Volumetric remodeling evaluated after frozen elephant trunk by 3D technology in acute type A aortic dissection

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Abstract

Background: Three-dimensional reconstruction technology is used to measure the volume of the descending aorta and to evaluate the characteristics of the remodeling of the descending aorta with different lengths after frozen elephant trunk (FET) treatment of acute type A aortic dissection (ATAAD). Methods: Three-dimensional reconstruction of the computed tomography angiography (CTA) of 48 cases ATAAD patients preoperatively and 1-3 months postoperatively was performed to measure the total volume of the aorta lumen model, descending aorta lumen volume, abdominal arterial lumen volume, as well as the true lumen (TL) and false lumen (FL) of each segment. The postoperative volumetric ratio was subtracted from the preoperative volumetric ratio, and the final distinction was made according to our remodeling classification criteria. Result: There were 13 (76.47%) positive remodeling cases, 9 (42.86%) stable remodeling cases, and 2 (20.00%) negative remodeling cases in the long FET group. In the short FET group, there were 4 (23.53%) positive remodeling cases, 12 (57.14%) stable remodeling cases, and 8 (80.00%) negative remodeling cases. As shown above, the data was obtained from the volumetric measurement and the morphological analysis of the three-dimensional reconstruction model. Conclusion: According to our classification criteria, long FET can promote the positive remodeling of the descending aorta, and it is meaningful for three-dimensional reconstruction to be used in volume measurement and morphological research.

INTRODUCTION

Acute type A aortic dissection (ATAAD) is a common and life-threatening aortic disease with significant morbidity and mortality [1]. The hospitalization rate of aortic dissection was 2.0/100'000 per year [2]. It was expected that emergency surgery was safe to rescue patients suffering from catastrophic conditions [3].

Most studies report the aortic diameter [4-5], several groups [6-7] recommend volumetric measurement and morphological changes as the accurate method to assess descending aortic remodeling. However, there was no volume classification assessment standard for ATAAD patients, and the remodeling result of different lengths after frozen elephant trunk(FET) implantation is still controversial.

Our purpose is to measure volumetric changes of ATAAD patients with different lengths of FET on computed tomography angiography (CTA) and use three-dimensional reconstruction technology to reconstruct models and evaluate the results of descending aorta remodeling.

PATIENTS AND METHODS

This retrospective study was approved by the Ethics Committee of Guangdong Provincial People's Hospital (No.GDREC2019840H(R1)) on April 4th, 2019. Individual written informed consent was obtained from each patient before surgery.

Patients

Between January 2017 to January 2021, 60 cases of ATAAD patients were operated on with ascending aorta replacement, total arch replacement, and FET. 48 cases patients were divided into two groups, according to FET length. For example, 80mm and 100mm were divided into short FET groups, 120mm and 150mm were divided into long FET groups. The range of aortic dissection involves the celiac artery, or the renal artery, or the bifurcation at the level of the iliac artery. All patients had no history of cardiovascular surgery. CTA scans were performed preoperative and postoperative 1 to 3 months. Preoperative and postoperative analysis and three-dimension reconstruction were performed on each patient.

Three-dimensional reconstruction and analysis

The patient's CTA images information was obtained from the hospitalization. CTA data were imported into Materialise's interactive medical image control system (MIMICS, version 19.0). MIMICS software was used to establish a digital three-dimensional model of the patient's aorta, distinguish the true and false lumen of the Total aorta (TA) by color, as well as descending aorta (DA), abdominal aorta (AbA), and analyzed all models volumes. All volumetric measurements were automatically measured by the computer.

TA was defined as along the pulmonary vein level at the ascending aorta to the horizontal bifurcation of the abdominal aorta. DA was defined as along the pulmonary vein level of the descending aorta to the celiac artery, and AbA was defined as along the celiac trunk to the horizontal bifurcation. The study area needed to calculate the volume was manually drawn in each CT slice. For each model of the aortic segment, calculate the volume values of the total aortic lumen (TAL), total true lumen (TTL), total false lumen (TFL), descending aorta aortic lumen (DAAL), descending aorta true lumen (DATL), descending aorta false lumen (DAFL), abdominal aorta aortic lumen (AbAL), abdominal aorta true lumen (AbTL), and abdominal aorta false lumen (AbFL), by the software. All volumes were expressed in mm^3. Thrombus was defined as missing on the three-dimension reconstruction model.

