Although statistically significant, these differences may not be clinically meaningful (0.2 to 0.7 on a 0 to 10 scale).[184] Furthermore, Oh *et al.*'s results should be interpreted with caution, as only two[177,178] of the five trials[176–178,180,181] included for analysis used multimodal analgesia.

For open colorectal surgery, multiple trials have previously demonstrated that, compared with placebo, transversus abdominis plane blocks result in decreased postoperative pain and morphine consumption.[53,174] However, thoracic epidural analgesia is still considered by many to be the criterion analgesic standard for laparotomy: thus the more pertinent clinical question resides in the comparison of transversus abdominis plane and thoracic epidural blocks.[185,186] Randomized trials investigating single-injection transversus abdominis plane blocks and continuous epidural catheters also highlight a second important methodologic issue pertaining to study design. For instance, for upper abdominal surgery (gastrectomy), Wu *et al.*[187] found that low thoracic epidural analgesia proved superior to bilateral subcostal transversus abdominis plane blocks in terms of breakthrough opioid consumption. However, the benefits associated with epidural analgesia seem to become less pronounced in recent years, as authors started using longer acting (liposomal) formulations of bupivacaine.[188–190] Furthermore, preliminary evidence seems to indicate that continuous (subcostal) transversus abdominis plane blocks outperform their single-injection counterparts.[191] These cumulative findings suggest that block duration constitutes an important confounding variable. Therefore, to properly investigate the benefits of transversus abdominis plane blocks for open colorectal surgery, one must compare continuous thoracic epidural blocks with continuous transversus abdominis plane blocks.

To date, three randomized controlled trials have tackled the issue with mixed findings.[192–194] Niraj *et al.*[192] and Ganapathy *et al.*[194] concluded that, compared with their thoracic epidural counterparts, subcostal transversus abdominis plane catheters (with or without concomitant lateral transversus abdominis plane catheters) result in similar analgesia but an increased need for breakthrough analgesics. In contrast, Wahba *et al.*[193] reported that, in patients with ischemic heart disease, thoracic epidural blocks resulted in decreased pain scores, 100-min longer analgesic duration, and 10.5-mg lower intravenous morphine consumption during the first 48 h as well as decreased sedation (during the first 24 h) and improved patient satisfaction (2 points on a 0 to 10 scale). Nonetheless, despite their findings favoring the use of thoracic epidural analgesia, Wahba *et al.*[193] opined that transversus abdominis plane blocks remain a valid analgesic option if thoracic epidural analgesia is contraindicated.

Based on the current understanding, we suggest the use of thoracic epidural analgesia for open colorectal surgery. However, subcostal transversus abdominis plane blocks remain a valid alternative for patients undergoing laparotomy in whom neuraxial blocks are contraindicated. We suggest further investigation to determine whether the benefits of (lateral) transversus abdominis plane blocks for laparoscopic colorectal surgery would persist in the setting of multimodal analgesia.

Appendectomy

To date, three randomized trials have investigated the benefits of transversus abdominis plane blocks for open appendectomy[195–197] and three studies have done the same for laparoscopic appendectomy.[198–200] Overall the findings have been fairly consistent. For open appendectomy, both lateral and posterior transversus abdominis plane blocks have been shown to result in decreased postoperative pain scores at rest and on movement as well as significant reductions in consumption of intravenous morphine (22 mg) and tramadol (78 mg) at 24 h and intravenous morphine (12.3 mg) at 48 h[195–197] despite the use of acetaminophen and diclofenac.[195,196] In contrast, for laparoscopic appendectomy, two trials have concluded that lateral transversus abdominis plane blocks provide no benefit in the setting of multimodal analgesia.[198,200] However, Tanngaard *et al.*[199] were able to obtain a cumulative decrease in static and dynamic pain during the first 12 h by supplementing lateral transversus abdominis plane blocks with subcostal transversus abdominis plane blocks. Because the lateral approach provides minimal benefits for laparoscopic appendectomy,[198,200] Tanngaard *et al.*'s encouraging results could perhaps be attributed to subcostal transversus abdominis plane blocks. Therefore, future trials should assess isolated subcostal as well as posterior transversus abdominis plane blocks in the setting of laparoscopic appendectomy.

