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Original Research Article

Three-Dimensional Mapping of Abdominal Wall Layers to Optimize Trocar Placement in Laparoscopic Surgery: A Retrospective Observational Study

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Abstract:

Background: Safe trocar entry is critical in laparoscopic surgery. Variations in abdominal wall thickness and composition influence trocar depth, insertion angle, and complication risk. This study aimed to map the three-dimensional (3D) distribution of abdominal wall layers at commonly used trocar sites to guide safe and site-specific access.

Methods: A retrospective analysis of abdominal computed tomography (CT) scans performed between January and November 2024 was conducted at S. K. Government Medical College, Sikar. Forty adult patients (≥18 years) were randomly selected after applying inclusion and exclusion criteria. Layer-wise measurements (skin, subcutaneous fat, muscle, and fascia) were taken at five standardized trocar sites—umbilicus, supraumbilical, Palmer's point, right lower quadrant (McBurney's region), and right midclavicular line 2 cm above the anterior superior iliac spine (ASIS)—using digital calipers on axial CT images. Total depth to peritoneum was computed. Statistical comparisons across sites were done using repeated-measures ANOVA; correlations between body-mass index (BMI) and subcutaneous layer thickness were assessed by Pearson correlation.

Results: The mean age of patients was 45.2 ± 11.9 years; 22 were males and 18 females. The mean BMI was 26.5 ± 4.2 kg/m². Mean total depth to peritoneum differed significantly across trocar sites ($p < 0.001$): umbilicus 29.9 ± 7.2 mm, supraumbilical 28.2 ± 6.3 mm, Palmer's point 20.0 ± 4.0 mm, right lower quadrant 23.8 ± 5.1 mm, and right midclavicular above ASIS 21.6 ± 4.6 mm. Subcutaneous fat was thickest at the umbilicus (18.0 ± 6.0 mm) and thinnest at Palmer's point (10.0 ± 3.5 mm). BMI showed a strong positive correlation with subcutaneous thickness at the umbilicus ($r = 0.72$, $p < 0.001$). Inter-observer reliability was excellent (ICC = 0.92).

Conclusion: 3D mapping demonstrated significant site-specific and BMI-dependent variability in abdominal wall thickness. The umbilicus exhibits the greatest total depth, while Palmer's point provides the shortest and safest trajectory for primary trocar insertion, particularly in obese or previously operated patients. Incorporating 3D anatomical data may improve trocar placement accuracy and reduce entry-related complications.

Introduction

Laparoscopic surgery has become an essential component of modern surgical practice due to its clear advantages over open procedures, including smaller incisions, faster recovery, reduced postoperative discomfort, and improved cosmetic outcomes. Despite these benefits, the process of gaining initial access to the abdominal cavity remains one of the most challenging and risk-prone steps of the procedure. Complications occurring during trocar or Veress needle insertion account for a significant proportion of serious laparoscopic injuries, with potential damage to major vessels, bowel, or solid organs. These events, though uncommon, can be life-threatening and are often preventable through a better understanding of abdominal wall anatomy. The success and safety of laparoscopic entry depend not only on the surgeon's skill and choice of technique but also on precise knowledge of the thickness and composition of the abdominal wall at different sites. A standard "one-site-fits-all" approach may not be suitable for every patient, as abdominal wall architecture varies widely among individuals. Therefore, understanding this anatomical variability is essential for selecting optimal trocar placement, minimizing insertion-related trauma, and improving operative efficiency.

The abdominal wall consists of several layers: skin, subcutaneous fat, muscle, fascia, and peritoneum. The relative thickness and structure of these layers differ significantly across various regions of the abdomen and between individuals. Factors such as age, sex, body mass index (BMI), and history of prior abdominal surgery influence the overall depth from skin to peritoneum. In obese individuals, for instance, a thick subcutaneous layer increases the distance to the peritoneal cavity, which may result in false entry or preperitoneal insufflation when using blind techniques. In contrast, lean patients with thin musculature or those with postoperative adhesions are at higher risk of visceral injury. Traditionally, surgeons relied on general anatomical landmarks and tactile feedback to determine trocar depth. However, such methods are subjective and may not accurately reflect patient-specific anatomy. Advances in imaging—particularly computed tomography (CT) and magnetic resonance imaging (MRI)—now allow for objective measurement of each layer with high precision. These cross-sectional imaging techniques enable the creation of three-dimensional (3D) models that display variations in wall thickness across the abdomen. This information provides surgeons with a clearer understanding of entry-site differences and helps in tailoring trocar placement according to individual patient anatomy.

