

3D morphometric analysis of the colon applied to a laparoscopic surgical approach. Cadaver study

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Abstract

Background: The anatomy of the colon can be studied using three-dimensional reconstructions obtained from radiological images. Laparoscopic surgery of the colon requires positional changes of the surgical table. The aim of this study is to define the changes that occurred in certain segments of the colons of cadavers after subjecting them to the conditions that are used in laparoscopic surgery of the colon.

Methods: Three cadavers were submitted to abdominal computerized tomography, first with no external, and then after the application of 15 mm of Hg of pneumoperitoneum and 15 degrees Trendelenburg, right or left lateral decubitus.

Results: Three-dimensional reconstruction of the images was performed for a morphological descriptive study of the pubic points, superior mesenteric artery, inferior mesenteric artery, hepatic flexure and splenic flexure. A total of 390 measurements were performed, 159 showed changes. The inferior mesenteric artery point modifications were the most strongly related to the other points. The transverse colon - pubic symphysis - descending colon angle depended on the pubic symphysis - descending colon distance, and the transverse colon - inferior mesenteric artery - descending colon angle depended on the inferior mesenteric artery - transverse colon distance.

Conclusions: The positional changes of the points studied were related to their attachment to the peritoneum, to the proximity of the neighbouring viscera and to their location in the abdomen.

Background

Colon morphology has been extensively described in classical treatises of human anatomy [1,2] and has been related to both visceral and bony neighbouring structures [3,4].

There is considerable anatomical variability of the colon, which can mostly be explained by embryological development. The rotation of the intestinal loops influences the location of the different segments [5]. The fusion of the peritoneal layers that occurs during the formation of the mesos and coalescence fascia can influence the length of certain sections of the colon and the positioning of its angles [6].

The anatomical study of the colon has employed analytical methods based on radiological images and the resulting three-dimensional reconstructions, including computerized tomography (CT), nuclear magnetic resonance (MRI) or virtual colonoscopy (CT-colonoscopy) [7-11]. With these techniques, it is possible to analyse how age, sex, body mass index and pelvic diameter can influence the morphology, the disposition of fixed points or the intraluminal volume of the colon, among other parameters [12], and the anatomy of this organ can be studied by moving the patient from a supine decubitus position to a prone or lateral decubitus position, an adjustment that is highly applicable in clinical practice [13-15].

During laparoscopic surgery of the colon, different decubitus positions have been proposed to facilitate the correct mobilization of the intra-abdominal viscera and thus achieve good colon exposure [16]. For example, to expose the sigmoid colon, the surgical table is placed in the Trendelenburg position, and to examine the splenic flexure and the descending colon, a certain degree of right lateral decubitus positioning is used [17,18]. Therefore, for a successful surgery, it is considered necessary to vary the position of the patient so that the disposition of the colon is also modified.

No reference has been found in the literature that specifically describes the changes in colon placement that result from changes in posture

Methods

In this study, we propose as a hypothesis that certain points of the colon change location depending on the decubitus position that is used and that these changes can be measured and analysed using radiological methods with three-dimensional reconstruction.

Cadavers. Placement and manipulation

The study was performed at the Jesus Usón Minimally Invasive Surgery Centre with three cadavers, two females (cadavers 1 and 3) and one male (cadaver 2), embalmed using the Thiel technique [19]. A Brilliance CT multi-cutter scanner was used (Philips Medical Systems, Nederland B.V). The image processing and measurement software used were OsiriX, Adobe Photoshop Elements 11 Editor and ImageJ.

A working protocol was established and repeated for the three cadavers. The cadavers were placed in the scanner on wooden wedges at a 15° angle to achieve the different postural changes. The pneumoperitoneum was created with a periumbilical Veress needle. Four 12-mm disposable trocars were placed in the epigastric periumbilical and both iliac fossa locations for the introduction of a 0° Storz scope and disposable forceps in the series required for the manipulation of the colon.

