

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/355692186>

# Evaluation of Safety of Overhead Upper Extremity Positioning During Fenestrated–Branched Endovascular Repair of Thoracoabdominal Aortic Aneurysms

Article in CardioVascular and Interventional Radiology · October 2021

DOI: 10.1007/s00270-021-02992-1

CITATIONS

4

READS

227

5 authors, including:



**Julianna Barreira Marcondes**

University of Texas Health Science Center at Houston

48 PUBLICATIONS 210 CITATIONS

SEE PROFILE



**Emanuel R. Tenorio**

University of Texas Health Science Center at Houston

219 PUBLICATIONS 2,238 CITATIONS

SEE PROFILE



**Gustavo S. Oderich**

University of Texas Health Science Center at Houston

721 PUBLICATIONS 13,139 CITATIONS

SEE PROFILE

## Query Details

[Back to Main Page](#)

### 1. Please confirm the section headings are correctly identified.

Section headings are correct

### 2. Please check the edit made in the article title.

Title is correct

### 3. Kindly check and confirm the updated details for the references [10, 13].

References are correct

G. B. Marcondes et al.: Evaluation of Safety of Overhead Upper Extremity Positioning During...

## Clinical Investigation

# Evaluation of Safety of Overhead Upper Extremity Positioning During Fenestrated–Branched Endovascular Repair of Thoracoabdominal Aortic Aneurysms

Giulianna B. Marcondes [Affiliationids : Aff1](#)

Emanuel R. Tenorio [Affiliationids : Aff1](#)

Guilherme Baumgardt [Affiliationids : Aff1](#)

Bernardo Mendes [Affiliationids : Aff2](#)

Gustavo S. Oderich [✉](#)

Email : [gustavo.oderich@uth.tmc.edu](mailto:gustavo.oderich@uth.tmc.edu)

[Affiliationids : Aff1, Correspondingaffiliationid : Aff1](#)

[Aff1](#) Advanced Aortic Research Program, McGovern Medical School, University of Texas Health Science Center at Houston, 6400 Fannin St, Suite 2850, Houston, TX, 77030, USA

[Aff2](#) Division of Vascular and Endovascular Surgery, Mayo Clinic, Rochester, MN, USA

Received: 1 June 2021 / Accepted: 12 October 2021

## Abstract

### Purpose

Peripheral nerve and brachial plexus injury can occur from compression or stretching during positioning for operative procedures. The aim of this study was to evaluate the safety of overhead upper extremity positioning to optimize imaging during fenestrated–branched endovascular aortic repair (FB-EVAR) of pararenal (PRA) and thoracoabdominal aortic aneurysms (TAAAs).

### Methods

Forty-four consecutive patients enrolled in a prospective non-randomized study underwent FB-EVAR with overhead upper extremity positioning. Patients underwent intra-operative neuromonitoring of upper and lower extremities and neurological examination prior to discharge and at 2 months following the procedure. End points were peripheral or brachial plexus nerve injury, quality of lateral projection and cone beam computed tomography (CBCT) and major adverse event (MAEs).

### Results

There were 28 (64%) male patients with mean age of  $74 \pm 8$  years treated for 10 PRAs (23%) and 34 (78%) TAAAs. Mean body mass index was  $29 \pm 7$  kg/m<sup>2</sup>, with 17 obese patients (39%). Open surgical upper extremity access was used in 19 patients (43%). Three patients (16%) had access-related complications, all focal brachial artery dissections treated by patch angioplasty. Two patients (5%) developed upper extremity changes in neuromonitoring, which immediately resolved with repositioning of the upper extremity. Technical success was 95%. Lateral projection and rotational CBCT were feasible in all patients with satisfactory imaging quality for catheterization and stenting of the celiac axis and superior mesenteric artery. There was one mortality (2%) at 30 days, and six patients (14%) had MAEs. There were no upper extremity neurological injuries.

Overhead upper extremity position allows optimal imaging on lateral projections and rotational CBCT during FB-EVAR. There were no upper extremity neurological injuries in this study.

