Original Article

Study of Individual Characteristic Abdominal Wall Thickness Based on Magnetic Anchored Surgical Instruments

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Abstract

Background: Magnetic anchored surgical instruments (MASI), relying on magnetic force, can break through the limitations of the single port approach in dexterity. Individual characteristic abdominal wall thickness (ICAWT) deeply influences magnetic force that determines the safety of MASI. The purpose of this study was to research the abdominal wall characteristics in MASI applied environment to find ICAWT, and then construct an artful method to predict ICAWT, resulting in better safety and feasibility for MASI.
Methods: For MASI, ICAWT is referred to the thickness of thickest point in the applied environment. We determined ICAWT through finding the thickest point in computed tomography scans. We also investigated the traits of abdominal wall thickness to discover the factor that can be used to predict ICAWT.
Results: Abdominal wall at C point in the middle third lumbar vertebra plane (L3) is the thickest during chosen points. Fat layer thickness plays a more important role in abdominal wall thickness than muscle layer thickness. "BMI-ICAWT" curve was obtained based on abdominal wall thickness of C point in L3 plane, and the expression was as follow: $f(x) = P1 \times x^2 + P2 \times x + P3$, where P1 = 0.03916 (0.01776, 0.06056), P2 = 1.098 (0.03197, 2.164), P3 = −18.52 (−31.64, −5.412), R-square: 0.99.
Conclusions: Abdominal wall thickness of C point at L3 could be regarded as ICAWT. BMI could be a reliable predictor of ICAWT. In the light of "BMI-ICAWT" curve, we may conveniently predict ICAWT by BMI, resulting a better safety and feasibility for MASI.

Key words: Individual Characteristic Abdominal Wall Thickness; Magnetic Anchored Surgical Instruments; Minimally Invasive Surgery

Introduction

Operation is the most important part of surgical treatment. Traditional operation means open surgery, which believes big scar, big surgeon. With the appearance of laparoscopy, minimally invasive surgery (MIS) opened a new era for surgery.[1,2] In order to get a smaller invasion, surgeons invented laparoendoscopic single-site surgery (LESS) and natural orifice transluminal endoscopic surgery (NOTES). Both of them reduced the numbers of transabdominal port sites and the limited access to the unconspicuous position. The single port approach made LESS and NOTES have potential benefits for patients, such as less pain and better wound cosmesis.[3-5] However, limitations of single port approach could not be neglected, including insufficient force torque, loss of triangulation, and an uncomfortable working angle of instruments.[6-8]

Cadeddu *et al*.[9] firstly presented a technology that termed magnetic anchoring and guidance system (MAGS) to overcome such shortages of single port approach in 2007. Thereafter, many magnetic anchored surgical instruments (MASI) have emerged, most of which were camera, dissector, and retractor instruments.[9-15] MASI is typically consisted of intra- and extra-corporeal magnets. The magnets could generate coupling force at a length that makes MASI free from trocar in the abdominal cavity, resulting in an appropriate triangulation and working angle. In brief, MASI would lead future development of MIS.[16-19]

However, widespread clinical application of MASI is still unclear. Open operation would be inevitable if MASI "drop out" from the abdominal wall. This seriously adverse event would occur when MASI is applied on an extremely thick abdominal wall because magnetic attraction forces exponentially diminish over distance.[20,21] Therefore, abdominal wall, especially for individual characteristic abdominal wall thickness (ICAWT), plays a key role in the safety of MASI. In other words, a convenient approach to predict each patient's ICAWT is needed to guide the design and application of MASI. Unfortunately, little work regarding the prediction of ICAWT has been done, which caused a current dilemma.

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In order to enhance the safety and feasibility of MASI, the purpose of this study was to determine ICAWT in MASI applied scenario and produce an artful way to predict each patient's ICAWT.