The ten series of the study were modified with different degrees of pneumoperitoneum and postural decubitus. Series 01 (BASELINE) was a control performed in supine decubitus without pneumoperitoneum. The remaining series were performed with 15 mm Hg of pneumoperitoneum. Series 02 (PNEUMOPERITONEUM) was performed in supine position. Series 03 (RIGHT SIDE) was performed with 15° right lateral decubitus positioning. Series 04 (LEFT SIDE) was performed with 15° left lateral decubitus positioning. In the following series, a 15° Trendelenburg tilt was applied. Series 05 (TRENDELENBURG) was performed with a 15° Trendelenburg tilt. Series 06 (TRENDELENBURG AND RIGHT SIDE) included both Trendelenburg tilt and 15° right lateral decubitus positioning. Series 07 (TRENDELENBURG AND LATERAL LEFT) included Trendelenburg tilt and 15° left lateral decubitus positioning. In the last three series, manipulation of the colon was introduced by elevating the greater omentum and exposing the transverse colon. Series 08 (OMENTUM) only included the elevation of the greater omentum with 15° Trendelenburg tilt. Series 09 (OMENTUM AND RIGHT SIDE) added 15° right

lateral decubitus positioning. Series 10 (OMENTUM AND LEFT SIDE) added 15° left lateral decubitus positioning. The same order of manipulation was always followed for all three cadavers.

Obtaining and processing CT images

Following the described protocol, DICOM images were obtained using 3-mm CT scan sections. These images were processed with OsiriX software. The colon surface was manually individualized in all sections, and its image density was modified to obtain three-dimensional reconstructions. Chromatic changes in the three-dimensional images were made using Adobe Photoshop Elements 11.

After bringing the three-dimensional images to the frontal plane, the reference points were marked for the proposed measures. These points were the anterior superior iliac spines (SPINE); the midpoint of the pubic symphysis (PUBIS); the root of the superior mesenteric artery (SMA); the root of the inferior mesenteric artery (IMA); the highest point of the colon in the right hemiabdomen, in the transition zone between the ascending colon and the transverse colon (HF); and the highest point of the colon in the left hemiabdomen, in the transition zone between the transverse colon and the descending colon (SA).

Morphometric study

The cadavers were always studied in the frontal position. These measurements were performed using the computer program ImageJ and were calculated in pixels, which were later transformed to centimetres, and in sexagesimal degrees. The reference measurement was the SPINE-SPINE distance. To minimize the possible degree of distortion that could result from modifying the cadavers' position relative to supine decubitus, this measure was used to apply a correction factor in each series. Thus, the differences observed in this measure after the cadavers were successively repositioned were less than 2‰. A correlation analysis was performed to assess the dependence of some variables on others.

Results

A total of 390 measurements were performed. Series 01 of the three cadavers was used as a reference and 159 measurements were modified more than 5% compared to this baseline. To systematize these results, we divided them into four sections depending on the angle and its components (**Fig. 1**).

The PUBIS-SMA distance increased in all series in cadaver 1; in cadaver 2, it increased in series 02; in cadaver 3, it was not modified. The PUBIS-IMA distance increased in the last four series in cadaver 1 and decreased in series 04; in cadaver 2 it increased in all cases; in cadaver 3, it was not modified. The SMA-IMA distance increased in cadaver 1 in all series except for series 07; in cadaver 2, it decreased in all series except series 02, in which it did not change; in cadaver 3, it increased in all series except series 04, in which it did not change. The correlation test showed very high values between PUBIS-SMA and PUBIS-IMA ($r = 0.94$) and between PUBIS-IMA and SMA-IMA, although the correlation was negative ($r = -0.86$). The correlation between PUBIS-SMA and SMA-IMA was high and negative ($r = -0.64$) (**Table 1**).

Table 1. Variables related to the distances between PUBIS-SMA-IMA.