Classification criteria

We referred to the standard reported [17] for Thoracic Aortic Endovascular Repair (TEVAR), and considered a significant change in volume of more than 10% as one of the classification criteria. On this basis, if the true lumen(TL) was enlarged (TL more than 10%), the false lumen(FL) was closed or FL less than 10%, it was defined as positive remodeling; the TL changed non-significantly (TL more than -10% and less than 10%), and the FL changed less than 50%, partial thrombosis or closed, was defined as stable remodeling; if the FL changed more than 50%, and the TL changed less than 10%, it was defined as negative remodeling.

Operative technique

All surgical patients started from the median sternum incision, and all received FET treatment for the dissection of the distal descending aorta. According to the length of the trunk, there are two groups of long and short trunks. The aortic repair in the short trunk group is performed under cardiopulmonary bypass and deep-moderate hypothermic circulatory arrest (20˜25), and the patients in this group are mainly unilateral cerebral perfusion. For patients in the long stent group, surgery was mainly performed under cardiopulmonary bypass and moderate-to-light hypothermic circulatory arrest (25˜30), and most patients with long trunks received bilateral cerebral perfusion.

Determination of the FET diameter was based on the measurement of preoperative CT. The size of FET was selected based on the TL diameter measured by preoperative CT or the direct measurement of descending aortic TL during the operation.

We followed a protocol aimed at preventing spinal cord ischemia (SCI), especially when performing long FET surgery, which was a standard procedure for our surgical team. Including the lower extremities were perfused through the femoral artery, when the circulation was arrested. Bilateral cerebral perfusion was through the innominate artery, left common carotid artery or axillary artery, and the circulation was arrested at moderate to mild hypothermia (25~30).

Data analysis

Data are indicated as mean ± standard deviation (SD) (Gaussian distribution) or median (range) (Skewed distribution) for continuous variables and as numbers and percentages for categorical variables. χ 2 (categorical variables), student t-test (normal distribution) were used to detect the differences among different FET lengths (binary variable). Categorical variables were compared across groups using Fisher's exact test. Values were considered statistically significant when P <0.05. All the analyses were performed with the statistical software packages R (http://www.R-project.org, The R Foundation) and EmpowerStats (http://www.empowerstats.com, X&Y Solutions, Inc, Boston, MA).

RESULT

Baseline

A total of 48 patients with acute Stanford type A aortic dissection underwent FET surgery. The baseline data and surgical data were shown in**Table 1** and **Table 2** . The propensity scores**(Table 3)** were matched according to the age and the FL distal position, the matching ratio was 1:1, and the balance test of length was shown in **Table 4** . All patients were divided into two groups, the short FET group, and the long FET group. After propensity score matching, the preoperative data of the two groups were balanced.

Intraoperative data in **Table 2** show that the long FET group received bilateral cerebral perfusion (P <0.001), femoral artery perfusion (P <0.001), and moderate-light hypothermic circulatory arrest (P <0.001); the short FET group received unilateral cerebral perfusion (P <0.001), axillary artery perfusion (P =0.046), and deep hypothermic circulatory arrest (P <0.001). In the postoperative patient data **(Table 2)** , the distal landing zone of the long FET group was Th8-9, and the distal landing zone of the short FET group was Th6-8. No deaths were observed in both groups of patients. There was no significant difference in stroke, SCI, infection, and leakage.

Three-dimension reconstruction

As shown in **Figure 1** , the three-dimension reconstruction model was based on the specific position of the aorta drawn on the coronal, sagittal, and transverse planes of CTA. The reconstruction model of the preoperative and postoperative aorta is shown in **Figure 2** , including postoperative models of the aorta implanted with 80mm, 100mm, 120mm, and 150mm FETs. The morphological volume of the descending aorta FL in the long FET group (120mm and 150mm) was significantly reduced compared to the short FET group (80mm and 100mm).

Total aorta

We measured the volume of the total aorta, and the results were shown in**Figure 3** . The percentage of TTL was increased, the percentage of TTL in TAL was also increased, and the percentage of FL was decreased. In the long FET group, TTL/FL was increased by 282%, TTL/AL was increased by 38%, and TFL/AL was decreased by 39%. In the short FET group, TTL/FL was increased by 194.5%, TTL/AL was increased by 35.5%, and TFL/AL was decreased by 36%.