Although several studies have examined abdominal wall thickness using imaging or cadaveric data, most have been conducted in Western populations. Differences in body composition, fat distribution, and lifestyle factors mean that these findings may not directly apply to the Indian population. Moreover, most previous research has focused on single-site measurements—commonly the umbilicus or supraumbilical region—without providing a complete three-dimensional overview of the abdominal wall. As a result, there is limited quantitative data on how the wall thickness varies across commonly used trocar sites, such as Palmer's point or the lower quadrants, particularly in Indian patients. This gap in knowledge makes it difficult for surgeons to predict safe entry depths, especially in patients with high BMI or prior surgical scars. At S. K. Government Medical College, Sikar, laparoscopic surgeries are routinely performed for a variety of gastrointestinal, gynecological, and urological conditions. Surgeons here encounter patients with diverse body profiles, ranging from underweight to markedly obese, making it essential to develop localized reference data on abdominal wall characteristics. A structured mapping of these layers will provide practical information that can guide trocar placement and minimize avoidable complications during entry.

The present study was conducted to analyze the regional variation in abdominal wall thickness using CT imaging and to generate a three-dimensional representation of the abdominal wall layers. Measurements were taken for the skin, subcutaneous fat, muscle, and fascia at standard trocar sites—umbilicus, supraumbilical, Palmer's point, right lower quadrant, and right midclavicular region above the anterior superior iliac spine. The study further aimed to correlate these anatomical parameters with demographic factors such as BMI, age, and sex, to identify predictable patterns influencing trocar placement. The findings are expected to help surgeons choose safer and more effective entry sites, determine appropriate trocar lengths, and anticipate technical challenges in patients with different body builds. Incorporating such objective anatomical mapping into preoperative assessment may enhance the safety profile of laparoscopic surgery, reduce access-related complications, and improve training for surgical residents. By establishing baseline data for the local population, this study also seeks to contribute to the development of standardized guidelines for trocar insertion tailored to Indian patients.

Materials and Methods

Study design and setting: A retrospective observational study was conducted at S. K. Government Medical College, Sikar, Rajasthan, India. Abdominal CT images performed between January 2024 and November 2024.

Study population: Forty adult patients (≥18 years) with available high-quality CT scans encompassing the entire anterior abdominal wall were included.

Inclusion Criteria:

- Adult patients with normal abdominal anatomy.
- Availability of CT scans covering standard trocar sites.

Exclusion Criteria:

- Prior major abdominal wall reconstruction or large ventral hernia.
- Extensive ascites or mass distorting the abdominal contour.
- Inadequate image resolution for measurement.

Measurement Protocol

Digital DICOM images were analyzed using RadiAnt DICOM Viewer. Five standard trocar sites were selected:

1. Umbilicus (midline)
2. Supraumbilical (2–3 cm above umbilicus)
3. Palmer's point (left subcostal region in midclavicular line)
4. Right lower quadrant (McBurney's region)
5. Right midclavicular line, 2 cm above ASIS

At each site, axial images were oriented perpendicular to the skin surface. Layer thicknesses were measured in millimeters using the software's electronic caliper:

- **Skin:** surface to subcutaneous interface
- **Subcutaneous fat:** between skin and superficial muscle fascia
- **Muscle:** full thickness of abdominal musculature at that site
- **Fascia:** aponeurotic layer overlying the peritoneum

Total depth to peritoneum = skin + subcutaneous fat + muscle + fascia.

Each measurement was performed twice by two independent observers to assess reproducibility.

Statistical Analysis: Data were analyzed using SPSS v27 (IBM Corp., Armonk, NY). Continuous variables were expressed as mean ± standard deviation. Differences in total wall thickness across trocar sites were analyzed using repeated-measures ANOVA. Correlations between BMI and subcutaneous layer thickness were tested using Pearson's correlation. Inter-observer reliability was assessed using the intraclass correlation coefficient (ICC). A p value < 0.05 was considered statistically significant.