CADAVER 1	PUBIS-SMA		PUBIS-IMA		SMA-IMA	
Series 01	21.83		16.64		5.19	
Series 02	23.62	é	16.79		6.83	ée
Series 03	23.7	é	16.65		7.05	ée
Series 04	23.48	é	15.55	ê	7.93	ée
Series 05	23.41	é	16.19		7.22	ée
Series 06	24.3	ée	16.58		7.72	ée
Series 07	23.49	é	18.16	ée	5.33	
Series 08	23.65	é	18.18	ée	5.47	é
Series 09	24.02	ée	18.13	ée	5.89	ée
Series 10	23.88	é	17.76	ée	6.12	ée
CADAVER 2	PUBIS-SMA		PUBIS-IMA		SMA-IMA	
Series 01	26.84		22.61		4.23	
Series 02	28.57	é	24.02	é	4.55	
Series 03	27.62		24.12	é	3.5	êê
Series 04	28.14		25.03	ée	3.11	êê
Series 05	27.31		24.51	é	2.8	êê
Series 06	27.45		24.7	é	2.75	êê
Series 07	26.97		24.76	é	2.21	êê
Series 08	27.24		24.45	é	2.79	êê
Series 09	27.23		24.76	é	2.47	êê
Series 10	27.52		25.04	ée	2.48	êê
CADAVER 3	PUBIS-SMA		PUBIS-IMA		SMA-IMA	
Series 01	28.24		24.17		4.07	
Series 02	29.21		24.06		5.15	ée
Series 03	29.08		24.29		4.79	ée
Series 04	28.63		24.57		4.06	
Series 05	28.2		23.88		4.32	é
Series 06	29.41		24.76		4.65	ée
Series 07	28.89		24.33		4.56	ée
Series 08	28.32		24.02		4.3	é
Series 09	28.61		24.14		4.47	ée
Series 10	28.51		24.07		4.44	é

The HF-SMA-SA angle increased in all series in cadaver 1; in cadaver 2, it increased in series 02 and 04 and decreased in series 07, 08, 09 and 10; in cadaver 3, it only changes in series 09, in which it increased. The SMA-HF distance in cadaver 1 increased in series 02, 03, 05, 06, 07, 08 and 09 and decreased in series 04; in cadaver 2, it increased in series 04, 08 and 09; in cadaver 3, it increased in series 08 and 10 and decreased in series 09. The SMA-SA distance decreased in all series in cadaver 1; in cadaver 2, it decreased in series 02; in cadaver 3, it increased in series 03, 04, 08 and 10. The correlation test showed high values for the relationships among these variables (**Table 2**).

Table 2. Variables related to the HF-SMA-SA angle.

CADAVER 1	HF-SMA-SA		SMA-HF		SMA-SA	
Series 01	131.46		9.21		11.67	
Series 02	152.3	ée	10.43	ée	8.76	êê
Series 03	147.41	ée	10.87	ée	8.04	êê
Series 04	145.11	ée	5.01	êê	9.60	êê
Series 05	150.18	ée	11.06	ée	8.23	êê
Series 06	149.87	ée	10.97	ée	7.69	êê
Series 07	146.21	ée	10.52	ée	9.02	êê
Series 08	147.94	ée	10.83	ée	9.99	êê
Series 09	146.6	ée	10.75	ée	8.75	êê
Series 10	148.87	ée	9.30		10.27	êê
CADAVER 2	HF-SMA-SA		SMA-HF		SMA-SA	
Series 01	143.75		9.93		8.94	
Series 02	163.6	ée	10.11		7.93	êê
Series 03	153.57		10.82		8.23	
Series 04	165.62	ée	11.53	ée	8.84	
Series 05	144.19		9.25		8.52	
Series 06	144.67		9.98		9.01	
Series 07	140.44	êê	9.02		8.73	
Series 08	116.02	êê	11.36	ée	9.44	
Series 09	112.46	êê	12.81	ée	9.58	
Series 10	124.2	êê	10.71		8.59	
CADAVER 3	HF-SMA-SA		SMA-HF		SMA-SA	
Series 01	171.95		7.34		10.07	
Series 02	165.39		7.82		9.99	
Series 03	169.64		7.56		13.24	ée
Series 04	170.84		6.84		11.23	ée
Series 05	169.34		7.07		10.27	
Series 06	169.64		7.82		10.54	
Series 07	168.43		7.17		10.52	
Series 08	161.67		8.41	ée	12.77	ée
Series 09	124.07	êê	5.92	êê	10.84	
Series 10	165.4		8.64	ée	12.25	ée

The HF-IMA-SA angle was modified in five series in cadaver 1 in various direction and magnitudes; in cadaver 2, it increased in all series from 02 to 07 and decreased in series 08 and 09. In cadaver 3, it only changed in the last three series, in which it decreased. The IMA-HF distance decreased in series 04, 07, 09 and 10 in cadaver 1; in cadaver 2, it increased in series 02, 03, 04, 08, 09 and 10 and decreased in series 07. In cadaver 3, it changed in seven series, with different directions and magnitudes. The IMA-SA distance in cadaver 1 changed irregularly in four series; in cadaver 2, it decreased in series 02, 03, 04, 05, 06 and 07; in cadaver 3, it did not change in series 06, decreased in series 03 and increased in the rest of the series. The correlation was strong and negative only for HF-IMA-AS and IMA-HF ($r = -0.66$) (**Table 3**).