Descending aorta

We measured the volume of the descending aorta. As shown in**Figure 4** , the percentage of DATL group was increased, the percentage of DATL in TAL was also increased, and the percentage of DAFL was decreased. In the long FET group, DATL/DAFL was increased by 190%, DATL/DAAL was increased by 31.5%, DAFL/DAAL was decreased by 37.5%, and DATL/TTL was increased by 9%. In the short FET group, DATL/DAFL was increased by 129%, DATL/DAAL was increased by 28%, DAFL/DAAL was decreased by 29%, and DATL/TTL was decreased by 1.5%.

Abdominal aorta

We measured the volume of the abdominal aorta and the results were shown in **Figure 5** . The percentage of AbTL was decreased, the percentage of AbTL in TATL was also decreased, and the percentage of AbFL was increased. In the long FET group, AbTL/AbFL was decreased by 13%, AbTL/AbAL did not change (P =0.6685), AbFL/AbAL was increased by 0.5%, and AbTL/TTL was decreased by 4.5%. In the short FET group, AbTL/AbFL was decreased by 13%, AbTL/AbAL was decreased by 5%, AbFL/AbAL was increased by 5%, and AbTL/TTL was decreased by 6%.

Remodeling

We performed three-dimensional reconstruction on CT of all patients, as shown in **Figure 6** and **Table 5** . After following our classification criteria for remodeling, there were 13 positive remodeling cases, 9 stable remodeling cases, and 2 negative remodeling cases in the long FET group, and in the short FET group, there were 4 positive remodeling cases, 12 stable remodeling cases, and 8 negative remodeling cases, based on the data obtained from the volumetric measurement and the morphological analysis of the three-dimensional reconstruction model.

DISCUSSION

We recommend using the classification method mentioned above for evaluation. It was more accurate to measure the volume of the descending aorta with three-dimensional reconstruction technology than to measure the maximum diameter and area because the morphological changes of the aortic dissection can be monitored.

To prevent negative remodeling, the number of FL exits should be reduced [9]. Aortic remodeling was related to a persistent FL with partial or complete thrombosis in 90% of cases [10]. The FL of the descending aorta was more prone to thrombosis than the abdomen, due to the blood supply of the internal organs artery entering through the abdomen FL, which preventing the closure of the FL [11]. But it would not cause paraplegia or death by elongate the FET to increase the coverage, and it could promote larger thrombus in the distal FL of the descending aorta contrary[12]. Due to increased FL thrombosis, the extended FET strategy was better at avoiding negative remodeling than standard FET [13]. However, the patent abdominal aorta FL without the coverage of FET may require a second-stage intervention operation [14]. Thus, the ability to accurately identify the expansion of the lumen had a great significance, because the wrong classification may underestimate the rate of FL expansion, which may lead to an increased risk of rupture [7].

Kozlov et al[13]. reported the incident of SCI was 0%, and the ratio of non-negative remodeling that distant landed on Th9 was 67.5% in the short FET group and that distal landed on the L1 was 80% in the long FET group. Similarly, Hoffman et al [15]. reported that choosing a distal landing zone at Th10 to Th12 was safe for SCI in the FET procedure of ATAAD. They performed a more extensive repair of the dissected aorta and blocked the FL clearly in the first procedure. Consequently, we suggest that the landing position on Th8 to Th9 in the long FET group could indeed promote the non-negative remodeling of the descending aorta, and the proportion of positive remodeling in the long FET group was significantly higher than that in the short FET group.

In summary, our classification method can more detailed and accurately evaluate the remodeling results of the descending aorta for measuring the volume. Long FET can be used to treat patients with ATAAD to obtain acceptable remodeling of the descending aorta after measuring the aortic volume. The use of three-dimensional reconstruction technology to establish aortic models can effectively study the morphological changes of the aorta. Compared with the diameter measurement method, volumetric measurement methods can provide more precise evidence for assessing postoperative aortic remodeling.

LIMITATION

The number of patients in this study was small, but the TL and FL of the aorta we analyzed involved the three-dimensional reconstruction and volume measurement of models of different regions. In addition, further research needs to include long-term follow-up patients to solve the problem.

CONCLUSION

We proposed that volumetric measurement could be used to the classification criteria to evaluate the degree of descending aortic remodeling, and prolonged to Th9 does not cause spinal cord injury.