Based on the current knowledge, we suggest the use of posterior or lateral transversus abdominis plane blocks for open appendectomy. The current evidence does not support the role of lateral transversus abdominis plane blocks for laparoscopic appendectomy. Further investigation is required to elucidate the potential benefits of subcostal or posterior transversus abdominis plane blocks for laparoscopic appendectomy.

Inguinal Hernia Repair

Transversus abdominis plane blocks have been extensively studied in the context of open[201–206] and laparoscopic inguinal hernia repair.[207–209] The most recent meta-analysis investigating the benefits of transversus abdominis plane blocks for hernia repair dates back to 2017.[210]

For open inguinal repair, lateral or posterior transversus abdominis plane blocks result in lower pain scores and opioid consumption compared with no block[203,206] or wound

infiltration.[201,205] In fact, Petersen *et al.*[202] have shown that lateral transversus abdominis plane blocks provide similar efficacy to ilioinguinal blocks combined with wound infiltration. For laparoscopic inguinal hernia repair, two trials have also found decreased pain and opioid requirement with lateral transversus abdominis plane blocks compared with no block[207] and portal local anesthetic infiltration.[208] However, for bilateral laparoscopic inguinal hernia repair, preperitoneal instillation of local anesthetic outperforms transversus abdominis plane blocks.[209] To date, of all published trials for open and laparoscopic inguinal hernia repair, only one[208] has employed the recommended multimodal regimen, which includes acetaminophen, nonsteroidal antiinflammatory drugs, as well as local anesthetic infiltration.[211] Thus, further investigation is required to determine whether the benefits of transversus abdominis plane blocks would persist despite the implementation of such multimodal analgesia.

In summary, based on the current knowledge, we suggest further investigation to determine whether the benefits of posterior and lateral transversus abdominis plane blocks for open and laparoscopic inguinal hernia repair would persist in the context of a multimodal analgesic regimen that includes acetaminophen, nonsteroidal antiinflammatory drugs, and local anesthetic infiltration.

Prostactectomy

To date, three studies have investigated the efficacy of transversus abdominis plane blocks for open prostatectomy.[212–214] Two of the three trials could not detect significant benefit associated with lateral transversus abdominis plane blocks. Thus, we do not suggest their use for open prostatectomy. However future studies are required to investigate posterior transversus abdominis plane blocks for the latter as well as the potential benefits of transversus abdominis plane blocks for laparoscopic prostatectomy.

Bariatric Surgery

To date, three studies have investigated the efficacy of transversus abdominis plane blocks for (laparoscopic) bariatric surgery.[55,215,216] Two studies reported that transversus abdominis plane blocks result in lower postoperative pain scores and analgesic consumption as well as quicker ambulation and oral intake.[55,215] Although statistically significant, the differences in pain scores (less than 2 on a 0 to 10 scale), intravenous morphine consumption at 24 h (3.1 mg), ambulation (less than or equal to 1.7 h), and oral intake (2.4 h) may not be clinically relevant.[55,215] Interestingly, in the only trial that used a multimodal analgesic regimen (*i.e.*, acetaminophen, ketorolac at the end of surgery, and periportal local anesthetic infiltration), Albrecht *et al.*[216] reported no clinical benefits associated with (subcostal) transversus abdominis plane blocks. Thus, further confirmatory investigation is required to elucidate the benefits of transversus abdominis plane blocks in the setting of multimodal analgesia.

Complications of Transversus Abdominis Plane Blocks

Complications related to transversus abdominis plane blocks can be attributed to the needle or the local anesthetic agent.