## Keywords

Fenestrated–branched endovascular aortic repair  
 Pararenal aortic aneurysm  
 Thoracoabdominal aortic aneurysm  
 Upper extremity position  
 Overhead position

## Introduction

Fenestrated and branched endovascular aortic repair (FB-EVAR) is widely utilized for treatment of pararenal (PRA) and thoracoabdominal aortic aneurysms (TAAAs). Advances in stent-grafts and imaging technology, better patient selection and increasing clinical experience have improved technical success with decreased morbidity in contemporary reports [1,2,3]. Optimal imaging is critical during these procedures for successful endovascular incorporation of the renal and mesenteric arteries. **AQ1** Advanced imaging features such as onlay fusion and rotational cone beam computed tomography (CBCT) have been used to minimize radiation exposure and for technical assessment [4,5,6,7]. Traditionally, patients treated by endovascular aortic repair are positioned in anatomical position with both upper extremities tucked lateral to the torso. In these cases, lateral imaging projections are often compromised and require more radiation exposure [8,9,10] **AQ2**.

Overhead upper extremity positioning may provide optimal imaging resolution in oblique or lateral views. Proper elbow and shoulder positioning and padding is important to relieve stretch tension and prevent brachial plexus or peripheral nerve injuries [11,12]. The aim of this study is to describe the safety and feasibility of overhead upper extremity position in a cohort of patients treated by FB-EVAR for complex aortic aneurysms.

## Methods

The study is a pilot single-center assessment of overhead upper extremity positioning in consecutive patients enrolled in a prospective non-randomized physician-sponsored investigational device study underwent FB-EVAR for PRA and TAAAs between September 2019 and June 2020. The study was approved by the Institutional Review Board, and all patients signed an informed consent form.

Demographics, clinical characteristics, cardiovascular risk factors, operative details and clinical outcome data were prospectively collected in case report forms and stored in an electronic data depository. Aneurysm classification and preoperative planning were determined by a high-resolution computed tomography angiography (CTA). Device design included manufactured patient-specific or off-the-shelf multi-branch stent-grafts (Cook Medical Inc., Australia and Denmark) according to physician preference. All patients were assessed prior to the operation for upper extremity mobility and were considered suitable for overhead upper extremity position. Patients who had limited mobility were excluded and had procedures performed using standard position with both upper extremities lateral to the torso. Intra-operative neuromonitoring with motor-evoked and somatosensory evoked potentials of the upper and lower extremities was used in all patients. If changes were noted in the upper extremities during the procedure, the arm position was changed from overhead to the standard position. Image quality was prospectively analyzed at the time of the procedure by the main operator and considered satisfactory or compromised. Neurological examination was performed after the operation, prior to dismissal and during follow-up visits.