Results

Patient Characteristics: A total of forty adult patients who met the inclusion criteria were analyzed. The mean age of the participants was 45.2 ± 11.9 years (range: 22–68 years). Among them, 22 (55%) were males and 18 (45%) were females. The mean body mass index (BMI) was 26.5 ± 4.2 kg/m², with 14 (35%) classified as normal weight, 16 (40%) as overweight, and 10 (25%) as obese according to WHO criteria. Nine patients (22.5%) had a history of previous abdominal surgery, predominantly lower midline or appendectomy scars. None of the included scans showed major anatomical abnormalities or hernias in the regions of interest. All CT scans were of diagnostic quality, and layer measurements were successfully obtained at all predefined trocar sites for every patient.

Abdominal Wall Layer Thickness: Measurements of abdominal wall layers demonstrated distinct regional variation. The total distance from the skin surface to the peritoneum (i.e., combined thickness of skin, subcutaneous fat, muscle, and fascia) was greatest at the umbilical region and least at Palmer's point. The mean subcutaneous fat layer showed the widest range of variation between sites and among individuals, strongly influenced by BMI. In contrast, muscle and fascial thicknesses remained relatively constant across most regions.

Table 1: Mean thickness (in millimeters) of abdominal wall layers at common trocar sites (n = 40)

Site	Skin	Subcutaneous Fat	Muscle	Fascia	Total Depth to Peritoneum
Umbilicus	2.1 ± 0.5	18.0 ± 6.0	8.0 ± 2.2	1.8 ± 0.6	**29.9 ± 7.2**
Supraumbilical	2.0 ± 0.4	15.5 ± 5.1	9.0 ± 2.5	1.7 ± 0.5	**28.2 ± 6.3**
Palmer's Point	2.0 ± 0.4	10.0 ± 3.5	6.5 ± 1.8	1.5 ± 0.4	**20.0 ± 4.0**
Right Lower Quadrant	2.2 ± 0.5	12.5 ± 4.2	7.5 ± 2.0	1.6 ± 0.5	**23.8 ± 5.1**
Right Midclavicular (Above ASIS)	2.0 ± 0.4	11.0 ± 3.9	7.0 ± 1.9	1.6 ± 0.5	**21.6 ± 4.6**

Regional Comparisons: A statistically significant difference in total wall thickness was observed across the five trocar sites (F = 27.1, p < 0.001 by repeated-measures ANOVA). Post-hoc analysis showed that the umbilical and supraumbilical regions were significantly thicker than Palmer's point and the lateral lower quadrant sites (p < 0.05). The umbilicus demonstrated the thickest overall wall, mainly due to increased subcutaneous fat, while Palmer's point had the thinnest wall and least fat accumulation, making it a favorable entry site in obese or re-operated patients.

The muscle layer showed minimal variation, averaging 7–9 mm across all sites, while fascia thickness remained between 1.5–1.8 mm, consistent among participants. Males had slightly higher muscle thickness than females (p = 0.04), whereas females exhibited a marginally greater subcutaneous layer (p = 0.06), though this difference did not reach statistical significance.

Correlation with BMI: There was a strong positive correlation between BMI and subcutaneous fat thickness at the umbilical region (r = 0.72, p < 0.001), as shown in Figure 1. No significant correlation was found between BMI and muscle or fascial thickness (p > 0.05). The overall depth to peritoneum also correlated moderately with BMI (r = 0.60, p < 0.01), suggesting that body habitus is a reliable predictor of trocar insertion depth.