In terms of needle-related adverse events, the abdominal wall is sufficiently vascularized to sustain needle trauma, as evidenced by the recent report of a (self-resolving) abdominal wall hematoma in an obstetrical patient with HELLP syndrome.[217] Furthermore, during the performance of transversus abdominis plane blocks, the needle tip can inadvertently traverse the transversus abdominis muscle (and peritoneum) thereby resulting in peritoneal breach and visceral injury.[43,218–220] Interestingly, if the needle tip is positioned just between the transversus abdominis muscle and the transversalis fascia (without puncturing the peritoneum), local anesthetic injection could result in transient femoral nerve blockade because the fascia iliaca constitutes the posterolateral continuation of the transversalis fascia.[221–223] The preceding complications underscore the importance of visualizing the entire length of the needle during the performance of ultrasound–guided transversus abdominis plane blocks.[224]

Because transversus abdominis plane blocks require relatively large injectates and are often carried out bilaterally, local anesthetic systemic toxicity remains a concern especially in elderly patients or those with decreased muscle mass. There exist multiple reports of local anesthetic systemic toxicity after the administration of (levo) bupivacaine (2.7 to 2.9 mg/kg)[225,226] as well as ropivacaine (4.9 to 7.9 mg/kg)[226,227] for transversus abdominis plane blocks. In none of these cases did the operators use adjunctive epinephrine to curtail local anesthetic plasmatic absorption.[228] Furthermore, in one report,[225] the 2.9-mg/kg dose of bupivacaine was administered to a patient experiencing acute fatty liver of pregnancy, a condition known to increase the free fraction of plasma bupivacaine (attributable to a decreased production of local anesthetic-binding serum proteins).[225] The prohibitively supratoxic dose (7.9 mg/kg) of ropivacaine reported by Sherrer *et al.*[227] stemmed from a lack of communication between surgeon and anesthesiologist, as the former carried out intraperitoneal local anesthetic infiltration (using 20 ml of ropivacaine 0.75%) before the latter's performance of transversus abdominis plane blocks (using 40 ml of ropivacaine 0.75%). Finally, local anesthetic injection in the transversus abdominis plane compartment may result in motor block of the thoracolumbar nerves. In turn, this could result in paresis of the abdominal muscles as evidenced by a bulge in the abdominal wall when the patient coughs or bears down.[229,230] In both reported cases, the bulge subsided uneventfully as the transversus abdominis plane block wore off.[229,230]

In summary, based on the current knowledge, care must be taken to visualize the entire length of the needle during the performance of transversus abdominis plane blocks to prevent breaching the transversus abdominis muscle and the

peritoneum thereby minimizing the risk of femoral blockade and visceral injury. Furthermore, a thorough analysis of risks and benefits must be undertaken before the performance of transversus abdominis plane blocks in coagulopathic patients. Finally, in addition to respecting ceiling doses of local anesthetic, the prudent anesthesiologist should consider using dilute local anesthetic concentrations as well as adjunctive epinephrine to delay local anesthetic plasmatic absorption, especially in subsets of patients at risk for local anesthetic systemic toxicity. Moreover, communication between surgeon and anesthesiologist is paramount to avoid supratoxic cumulative doses resulting from concomitant local anesthetic infiltration and transversus abdominis plane blocks.

Alternative Truncal Blocks

From an anatomical standpoint, abdominal truncal blocks can performed anywhere from neuraxial (*i.e.*, caudal block) and paraneuraxial (*e.g.*, thoracic paravertebral block, erector spinae plane block, retrolaminar, transmuscular quadratus lumborum blocks) locations to terminal compartments (*e.g.*, rectus sheath block) or terminal neural targets (*i.e.*, ilioinguinal and iliohypgastric nerve). To date, transversus abdominis plane blocks have been compared with a plethora of alternatives such as caudal blocks,[231–233] thoracic paravertebral blocks,[234] quadratus lumborum blocks,[235–238] rectus sheath blocks,[63,64,159,239] and ilioinguinal and iliohypogastric nerve blocks.[233,240–244] To highlight the best evidence, only randomized controlled trials published in PubMed-indexed journals were retained for analysis.