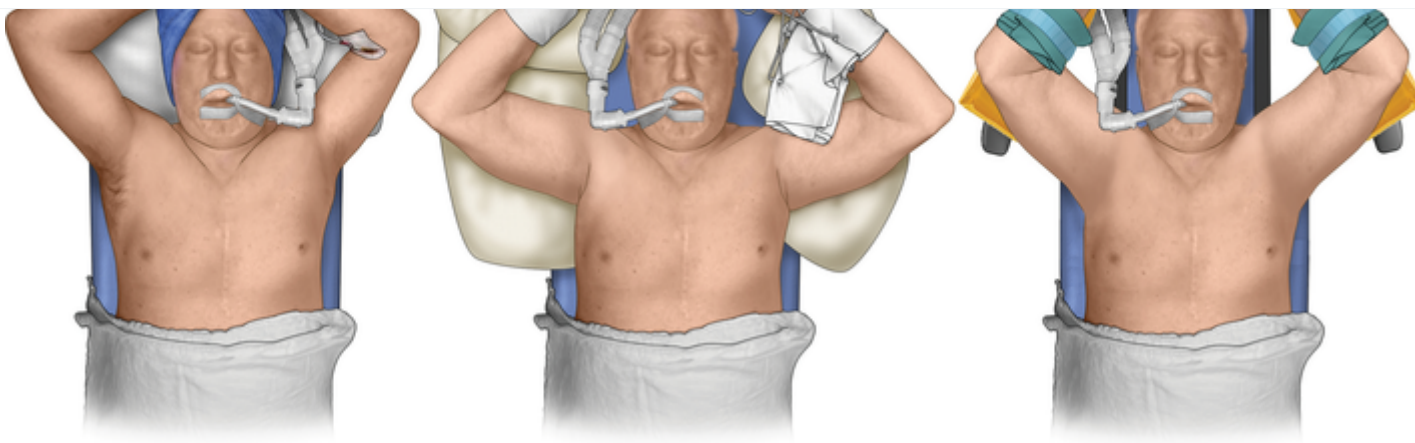
## Overhead Upper Extremity Positioning

The patient was examined prior to anesthesia for upper extremity mobility by positioning both upper extremities above the head for a few minutes while observing for any discomfort or symptoms of pain or paresthesia. If the initial maneuver was negative, the patient underwent general anesthesia and monitoring lines were placed. The patient was then positioned using standard head cushioning and eye protection with foam eye protector. For patients with wide overhead mobility and minimal limitation, a towel with loose ends was wrapped and clipped around the patient's forehead for wrist support (Fig. 1A). Cushioning and blankets were placed on both sides of the patient's upper extremities and around the head and shoulder level. These provided support and padding for patient's upper extremities while assuring a stable position. Central venous access lines were placed in the jugular vein and routed toward the ipsilateral side, while airway tubing was placed in the contra-lateral side. Each of the upper extremities was elevated above the head with the elbows positioned forward and upward, avoiding > 90° abduction. The wrists were secured to the towel wrapped around the forehead and/or to the supporting blankets with metal clips. If patient's overhead mobility was limited and did not allow placement of the wrists above the head, these were positioned by the side of the head. (Fig. 1B). Since the completion of this pilot study, we have progressed to using a supporting device to facilitate the overhead upper extremity positioning (Fig. 1C). Once proper function of anesthesia monitoring lines and adequacy of the imaging gantry position was checked, the patient was prepped and draped in standard fashion allowing surgical access to the axilla, chest, abdomen and both groins (Fig. 2).

### Fig. 1

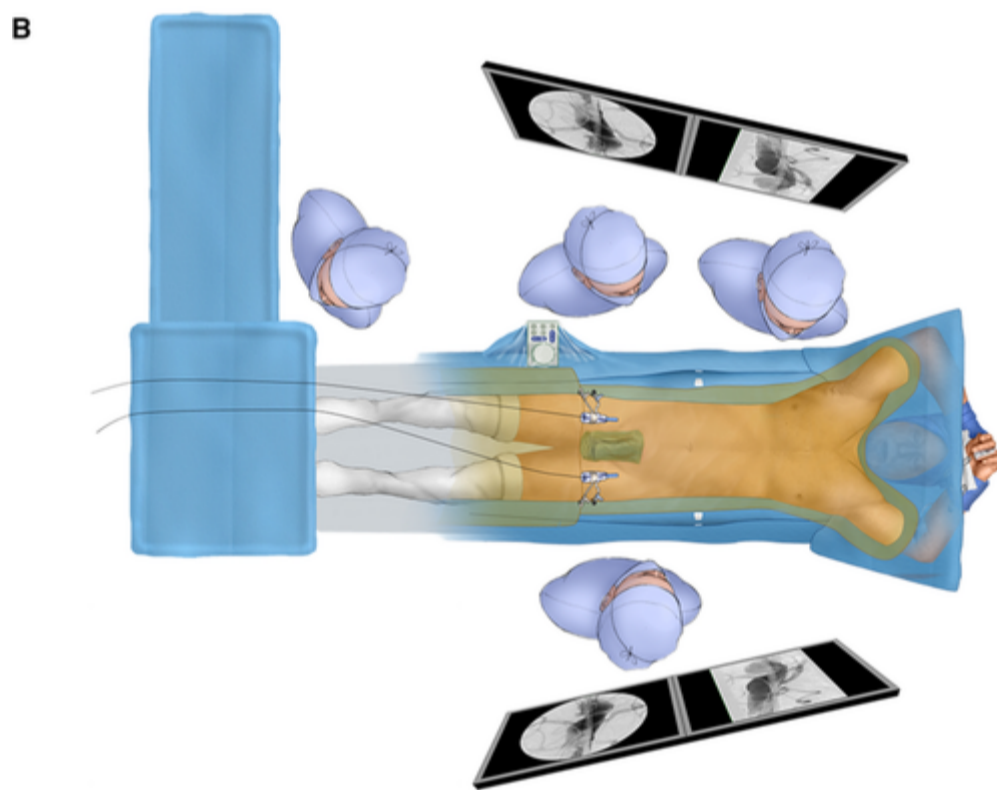
Patient with adequate shoulder mobility under overhead upper extremity positioning (A) and with limited shoulder mobility (B). Supporting device manufactured to facilitate the overhead upper extremity positioning (C)