Table 3. Variables related to the HF-IMA-SA angle

CADAVER 1	HF-IMA-SA		IMA-HF		IMA-SA	
Series 01	89.60		13.40		13.62	
Series 02	89.94		13.04		13.18	
Series 03	88.83		13.31		12.43	ê
Series 04	65.94	êê	10.07	êê	14.74	é
Series 05	91.86		13.09		13.50	
Series 06	84.55	êê	13.75		12.87	ê
Series 07	99.75	ée	11.88	êê	12.78	ê
Series 08	101.03	ée	12.74		13.30	
Series 09	96.08	é	12.43	ê	13.04	
Series 10	93.19		12.04	êê	13.68	
CADAVER 2	HF-IMA-SA		IMA-HF		IMA-SA	
Series 01	105.12		11.05		11.36	
Series 02	112.13	é	11.70	é	9.66	êê
Series 03	116.37	ée	12.14	é	9.75	êê
Series 04	130.25	ée	12.87	ée	9.48	êê
Series 05	110.83	é	10.71		9.69	êê
Series 06	113.55	é	11.43		10.02	êê
Series 07	114.94	ée	9.99	ê	9.70	êê
Series 08	98.38	ê	12.45	ée	11.03	
Series 09	94.23	êê	13.64	ée	11.66	
Series 10	103.68		11.61	é	10.31	
CADAVER 3	HF-IMA-SA		IMA-HF		IMA-SA	
Series 01	135.74		7.23		11.33	
Series 02	132.03		7.30		11.89	é
Series 03	131.91		7.76	é	11.01	ê
Series 04	137.04		6.31	êê	12.77	ée
Series 05	132.14		6.79	ê	12.04	é
Series 06	133.01		7.68	é	11.86	
Series 07	134.40		6.63	ê	12.25	é
Series 08	119.00	êê	8.21	ée	15.76	ée
Series 09	80.30	êê	7.87	ée	14.30	ée
Series 10	121.44	êê	7.23		15.99	ée

The HF-PUBIS-SA angle did not change in cadaver 1; in cadaver 2, it decreased in series 06, 07 and 08; in cadaver 3, it increased in series 02 and decreased in the last three series. The PUBIS-HF distance did not change in cadavers 1 and 2; in cadaver 3, it increased in series 09 and decreased in series 10. The PUBIS-SA distance did not change in cadaver 1; in cadavers 2 and 3, it increased in series 08, 09 and 10. The correlation was only strong between HF-PUBIS-SA and PUBIS-SA, and the relationship was negative ($r = -0.71$) (Table 4).

Table 4. Variables related to the HF-PUBIS-SA angle.

CADAVER 1	HF-PUBIS-SA		PUBIS-HF		PUBIS-SA	
Series 01	39.83		39.83		29.08	
Series 02	39.08		26.43		28.87	
Series 03	38.77		26.33		27.81	
Series 04	29.30		25.06		29.09	
Series 05	39.87		25.62		28.60	
Series 06	37.96		26.51		28.87	
Series 07	39.37		25.90		29.58	
Series 08	41.45		26.24		30.09	
Series 09	39.08		26.49		29.93	
Series 10	38.66		26.58		30.08	
CADAVER 2	HF-PUBIS-SA		PUBIS-HF		PUBIS-SA	
Series 01	37.99		30.72		32.56	
Series 02	37.45		30.23		32.30	
Series 03	38.24		31.26		32.04	
Series 04	36.75		30.22		32.72	
Series 05	36.60		30.61		32.07	
Series 06	36.00	ê	30.87		32.46	
Series 07	34.55	ê	30.48		32.12	
Series 08	31.46	êê	29.13		35.01	é
Series 09	34.69		31.95		35.82	ée
Series 10	36.13		30.63		35.58	é
CADAVER 3	HF-PUBIS-SA		PUBIS-HF		PUBIS-SA	
Series 01	33.34		27.10		32.30	
Series 02	35.16	é	26.61		32.59	
Series 03	33.05		27.20		33.00	
Series 04	34.42		27.01		33.27	
Series 05	34.25		26.58		31.68	
Series 06	33.58		27.20		33.05	
Series 07	32.65		26.79		32.53	
Series 08	31.05	ê	25.87		38.34	ée
Series 09	21.35	êê	29.02	é	38.10	ée
Series 10	29.49	êê	25.03	ê	38.56	ée