AUTHOR CONTRIBUTIONS

Xiaoping Fan designed this study; Guangtian Chen and Xinjian Yan obtained and analyzed the data. Qiuer Liang, Jie He, Jihai Peng, and Chaojie Wang analyzed and collated the data. Guangtian Chen and Xinjian Yan drafted the manuscript. All authors have approved the article.

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Figure Legends

Figure 1 . Materialise's interactive medical image control system (MIMICS, version 19.0); (A) Coronal plane; (B) Transverse plane; (C) sagittal plane; (D) Three-dimension reconstruction model.

Figure 2 . The reconstruction model of the preoperative and postoperative aorta; Postoperative models of the aorta implanted with 80mm, 100mm, 120mm, and 150mm FETs. The morphological volume of the descending aorta FL in the long FET group (120mm and 150mm) was significantly reduced compared to the short FET group (80mm and 100mm).

Figure 3 . The total aorta; (A) Postoperative and preoperative volumetric changes of TTL/TFL. (B) Postoperative and preoperative volumetric changes of TFL/TAL. (C) Postoperative and preoperative volumetric changes of TTL/TAL. $P^*<0.05$.

Figure 4 . The descending aorta; (A) Postoperative and preoperative volumetric changes of DATL/DAFL. (B) Postoperative and preoperative volumetric changes of DATL/DAAL. (C) Postoperative and preoperative volumetric changes of DAFL/DAAL. (D) Postoperative and preoperative volumetric changes of DATL/TTL. $P^*<0.05$.

Figure 5 . The abdominal aorta; (A) Postoperative and preoperative volumetric changes of AbTL/AbFL. (B) Postoperative and preoperative volumetric changes of AbTL/AbAL. (C) Postoperative and preoperative volumetric changes of AbFL/AbAL. (D) Postoperative and preoperative volumetric changes of AbTL/TTL. $P^*<0.05$.

Figure 6 . Postoperative remodeling results of descending aorta; Coordinate: 0=short; FET group; 1=long FET group; result: 1=negative remodeling; 2=stable remodeling; 3=positive remodeling. $P=0.0123$.

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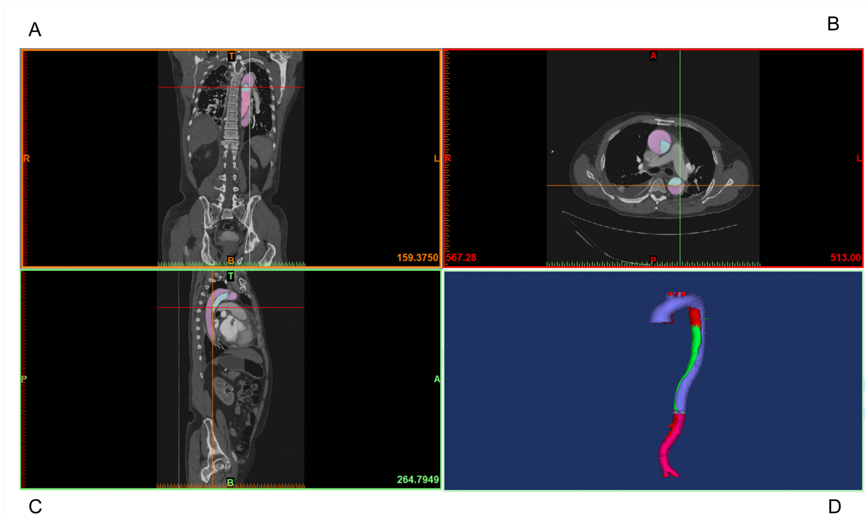