**Fig. 2**

Patient ready for standard surgical procedure, eyes, head and arms protected and secured, anesthesia lines tested and functional. Elbows are flexed and placed in an elevated plane and arm abduction is limited to  $90^\circ$  (A). The primary operator, first assistant and scrub nurse are positioned to the right side of the table with the second assistant to the left side of the table. The C-arm is positioned from the head of the table to facilitate access from both sides (B)



## Statistical Analysis

Data were analyzed and reported according to the Society for Vascular Surgery (SVS) reporting standards for endovascular repair of aneurysms involving the renal and mesenteric arteries [13]. Intra-operative upper extremity arterial access complications and changes in upper extremity neuromonitoring by somatosensory evoked potential (SSEP) were assessed and reported. Changes in SSEP were considered significant if the baseline evoked potential amplitude decreased by at least 75% [14]. Technical success was defined by successful delivery of all intended stents with patent target vessels. Early outcomes were assessed within 30 days of the procedure or within the duration of the hospital stay, if longer than 30 days. Major adverse events (MAEs) included any cause of mortality, myocardial infarction, respiratory failure, major stroke, paraplegia, gastrointestinal ischemia requiring surgical resection, and acute kidney injury (AKI) according to RIFLE criteria [15]. Access complications, early reinterventions, and upper extremity postoperative symptoms were also reported. Categorical variables were presented as numbers and percentages, and continuous variables were presented as mean, standard deviation and median with interquartile ranges (Q1–Q3). Data analysis was conducted using open-source available software (The Jamovi Project 2020, Jamovi Version 1.2, Sidney, Australia).

## Results

There were 62 patients treated by FB-EVAR during the study period. From this group, 18 patients (29%) had limited upper extremity mobility and were excluded from the analysis due to inability to tolerate overhead upper extremity positioning. Forty-four patients who had FB-EVAR with limited upper extremity mobility were included in the analysis. There were 28 males (64%) and 16 females (36%) in the analysis.

(36%) patients with mean age of  $74 \pm 8$  years-old (Table 1). Aneurysm classification was PRA in ten patients (23%) and TAAA in 34 patients (77%). The mean body mass index (BMI) was  $29 \pm 7$  kg/m<sup>2</sup>, and 17 patients (39%) were classified as obese (BMI  $\geq 30$  kg/m<sup>2</sup>), including one who had BMI of 55 kg/m<sup>2</sup>. The most prevalent cardiovascular risk factors were history of tobacco use and hypertension in 39 patients (89%) each, hypercholesterolemia in 35 patients (80%), coronary artery disease in 25 patients (57%) and stage III–V chronic kidney disease in 20 patients (45%). American Society of Anesthesiologist (ASA) classification  $\geq 3$  was present in 21 patients (48%). The mean aortic aneurysm diameter was  $64 \pm 11$  mm.

**Table 1**

Demographics, clinical and anatomical characteristics of 44 patients treated by FB-EVAR with overhead upper extremity position

All patients <i>n</i> = 44	
<i>n</i> (percent) or mean $\pm$ SD (median, IQR)	
Demographics	
Mean age (years)	74 $\pm$ 8 (75, 70–78)
Age > 80 years	9 (20)
Male gender	28 (64)
BMI (kg/m <sup>2</sup> )	29 $\pm$ 7 (29, 25–34)
Obesity (BMI $\geq 30$ kg/m <sup>2</sup> )	17 (39)
Cardiovascular risk factors	
Cigarette smoking	39 (89)
Hypertension	39 (89)
Hypercholesterolemia	35 (80)
Coronary artery disease	25 (57)
Chronic kidney disease stages III–V	20 (45)
Chronic obstructive pulmonary disease	6 (14)
Peripheral artery disease	5 (11)
Diabetes mellitus	5 (11)
Congestive heart failure	4 (9)
Stroke or TIA	3 (7)
Preoperative evaluation	
Creatinine (mg/dL)	1.1 $\pm$ 0.3 (1.1, 0.9–1.3)
eGFR (ml/min/1.73 m <sup>2</sup> )	65 $\pm$ 21 (61, 50–75)
ASA score	
Class 2	23 (52)
Class 3	20 (46)
Class 4	1 (2)
Prior aortic repair	
Open aortic repair	10 (23)
TEVAR	9 (20)
EVAR	3 (7)
Endovascular arch repair	1 (2)
FB-EVAR	0 (0)
Emergency setting	
Symptomatic non-ruptured	1 (2)
Anatomic characteristics	
Largest aortic diameter, mm	64 $\pm$ 11 (61, 57–67)
Aneurysm type	
Pararenal	10 (23)
Extent I	2 (5)
Extent II	10 (23)
Extent III	2 (5)
Extent IV	20 (45)