Methods

Since magnetic forces exponentially diminish over distance, ICAWT should be the maximum thickness of abdominal wall in MASI applied scenario. In this work, we determined ICAWT through finding the thickest point in MASI's applied environment by computed tomography (CT) scans. Then we discovered body mass index (BMI) might have a close relationship with ICAWT by investigating the traits of abdominal wall. Ultimately, we construct "BMI-ICAWT" curve to predict each patient's ICAWT. This curve could make the clinical application of MASI more precise and safer.

Patients

The study was approved by the Ethics Committee of First Affiliated Hospital of Xi'an Jiaotong University and informed consent was obtained from all the participating patients.

Between September 2012 and November 2012, 60 patients from Department of Hepatobiliary Surgery in First Affiliated Hospital of Xi'an Jiaotong University were chosen as Group 1 (30 men, 30 women, aged from 20 to 70 years, median age of 42 years). In Group 1, the thickness of abdominal wall, muscle layer, and fat layer at chosen points was measured to characterize the thickest point at MASI's applied environment and explore the factor that deeply influenced the abdominal wall thickness. The thickness of the thickest point could be defined as ICAWT. Between December 2012 and February 2013, 60 patients from Department of Hepatobiliary Surgery in First Affiliated Hospital of Xi'an Jiaotong University were chosen as Group 2 (30 men, 30 women, aged from 28 to 75 years, median age of 46 years). In Group 2, each patient's ICAWT and BMI were measured to construct "BMI-ICAWT" curve. The baseline information of the patients in Group 1 and Group 2 is shown in Table 1.

Table 1: The baseline information of the patients

Characteristics	Group 1 (n = 60)	Group 2 (n = 60)
Age, years, median (range)	42 (20–70)	46 (28–75)
Male/female, n	30/30	30/30
Blood type, n		
A	16	12
B	17	18
O	12	16
AB	15	14
Child-pugh classification, n		
A	50	46
B	7	10
C	3	4
HBV/HCV infection, %	43.3	40.0
Operation, %		
LC	75.0	66.7
Liver resection	8.3	13.3
PD	8.3	10.0
Liver transplantation	3.3	3.3
Others	5.0	6.7

HBV: Hepatitis B virus; HCV: Hepatitis C virus; LC: Laparoscopic cholecystectomy; PD: Pancreaticoduodenectomy.

Choice of measuring plane and point

The thickness of abdominal wall, muscle layer, and fat layer was measured through CT scans. Based on MASI applied scenario, from cranial side to caudal side, we chose five planes to measure: The second porta hepatis plane (P2), the first porta hepatis plane (P1), the middle first lumbar vertebra plane (L1), the middle second lumbar vertebra plane (L2), and the middle third lumbar vertebra plane (L3). At each plane, from left to right, we chose three specific points, named C, D, and E. The methods of choosing specific points are shown in Figure 1.

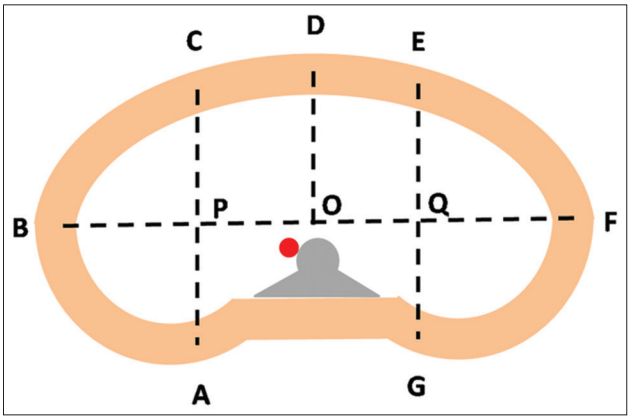

Figure 1: The methods of choosing specific points at chosen plane: BF is the transverse diameter; *P* and Q are third points of BF which are automatically generated by imaging software; O is the midpoint of BF; AC passes P, GE passes Q, OD passes O and they are all perpendicular to BF; AC, GE, and OD cross anterior abdominal wall at C, E and D respectively; C, D, and E are chosen points.