Discussion

Computer-aided anatomical analysis with the DICOM protocol is the most widely used medical imaging standard for the study and transfer of images [20-22]. This technology allowed us to examine the positions of different points of the abdominal viscera induced by different decubitus positions [13-15]. Our results are both descriptive and quantifiable. To perform interventions in laparoscopic surgery, the patient is positioned in decubitus to make the viscera targeted for the surgery more accessible [16]. However, the use of these decubitus positions is intuitive and is based on the positioning of organs [14,16]). Our results were not homogeneous, so the mobility of the different points studied could be related to more than one factor, such as fixations to the peritoneum and the proximity of other viscera.

Limitations of the study could include the small number of cadavers used and the method of fixation. Regarding the first, the performance of ten series in each of the three cadavers significantly increased the sample size of our study, so we consider the total number of measurements sufficient to initially assess the movements of the colon. Regarding the second point, the Thiel technique is the fixation technique used for training models for laparoscopic surgery [19,23]. Since it does not make the cadaver excessively stiff, it is considered ideal for the study of the mobility of the abdominal viscera [19].

Our descriptive results are difficult to systematize when compared with the individual characteristics of the colon. Cadaver 1 had the longest colon and had the largest number of modified variables. Cadaver 2 had a very short colon and an intermediate number of modified variables. Finally, the colon of cadaver 3 had an intermediate length and the fewest modified variables. These results do not support the hypothesized relationship between size of the colon and the changes in the variables.

The correlations between the pubis and the mesenteric arteries and the mesenteric arteries with themselves suggest that when the distance from the pubis to the inferior mesenteric artery is modified, the distance and direction from the pubis to the superior mesenteric artery also changes. However, the distance from the pubis to the superior mesenteric artery and from the pubis to the inferior mesenteric artery is related to the distance between the two mesenteric arteries, although in a different direction. This leads us to propose that the distance between the two arteries tends to compensate for variations in the distance from the pubis to the superior mesenteric artery. Thus, the inferior mesenteric artery point could be more mobile than the superior mesenteric artery point. This proposal can be explained by the fact that the superior mesenteric artery is pinched by the pancreas at its outlet, increasing the mobility of the inferior pancreaticoduodenal artery as it enters the mesentery artery [1-4]. These three characteristics make the superior mesenteric artery more limited in its movements than the inferior mesenteric artery, which simply attaches to the parietal peritoneum [1-4].

According to the correlation test, the angle between the inferior mesenteric artery and the colic flexures increases as the distance from the mesenteric artery exceeds the hepatic flexure and vice versa. The hepatic flexure is in direct contact with the renal fascia since the peritoneal folds that attach it to the posterior wall are very short; this configuration confers limited mobility. In contrast, the splenic flexure is attached to the wall by the phrenicocolic ligament, which is a longer peritoneal fold and thus allows more mobility (Gallot, 2006; Bourgouin et al., 2012; Barussaud et al., 2015; Gao et al., 2017). Therefore, when the inferior mesenteric artery is mobilized, the angle formed between it and the colic flexures is more closely related to the distance between the artery and the hepatic flexure, which has a fixed end, than to the distance from the splenic flexure, whose two extremes are more lax.

The variables related to the angle between the superior mesenteric artery and the colic flexures changed in different directions, and a high correlation index was not obtained. This may be because, as noted above, the superior mesenteric artery point depends on the pancreas, the pancreaticoduodenal artery outlet, and the mesenteric root, making it difficult to predict their movements in relation to the hepatic and splenic flexures (Gallot, 2006; Bourgouin et al., 2012; Barussaud et al., 2015; Gao et al., 2017).