Transversus Abdominis Plane Block *versus* Caudal Block (in Pediatric Patients)

Three randomized trials have compared ultrasound-guided (lateral or posterior) transversus abdominis plane blocks and (landmark- or ultrasound-guided) caudal blocks in children undergoing lower abdominal surgery (*i.e.*, ureteroneocystostomy, herniorrahphy, orchidopexy, hydrocelectomy, testicular detorsion).[231–233] In two trials, transversus abdominis plane blocks resulted in significant advantages compared with caudal blocks, as patients required less breakthrough intravenous morphine (0.05 mg/kg *vs.* 0.09 mg/kg) at 24 h.[231] Furthermore, fewer children reported pain during the 6-h to 24-h postoperative interval (44% *vs.* 75%).[232] However, one trial failed to detect significant differences between transversus abdominis plane and caudal blocks in terms of pain and analgesic consumption.[233]

Transversus Abdominis Plane Block *versus* Thoracic Paravertebral Block

To date, only one trial has compared lateral transversus abdominis plane and thoracic paravertebral blocks. In 2012, Melnikov *et al.*[234] compared bilateral ultrasound-guided lateral transversus abdominis plane blocks with bilateral T10 thoracic paravertebral blocks in patients undergoing vertical laparotomy for total hysterectomy with salpingo-oophorectomy. Although the transversus abdominis plane group displayed a significant higher cumulative opioid (ketomebidon) consumption at 24 and 48 h, there were no intergroup differences in terms of pain scores and patient satisfaction.[234]

Transversus Abdominis Plane Block *versus* Quadratus Lumborum Block

Four randomized trials have compared ultrasound-guided lateral transversus abdominis plane blocks and quadratus lumborum blocks (with local anesthetic injection on the anterolateral aspect of the quadratus lumborum muscle) with similar results.[235–238] In the setting of Cesarean section, open hysterectomy, inguinal hernia, orchiopexy, and lower abdominal surgery, quadratus lumborum blocks result in 2.5- to 7.5-mg decreases in morphine consumption at 24 h compared with their transversus abdominis plane counterparts.[235,237,238] Furthermore, three of the four trials also found lower pain scores[236–238] and two studies reported 80% longer analgesic duration with quadratus lumborum blocks.[237,238]

Transversus Abdominis Plane Block *versus* Rectus Sheath Block

To date, two small pharmacologic trials (combined n = 72) have compared lateral ultrasound-guided transversus abdominis plane blocks and rectus sheath blocks in patients undergoing laparoscopic gynecologic surgery.[63,64] Both studies reported that transversus abdominis plane blocks displayed a 34% to 47% earlier peak of local anesthetic plasma levels. Whereas one trial found no differences in postoperative analgesia,[64] the other one observed longer postoperative analgesia in the transversus abdominis plane group.[63] In a recent trial, Abo-Zeid *et al.*[239] also reported longer analgesic duration (and lower breakthrough opioid consumption) after abdominoplasty with lateral transversus abdominis plane blocks compared with rectus sheath blocks. In 2017, Cowlishaw *et al.*[159] compared continuous subcostal transversus abdominis plane blocks (inserted with ultrasound guidance by anesthesiologists) and rectus sheath blocks (inserted under direct vision by surgeons) in patients undergoing midline laparotomy for gynecologic oncologic surgery. These authors found no intergroup differences in terms of postoperative pain and breakthrough opioid consumption.[159]

The analgesic difference between transversus abdominis plane and rectus sheath blocks could be partly ascribed to the site of surgical incision. Because rectus sheath blocks anesthetize somatic structures confined to the territory of the rectus abdominis muscle, their clinical usefulness may be highest in the setting of midline laparotomy (as evidenced by Cowlishaw *et al.*'s results[159]). In contrast, when the surgical incision exceeds the confines of the rectus abdominis muscle (*e.g.*, laparoscopic gynecologic surgery[63] or abdominoplasty,[239]) transversus abdominis plane blocks may offer improved versatility.