Measure of thickness of abdominal wall, muscle layer, and fat layer

The images of MASI's applied environment were obtained through a 64-slice CT unit (Philips, Amsterdam, The Netherlands). According to the characteristic of abdominal CT scans, the imaging software (provided by CT unit) was used to measure the abdominal wall thickness at chosen points. For each point, the thickness of muscle layer and fat layer was also measured, respectively, due to the difference in CT value. Afterward, "abdominal wall thickness-plane" curve, "muscle layer thickness-plane" curve, and "fat layer thickness-plane" curve for point C, D, and E were obtained. These curves were used to find the thickest point and study the traits of abdominal wall in MASI's applied environment.

Statistical analysis

SPSS 18.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The mean and standard deviation (SD) of thickness for each layer at chosen points were acquired,

which is needed for the construction of "thickness-plane" curves.

"Body mass index-individual characteristic abdominal wall thickness" curve

Based on prior trials in Group 2, BMI could be a good predictor of ICAWT. The BMI for a person was defined as their body mass divided by the square of their height. Then "BMI-ICAWT" curve was fit by polyfit module of software MATLAB (R2012a [7.14.0.739], MathWorks, USA), and function expression of the curve was also obtained.

Results

Through the trial based on Group 1, the thickness of abdominal wall, muscle layer, and fat layer at chosen points was measured. The thickness data for point C, D, and E are shown in Table 2. We also obtain "abdominal wall thickness-plane" curve, "muscle layer thickness-plane" curve and "fat layer thickness-plane" curve for point C, D, and E shown in Figure 2. According to these curves, we observed that: For abdominal wall: (1) The thickness was symmetrical and the ventrimeson was symmetry axis; (2) the thickness of both lateral points was larger than the middle one; (3) the lower the plane was, the thicker it became; (4) the thickness of the abdominal wall at point C in plane L3 was the largest in chosen points. For muscle layer: (1) It shared the same symmetric characteristics with abdominal wall; (2) it was thinner in lower plane that was opposite to the law of abdominal wall; (3) muscle layer was thinner than fat layer. For fat layer: (1) It shared the same symmetric characteristics with abdominal wall; (2) it was thicker in lower plane that was in line with abdominal wall; (3) fat layer was thicker than muscle layers.

In sum, point C in plane L3 was the thickest point in MASI applied scenario, so we can define the thickness of point C as ICAWT. Compared with muscle layer, fat layer was thicker and shared the same law with the abdominal wall in thickness changing, so it played a crucial role in abdominal wall thickness. In addition, BMI was closely related to the fat layer thickness, so we chose BMI as a predictor of ICAWT.

According to the trial based on Group 2, we got 60 patients' ICAWT and their BMI. Using these data, we obtained "BMI-ICAWT" curve [Figure 3]. The function expression was as follows: $f(x) = P1 \times x^2 + P2 \times x + P3$, where P1 = 0.03916 (0.01776, 0.06056), P2 = 1.098 (0.03197, 2.164), P3 = −18.52 (−31.64, −5.412), R-square: 0.99. By this function expression, simply relied on BMI, we can gain patient's ICAWT to enhance the safety and feasibility of MASI.

Discussion

Due to the features of magnetic coupling force, MASI can be free from trocar position and make full use of abdominal

Table 2: Thickness data for points C, D, and E (mean ± SD, mm, *n*=60)

Planes	C point			D point			E point		
	Abdominal wall	Muscle layer	Fat layer	Abdominal wall	Muscle layer	Fat layer	Abdominal wall	Muscle layer	Fat layer
P2	21.70 ± 3.97	10.35 ± 3.78	11.35 ± 4.46	16.45 ± 5.68	5.45 ± 1.88	11.00 ± 3.50	16.45 ± 5.68	11.38 ± 3.76	10.89 ± 3.79
P1	22.47 ± 5.62	9.4 ± 3.47	13.07 ± 6.92	18.28 ± 6.84	7.82 ± 2.32	10.46 ± 2.82	18.28 ± 6.84	11.18 ± 3.21	11.73 ± 4.42
L1	23.77 ± 5.62	8.75 ± 2.23	15.02 ± 5.54	19.53 ± 4.74	2.81 ± 0.77	16.72 ± 4.58	19.53 ± 4.74	8.54 ± 2.45	14.42 ± 5.84
L2	25.18 ± 6.00	6.95 ± 2.42	18.23 ± 7.4	22.88 ± 6.07	3.17 ± 0.87	19.71 ± 5.46	22.88 ± 6.07	7.43 ± 2.13	17.09 ± 6.54
L3	26.75 ± 6.46	7.95 ± 2.85	18.79 ± 6.74	22.50 ± 7.14	2.90 ± 0.93	19.60 ± 6.45	22.50 ± 7.14	8.93 ± 2.94	16.64 ± 5.97