The variables related to the angle between the pubis and the colic flexures were the least modified, possibly because the pubis is a fixed point just as the hepatic flexure is and the size of this angle is inversely related to the displacements of its most mobile point, such as the splenic flexure. This may explain the high correlation index between the angle formed by the pubis and the colic flexures and the distance from the pubis to the splenic flexure.

Changes in the position of certain segments of the colon have been identified during virtual colonoscopy studies when the patient changes from supine to prone position (Rottgen et al., 2005; Punwani et al., 2009; Pirlet et al., 2014). These changes may be due to the need for insufflation of the colon to carry out the study. In fact, in endoscopic studies, the lateral decubitus position can be changed to the supine decubitus position to achieve a better intraluminal approach to the colic frame (Rottgen et al., 2005).

Laparoscopy is currently the technique of choice for most surgical procedures on the colon. Many studies have been published comparing laparoscopic surgery with open surgery and showing the benefits of laparoscopic surgery (Weeks et al., 2002; Wong et al., 2012). The series established in the working protocol reproduced the different postural changes performed during surgery. The aim of lateral decubitus positioning is to displace the intestinal loops towards the corresponding side, obtaining a good exposure of the colon, and to attempt greater medial displacement of the hepatic flexure or the splenic flexure (according to the side) when performing correct traction. More mobile points, such as the ileocecal junction or even the descending colon-sigmoid junction, may have greater displacement (Sadler et al., 2007; Shimizu et al., 2016). Regarding our proposal, our quantitative results are imprecise. However, the correlation analysis allowed us to relate the displacements of the studied points to one another. In this way, we have associated these displacements with the mobility of the points according to their insertion in the peritoneum. A short insertion allows little mobility (hepatic flexure), in contrast with a long insertion (splenic flexure) or a less fixed insertion (inferior mesenteric artery). When the point studied was related to additional factors, such as the proximity of another organ or vessel (superior mesenteric artery), the displacement was more difficult to determine. Thus, when a distance is defined by a fixed point and a moving point, it is easier to determine its angle than if the segment is delimited by two moving points.

Conclusions

Colon undergoes changes in the location of certain segments in the application of factors such as position changes and pneumoperitoneum pressure. These changes, which can be measured by three-dimensional reconstruction images, could be related to their fixations to the peritoneum, to the proximity of the neighbouring viscera and to their location in the abdomen.

Declarations

Ethics approval and consent to participate

The use of the images and the collection of data were approved by the Clinical Research Ethics Committee of Aragón. The cadavers were voluntarily donated to the Jesus Usón Minimally Invasive Surgery Centre, with a written informed consent for use in scientific studies.

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by JF, JDE, FMS, VEG, MJL, IC, JAF, JM, CL and JU. The first draft of the manuscript was written by JF and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

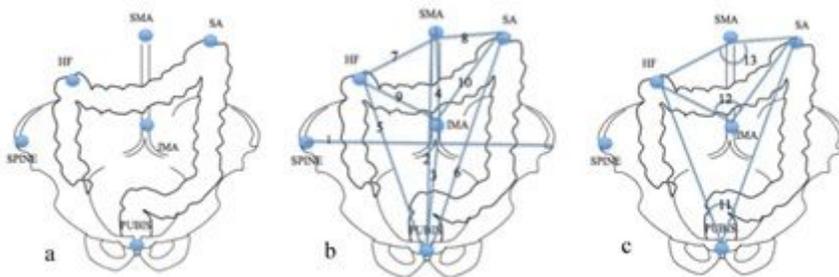


Figure 1

Location of the variables proposed in the study as reference points and as measures of length and angle. a: Proposed reference points. b: Measurements of the proposed lengths: SPINE-SPINE length (1), PUBIS-SMA length (2). PUBIS-IMA length (3). SMA-IMA length (4). PUBIS-HF length (5). PUBIS-SA length (6). SMA-HF length (7). SMA-SA length (8). IMA-HF length (9). IMA-SA length (10). c: Proposed angle measurements: HF-PUBIS-SA angle (11). HF-SMA-SA angle (12). HF-IMA-SA angle (13).