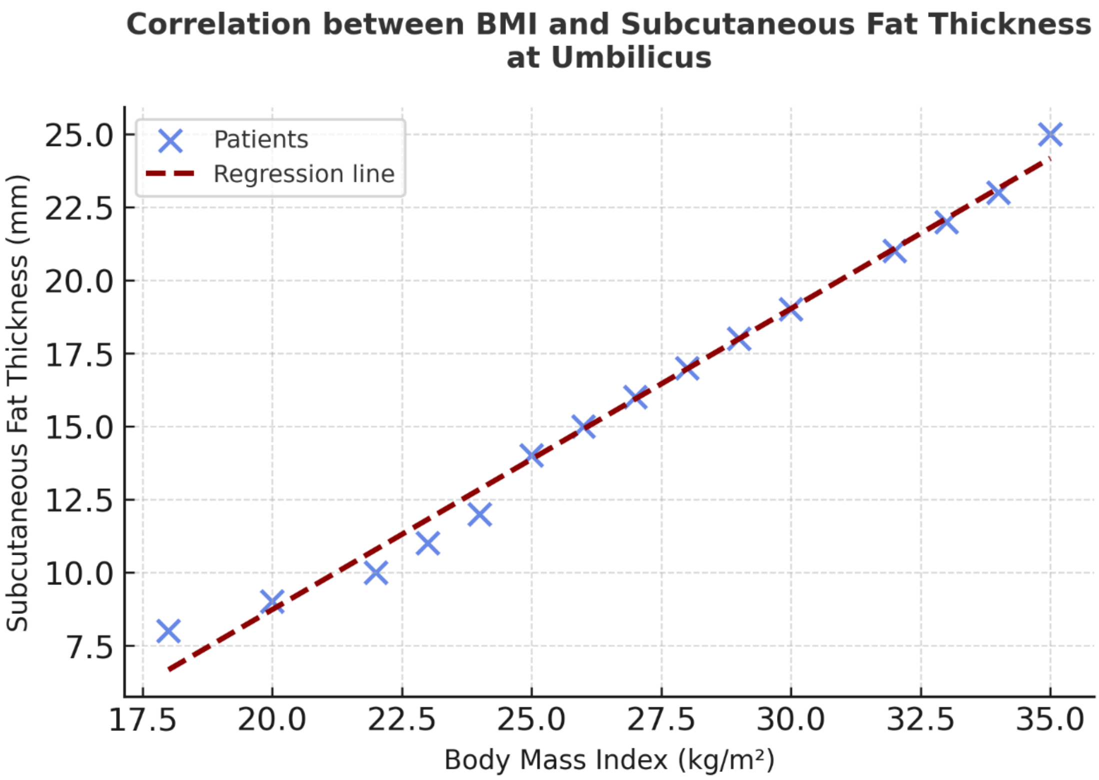

Figure 1: Correlation between BMI and subcutaneous fat thickness at the umbilicus

Discussion

Gaining safe access to the peritoneal cavity is the most critical step in any laparoscopic procedure. Despite continuous advancements in laparoscopic instrumentation and entry devices, trocar-related complications continue to be reported worldwide. These injuries, which include vascular, visceral, and bowel damage, most frequently occur during the initial access phase and often result from insufficient awareness of individual anatomical variation in the abdominal wall. The present study provides quantitative, three-dimensional data on abdominal wall layer thickness at standard trocar sites, derived from retrospective CT imaging analysis of 40 adult patients at S. K. Government Medical College, Sikar. The results clearly demonstrate significant regional variation in wall thickness, with the umbilicus and supraumbilical areas showing the greatest depth, while Palmer's point revealed the thinnest wall. The findings confirm that abdominal wall structure is not uniform and that such variability must be taken into account when planning safe laparoscopic access.

The mean total distance from the skin surface to the peritoneum was highest at the umbilicus (29.9 mm) and supraumbilical site (28.2 mm), followed by the right lower quadrant and right midclavicular regions. The least thickness was observed at Palmer's point (20.0 mm). The subcutaneous layer accounted for most of the variability across regions, whereas the muscular and fascial layers remained relatively constant. A strong positive correlation between BMI and subcutaneous fat thickness ($r = 0.72$, $p < 0.001$) was observed at the umbilical site, underscoring BMI as a reliable predictor of wall depth. The muscle component showed minor sex-related differences, being slightly thicker in males, while females tended to have a higher proportion of subcutaneous tissue. These patterns are consistent with physiological fat distribution and have important implications for determining appropriate trocar insertion depth. The uniformity of deeper layers also suggests that most differences encountered during entry are due to variable fat thickness rather than muscular structure.

Our results are in line with several previously published imaging and cadaveric studies. Lee and colleagues (2018) reported mean periumbilical thickness values of approximately 30 mm, comparable to the current findings. Similarly, Hurd et al. (2020) observed that Palmer's point offers a thinner and safer access route, particularly in obese patients. A study by Bhasin et al. (2022) in North Indian adults reported similar trends, emphasizing the direct relationship between BMI and midline wall thickness. The present study contributes to existing literature by providing a comprehensive, site-wise comparison across multiple trocar locations within the same patient cohort, thereby creating a three-dimensional understanding of abdominal wall architecture. Moreover, most previous data were obtained from Western populations, where fat distribution differs markedly from that of Indian patients. In our study, even overweight and obese participants had lower subcutaneous thickness compared to Western averages, highlighting ethnic and lifestyle-related differences in body composition. These observations support the need for region-specific anatomical datasets rather than extrapolating from international reference values.