SD: Standard deviation.

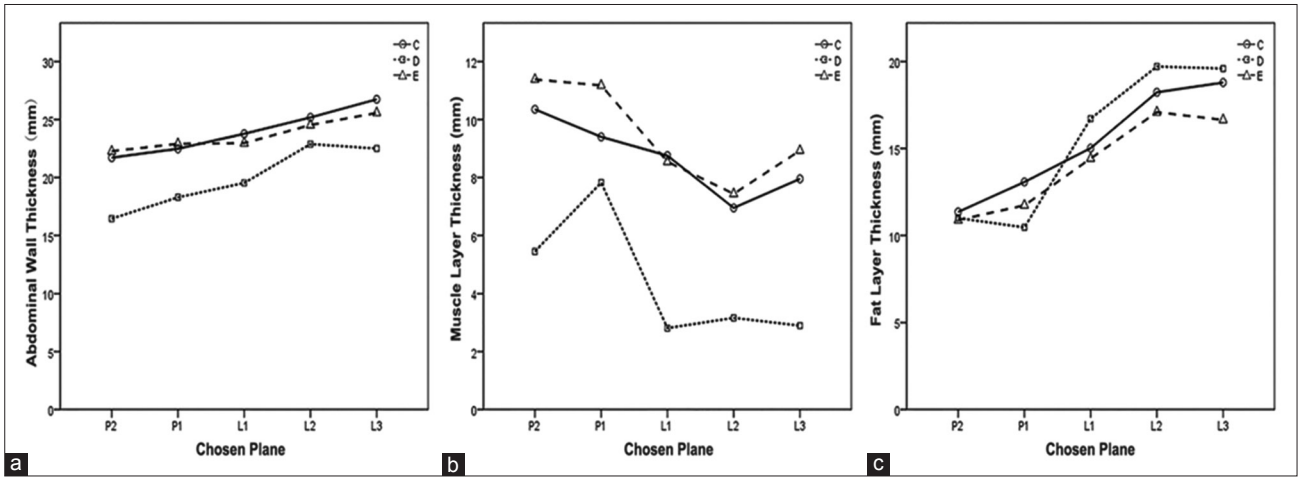

Figure 2: The "thickness-plane" lines for chosen points. (a) The "abdominal wall thickness-plane" line for chosen points. (b) The "muscle layer thickness-plane" line for chosen points. (c) The "fat layer thickness-plane" line for chosen points.

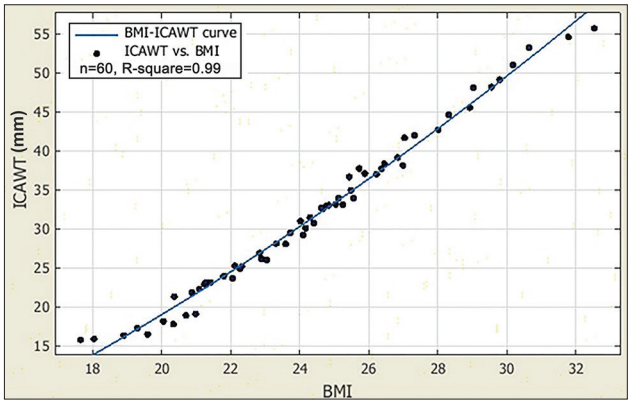

Figure 3: "BMI-ICAWT" curve. BMI: body mass index; ICAWT: individual characteristic abdominal wall thickness.

cavity, leading a better triangulation and working angle for instruments. It is a promising solution to meet the challenges of NOTES and LESS.[8,11,14,15] However, because of lacking necessary information about the individual abdominal wall, the design and application of MASI were unspecific. As a result, many scholars suspected the safety of MASI for the risk of "drop out," which can be caused by the variation in abdominal wall thickness from people to people.[20,21] Only under deep study on the abdominal wall can we expect a bright future for MASI.