Transversus Abdominis Plane Blocks *versus* Ilioinguinal and Iliohypgastric Nerve Block

To date, five trials have compared lateral transversus abdominis plane blocks and ilioinguinal and iliohypogastric nerve blocks in the setting of inguinal hernia repair with mixed results.[233,240–242,244] In two randomized controlled trials, transversus abdominis plane blocks provided better postoperative analgesia than ilioinguinal and iliohypogastric nerve blocks.[233,241] However, the results of these two studies should be interpreted with caution, as one trial carried out ilioinguinal and iliohypogastric blocks with a blind technique,[240] whereas the other attributed its findings to the operators' lack of experience with ilioinguinal and iliohypogastric nerve blocks.[233] In fact, studies by Fredrickson *et al.*[240] and Kamal *et al.*[244] concluded that, when performed with ultrasound guidance, ilioinguinal and iliohypogastric nerve blocks result in superior postoperative analgesia[240] as well as 28% longer analgesic duration[244] and lower breakthrough analgesic consumption[240,244] than lateral transversus abdominis plane blocks. To complicate matters further, Okur *et al.*[242] recently found minimal differences between the two blocks.

In 2017, one trial compared bilateral lateral transversus abdominis plane blocks with bilateral ilioinguinal and iliohypogastric nerve blocks for patients undergoing Cesarean delivery.[243] Although postoperative pain scores were similar in both groups, patients allocated to transversus abdominis plane blocks required 1,000 mg less breakthrough tramadol during the first 24 h.

In summary, based on the current knowledge, we suggest the use of lateral quadratus lumborum blocks over lateral transversus abdominis plane blocks for lower abdominal surgery (*e.g.*, Cesarean delivery, hysterectomy, inguinal herniorraphy and orichiopexy surgery). In light of contradictory or preliminary findings, further trials are required to compare lateral and posterior transversus abdominis plane blocks with caudal blocks, thoracic paravertebral blocks, rectus sheath blocks, and ilioinguinal and iliohypogastric nerve blocks.

Current Knowledge and Future Research

In summary, over the last 18 yr, transversus abdominis plane blocks have been the topic of considerable research. At times, the collective results of published trials can be difficult to interpret in light of two important confounding variables. First, the term *transversus abdominis plane block* encompasses various approaches that result in radically different somatic and visceral coverage. For instance, whereas the lateral approach can be used for infraumbilical surgery, its subcostal counterpart should be preferred for procedures involving the upper abdomen. Furthermore, of the three described approaches, only the posterior one can achieve local anesthetic spread to the paravertebral spaces, thereby providing sympathetic blockade and visceral analgesia. Therefore any positive (analgesic) outcome related to transversus abdominis plane block should be viewed as approach-specific. Conversely, even if a given approach fails to provide benefits for a surgical intervention, it should not deter operators (and researchers) from exploring an alternative approach. Second, the findings of any comparative trial axiomatically depend on the control group. Because multimodal analgesia has become normative in clinical practice, trials involving transversus abdominis plane blocks that omitted its use in their control group leave many questions unanswered. One need only think of the fact that the initial benefits reported with transversus abdominis plane blocks after Cesarean delivery quickly dissipated when intrathecal morphine was incorporated to the standard analgesic regimen. Unfortunately, to date, many published trials have either compared transversus abdominis plane blocks with no treatment or failed to provide adequate multimodal analgesia to their control groups.

Despite the contradictory findings, scarcity of evidence, and shortcomings afflicting some randomized controlled trials, certain clinical suggestions can nonetheless be made (table 1). Overall, transversus abdominis plane blocks appear most beneficial in the setting of open appendectomy (posterior or lateral approach). Lateral transversus abdominis plane blocks are not suggested for laparoscopic hysterectomy, laparoscopic appendectomy, and open prostatectomy. However, transversus abdominis plane blocks could serve as an analgesic option for Cesarean delivery (posterior or lateral approach) and open colorectal section (subcostal or lateral approach) if there exist contraindications to intrathecal morphine and thoracic epidural analgesia, respectively.