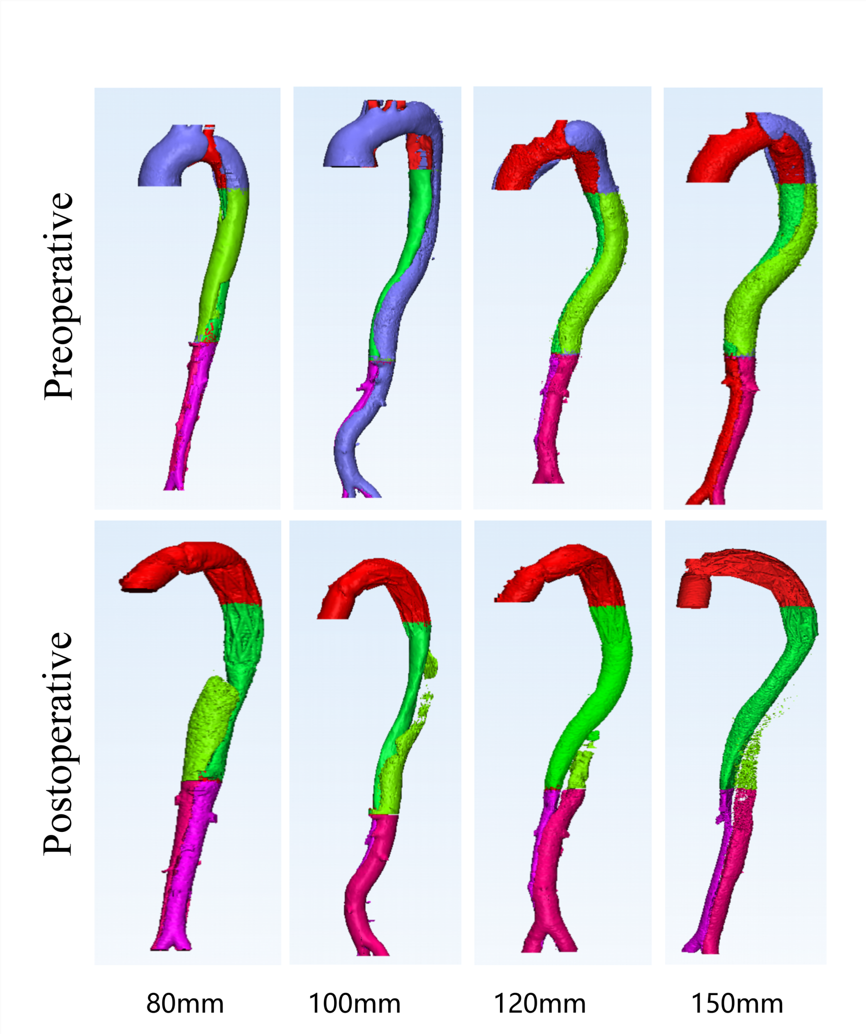
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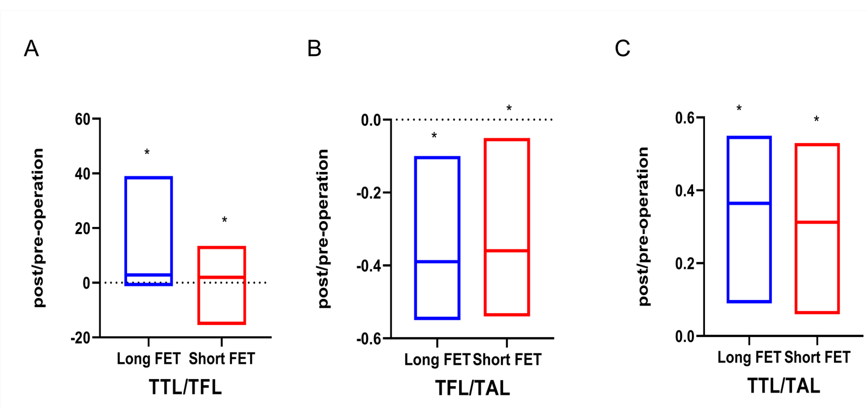
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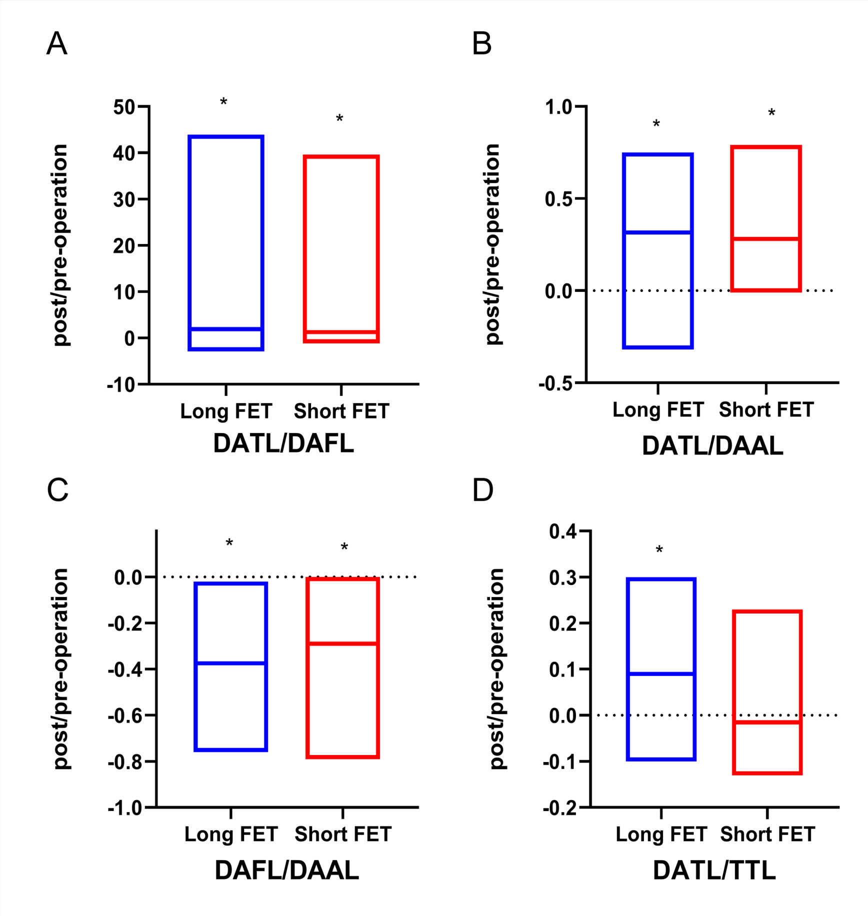
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