The magnetic strength is mainly determined by the distance and magnetic conductivity between two magnets. As to abdominal wall, the magnetic strength influences magnetic attraction in two fields: One is the thickness, which decides the distance between intra- and extra-corporeal magnet; the other one is the magnetic conductivity. The abdominal wall is primarily consisted of fat and muscle, and both of them have the similar magnetic conductivity with air.[22] What's more, the magnetic strength exponentially increases or decreases with the distance change. Therefore, the thickness of the abdominal wall is the most valuable information for the design and application of MASI.

Previous studies about abdominal wall thickness based on MASI were focused on the wave range,[21-24] because a widely accepted view was that individual abdominal wall thickness should be a wave range, not an exact value. However, in order to enhance the safety and feasibility of MASI, an exact value of thickness is needed because it can be used to guide the design and application of MASI for every individual. In our study, we provided a novel conception to define this exact value, ICAWT. ICAWT is the maximum thickness in MASI applied scenario, and also is the most difficult part for MASI to anchor and guide according to magnetic traits. In this study, we demonstrated that point C at L3 was the thickest one at MASI applied environment. In sum, ICAWT could be defined as the thickness of point C at L3.

The limited functions made MASI still apply at simple operations, such as gallbladder resection, liver biopsy, and so on.[12-14] Therefore, MASI applied scenario was mainly at upper abdomen area which is higher than umbilicus. To avoid omission, we chose L3 as the lowest plane to investigate, which was obvious lower than umbilicus. We also chose three specific points at each plane to enrich the data. The abdominal wall is principally composed of fat layer and muscle layer. Our data suggested that in MASI applied scenario, the change law of fat layer thickness was similar to abdominal wall thickness, but the change law of muscle layer thickness was opposite. Moreover, the thickness of the fat layer was apparently much thicker than muscle layer. Therefore, fat layer thickness at thickest point might be used to predict ICAWT. Furthermore, fat layer thickness had a close relationship with individual obesity level, and BMI was a simple and effective index to reflect individual obesity level.[25,26] Hence, BMI could be a predictor for the ICAWT. In our study, we creatively constructed "BMI-ICAWT" curve to predict ICAWT by BMI. This method made a significant improvement in measuring abdominal wall thickness compared with previous methods, such as ultrasound scanner and spinal needle, which need an extra load of examinations and are more expensive. As a result, "BMI-ICAWT" curve might be a more convenient approach for surgeons to get patient's ICAWT, which is critical to guide specific design and application of MASI and enhance its safety and feasibility.

It is important to note that ascites and hydrothorax would disturb the relationship between BMI and ICAWT, so our theory is not suitable for such patients. In this study, the "BMI-ICAWT" curve was constructed according to the abdominal wall thickness of East Asians, so it was uncertain whether this curve could be used for other races. In addition, the difference between male and female regarding the abdominal wall thickness should also be considered, which was limited by the sample size in current research. Future study about "BMI-ICAWT" curve should recruit a larger sample size to investigate the difference between races and sex. At the same time, our future work would also focus on finding other predictor of ICAWT, such as abdomen circumference that may be more convenient.

In conclusion, ICAWT is a significant factor to guide the design and application of MASI, and it can be defined as the thickness of point C at L3, which is the thickest point in MASI applied scenario. Since fat layer deeply influences abdominal thickness, BMI can be regarded as a predictor of ICAWT. "BMI-ICAWT" curve presented in this study provides an easy approach for surgeons to predict each patient's ICAWT by BMI, which would lead a safer application of MASI and prompt the development of MIS.

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