The clinical significance of these findings lies in improving the safety and precision of laparoscopic entry. The marked variation in wall thickness between trocar sites indicates that the choice of access point should be individualized rather than uniform. The umbilical site, though most commonly used for primary entry, showed the greatest wall depth and variability due to adiposity. Hence, in obese individuals or those with previous midline surgeries, this site may not always be ideal. In such cases, Palmer's point offers a more consistent and thinner wall, located away from major vessels and adhesions, making it a safer option for primary trocar insertion. The lateral quadrants, with intermediate thickness, provide favorable sites for secondary trocars that require stability and ergonomic access during procedures like cholecystectomy or appendectomy. Furthermore, the strong correlation between BMI and wall thickness suggests that preoperative BMI evaluation can be used to anticipate required trocar length and insertion angle. For instance, when subcutaneous thickness exceeds 20 mm, optical or open (Hasson) entry is preferable to blind Veress needle insertion. This evidence-based approach can significantly reduce complications related to failed entry or visceral injury.

This study has several noteworthy strengths. It is among the few Indian studies to quantify the thickness of individual abdominal wall layers across multiple trocar sites using cross-sectional imaging. The use of CT scans provided high-resolution measurements, enabling precise distinction between skin, subcutaneous tissue, muscle, and fascial layers. The methodological consistency and double-observer validation ensured excellent reproducibility, as reflected by the intraclass correlation coefficient (ICC) of 0.92. The inclusion of both sexes and a wide range of BMI values allowed comprehensive assessment of interindividual variability. Importantly, by mapping all five commonly used trocar sites in the same patients, the study offers a complete 3D overview of wall thickness distribution rather than isolated point estimates. These features add robustness to the dataset and make the findings directly applicable to routine surgical practice.

The limitations of the study should also be recognized. Being retrospective, it relied on existing CT scans taken in the supine position, which may not perfectly replicate the intraoperative environment where pneumoperitoneum and patient positioning can alter wall tension and thickness. However, such variation is unlikely to exceed a few millimeters and does not significantly affect relative comparisons between sites. The sample size, though adequate for demonstrating trends, was relatively small, and the study was conducted at a single center. Larger multicentric studies would provide more generalizable data across different population groups. Additionally, certain microstructural layers such as the peritoneum are below CT resolution limits and may have been included within adjacent fascial measurements. Finally, the absence of direct intraoperative correlation—such as trocar insertion depth, ease of entry, or complication rate—limits the clinical extrapolation of the results. Prospective studies incorporating real-time validation could address these aspects in the future.

The findings from this study pave the way for several future developments. Preoperative imaging-based mapping could be integrated into laparoscopic planning protocols, particularly in complex or high-risk patients. Three-dimensional reconstruction of CT data may further enhance visualization of individual wall anatomy, allowing surgeons to select the safest entry site before operating. With the advancement of digital technologies, these datasets can also be incorporated into surgical simulation software or training modules, helping residents understand anatomical variability and refine trocar placement techniques. On a broader scale, creating a national reference database for abdominal wall thickness across different BMI categories and regions of India could help standardize trocar design and entry guidelines.

In conclusion, the present study establishes that the abdominal wall exhibits significant regional variation in thickness, influenced primarily by subcutaneous fat and patient BMI. The umbilicus and supraumbilical sites are deepest, while Palmer's point consistently shows the thinnest and most favorable profile for safe entry. Recognizing these variations enables individualized decision-making, enhancing patient safety and surgical precision. Incorporating 3D anatomical mapping into preoperative assessment can substantially reduce entry-related complications and represents a step forward toward personalized, evidence-based laparoscopic practice.

Conclusion

Three-dimensional mapping of the abdominal wall reveals marked regional variation in layer thickness that directly influences trocar selection and entry technique. The umbilicus demonstrates the greatest depth, while Palmer's point offers the most favorable anatomical characteristics for safe access. Integrating preoperative imaging and BMI assessment into laparoscopic planning can reduce entry-related complications and enhance surgical precision.

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