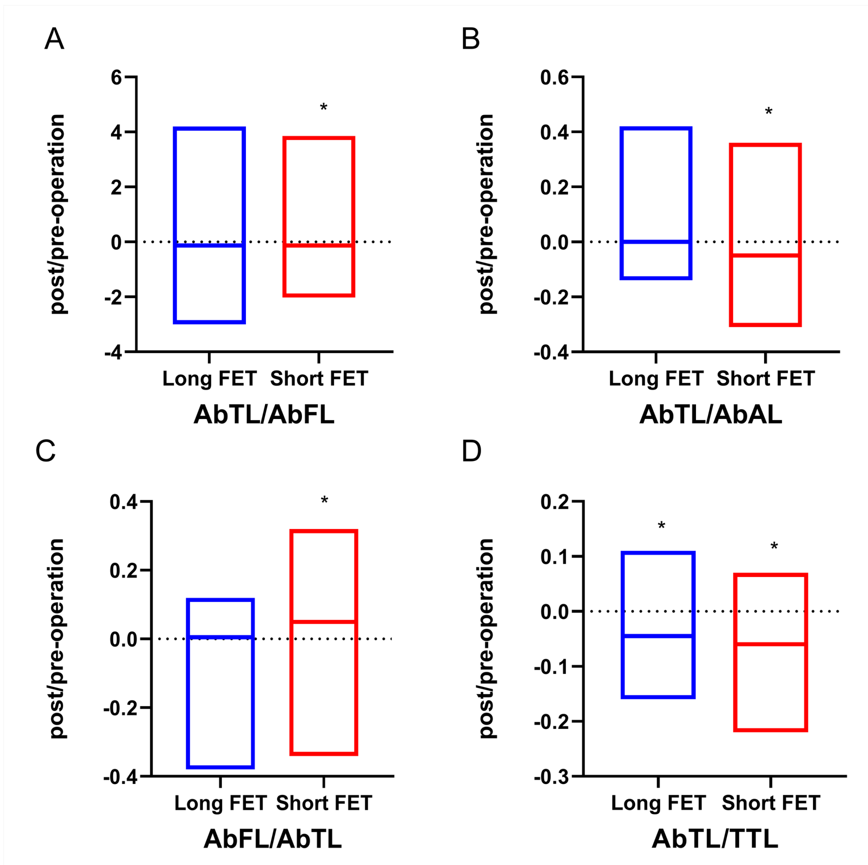
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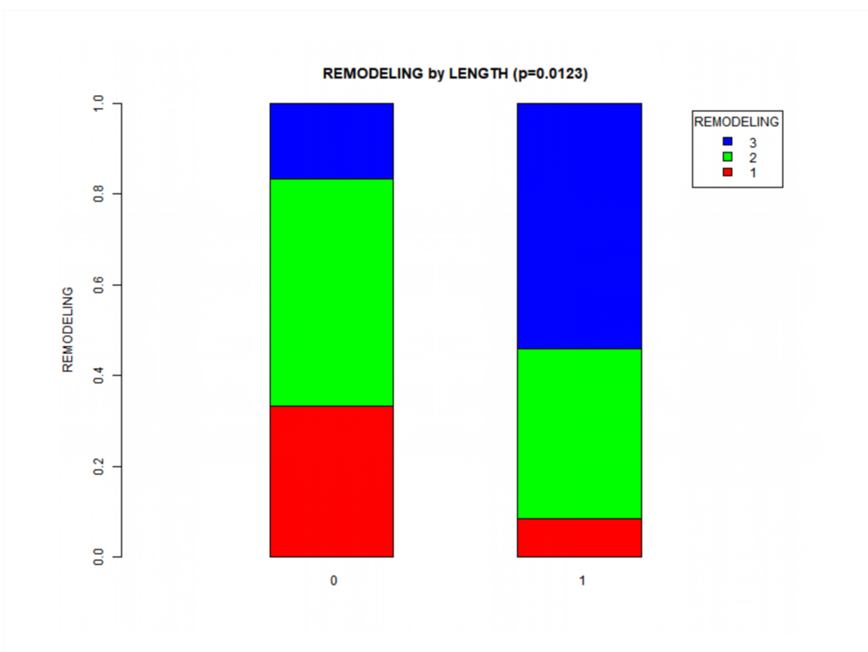
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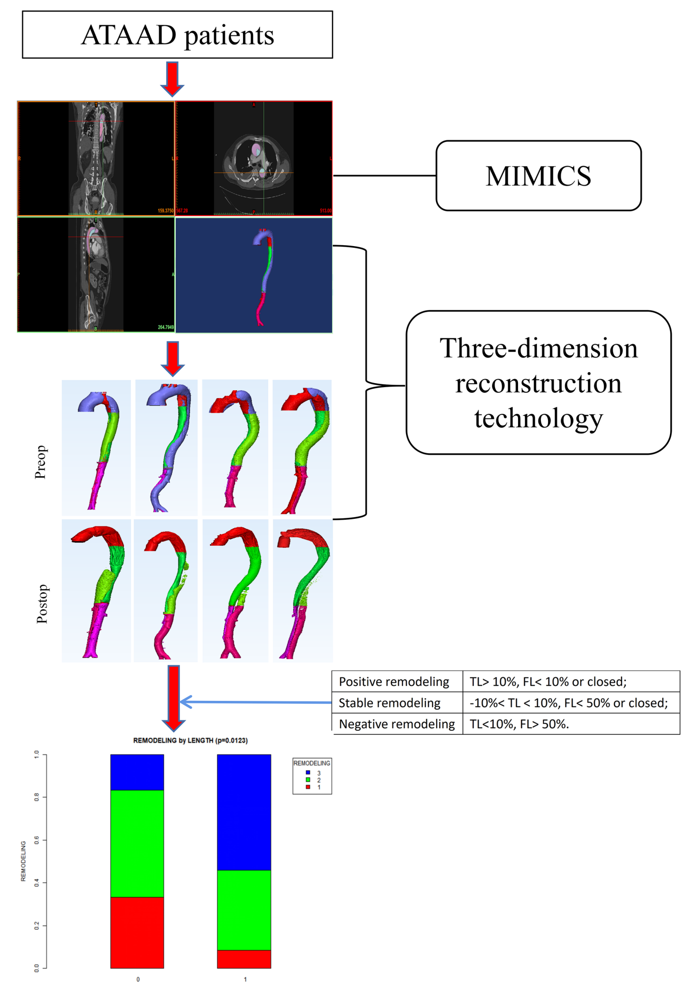
ATAAD patients
MIMICS
Three-dimension reconstruction technology
Preop
Postop
Positive remodeling
TL> 10%, FL< 10% or closed;
Stable remodeling
-10%< TL < 10%, FL< 50% or closed;
Negative remodeling
TL<10%, FL> 50%.
REMODELING by LENGTH (p=0.0123)
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