Table 1. Authors' Suggestions Pertaining to Clinical Indications and Alternatives for TAP Blocks

Clinical indications	• Cesarean delivery: posterior and lateral TAP block not recommended if long-acting intrathecal opioids are used (1)
	• Laparoscopic cholecystectomy: subcostal approach recommended over lateral approach if the operator elects to perform a TAP block (2)
	• Laparoscopic hysterectomy: lateral TAP block not recommended (1)
	• Open colorectal surgery: thoracic epidural block recommended (lateral or subcostal continuous TAP blocks recommended if contraindication to neuraxial block) (2)
	• Open appendectomy: posterior or lateral TAP block recommended (2)
	• Laparoscopic appendectomy: lateral TAP block not recommended (2)
	• Open prostatectomy: lateral TAP block not recommended (2)
Alternative truncal blocks	• Quadratus lumborum block (lateral or Type 1): recommended over lateral TAP block (2)

Levels of evidence are indicated in parentheses. Based on the Oxford Levels of Evidence (Level 1 = systematic review of randomized trials or n-of 1 trials; Level 2 = randomized trial or observational study with dramatic effect; Level 3 = nonrandomized controlled cohort or follow-up study; Level 4 = case–series or case–control studies, or historically controlled studies; Level 5 = mechanism-based reasoning). TAP, transversus abdominis plane.

Table 2. Clinical Areas Pertaining to TAP Blocks Warranting Further Investigation

- Comparison between subcostal and posterior TAP block
- Comparison between posterior TAP block and lateral (type 1) quadratus lumborum block
- Optimal technique for surgical TAP block
- Optimal single dose and mode of administration for either dexamethasone, dexmedetomidine, magnesium, or buprenorphine for TAP block
- Optimal combination of multimodal regional analgesia (dexamethasone ± dexmedetomidine ± magnesium ± buprenorphine) for TAP block
- Comparison between continuous TAP block and single-injection TAP block using liposomal bupivacaine
- Benefits of TAP blocks in the setting of multimodal analgesia for laparoscopic cholecystectomy (subcostal approach), hysterectomy (posterior/lateral approach), laparoscopic colorectal surgery (lateral approach), open/laparoscopic inguinal hernia repair (posterior/lateral approach), laparoscopic prostatectomy (posterior/lateral approach)
- Posterior TAP block for laparoscopic hysterectomy, laparoscopic appendectomy, and open prostatectomy
- Posterior or lateral TAP block for laparoscopic prostatectomy
- Comparison between posterior TAP block and thoracic epidural block for open colorectal surgery with emphasis on respiratory and gastrointestinal (*i.e.*, return of bowel function) outcomes
- Further comparison between (posterior/lateral) TAP block and caudal, thoracic paravertebral, rectus sheath, and ilioinguinal/iliohypogastric block
- Comparison between (posterior) TAP block and newer truncal block (*e.g.*, anterior quadratus lumborum block, retrolaminar block, erector spinae plane block)

TAP, transversus abdominis plane.

Currently, knowledge gaps remain that require further investigation (table 2). For instance, posterior and subcostal transversus abdominis plane blocks should be compared in clinical settings (upper abdominal surgery); differences between posterior transversus abdominis plane blocks and lateral (*i.e.*, type 1) quadratus lumborum blocks should be elucidated; the optimal dose, mode of administration, and combination of adjuvants to prolong transversus abdominis plane blocks requires future investigation. Furthermore, posterior transversus abdominis plane blocks should be investigated for surgical interventions in which their lateral counterparts have proven not to be beneficial (*i.e.*, laparoscopic hysterectomy, laparoscopic appendectomy, open prostatectomy). For such trials, it will be paramount that the control group receive adequate multimodal analgesia. More importantly, because posterior transversus abdominis plane blocks can purportedly provide sympathetic blockade and visceral analgesia, they should be compared with thoracic epidural analgesia for open colorectal surgery with emphasis on respiratory and gastrointestinal (*i.e.*, return of bowel function) outcomes as well as adverse events such as hypotension. Moreover, in the context of an ever-expanding array of ultrasound-guided truncal blocks,[2] the benefits (if any) of transversus abdominis plane blocks over newer and more proximal interfascial plane blocks (*i.e.*, retrolaminar, erector spinae plane, and anterior quadratus lumborum blocks) need to be investigated with well-designed and adequately powered trials.[2,4,5] Finally, in addition to postoperative pain scores and breakthrough opioid consumption, future randomized controlled trials should consider including cost analyses as well as hard outcomes such as length of stay.

Research Support

Competing Interests

The authors declare no competing interests.

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