*SD* Standard deviation; *IQR* interquartile range; *BMI* body mass index; *TIA* Transient ischemic attack; *eGFR* estimate glomerular filtration rate; *ASA* American society of anesthesiologists; *TEVAR* thoracic endovascular aneurysm repair; *EVAR* endovascular aneurysm repair; *FB-EVAR* Fenestrated-branched endovascular aneurysm repair

All procedures were performed under general endotracheal anesthesia in a hybrid operating room using GE Discovery IGS 740 system (GE Healthcare, Chicago, Ill). Devices were patient-specific in 35 patients (80%) and off-the-shelf in nine patients (20%) (Table 2). There were 171 renal and mesenteric vessels incorporated by 114 fenestrations, 52 directional branches and five double-wide scallops, with a mean of  $3.9 \pm 0.4$  target vessels per patient. Thirty-seven patients (84%) had bilateral percutaneous femoral approach, and 19 patients (43%) had open surgical exposure of the upper brachial artery, which was obtained in the right side in 14 patients. The brachial artery access site was closed primarily in 16 patients and with bovine patch angioplasty in three patients. Technical success was obtained in 42 patients (95%) and 169 targeted vessels (99%). Two patients had loss of one of the renal arteries targets due to inability to catheterize the vessel or a dissection. Two patients (5%) developed decrease in intra-operative SSEP in one of the upper extremities during the initial 30 min of the procedure, which was treated with repositioning of that extremity to the anatomical position lateral to the torso. This maneuver resulted in immediate reversion of the sensory changes.

**Table 2**

Procedural details and device design of 44 patients treated by FB-EVAR with overhead upper extremity position

All patients <i>n</i> = 44	
<i>n</i> (percent) or mean $\pm$ SD (median, IQR)	
General anesthesia	44 (100)
<i>Device design</i>	
Patient specific	35 (80)
Off-the-shelf	9 (20)
<i>Total target vessels</i>	171 (100)
Fenestrations	114 (67)
Branches	52 (30)
Double-wide scallops	5 (3)
<i>Percutaneous femoral approach</i>	39 (89)
Unilateral	2 (5)
Bilateral	37 (84)
<i>Brachial or axillary access</i>	19 (43)
Right	14 (74)
Left	5 (26)
Intraoperative access complication	3 (16)
Amount of contrast material used (ml)	173 $\pm$ 82 (147, 125–225)
Total operative time (minutes)	214 $\pm$ 85 (187, 154–271)
Total fluoroscopy time (minutes)	76 $\pm$ 26 (70, 56–89)
Cumulative air kerma (Gy)	1.3 $\pm$ 0.6 (1.2, 0.8–1.5)
Dose area product (Gy.cm <sup>2</sup> )	179 $\pm$ 84 (167, 123–219)
Estimated blood loss (ml)	383 $\pm$ 443 (240, 100–500)
Technical success per patient	42 (95)
Technical success per target vessel	169 (99)
<i>SD</i> Standard deviation; <i>IQR</i> interquartile range	

All patients had satisfactory imaging quality during lateral or oblique views for catheterization and stenting of the celiac axis and superior mesenteric artery. The mean total operative time, fluoroscopy time and contrast use were  $214 \pm 85$  min,  $76 \pm 26$  min and  $173 \pm 82$  ml, respectively. Cumulative air kerma and dose area product were  $1.3 \pm 0.6$  Gy and  $179 \pm 84$  Gy.cm<sup>2</sup>, respectively.

There was one mortality (2%) at 30 days due to massive arthero-embolization leading to bowel ischemia, necrotizing pancreatitis, and multi-system organ failure (Table 3). Six patients (14%) had any MAE, including paraplegia in three patients (7%) and acute kidney injury or bowel ischemia requiring resection in two patients (5%) each. One patient (2%) had a minor right hemispheric stroke ipsilateral to the side of upper extremity access. Other complications included aortic intramural hematoma proximal to the aortic device, which was treated conservatively, and a renal artery branch perforation, which required coil embolization. There were no brachial plexus or upper extremity peripheral nerve injuries.

**Table 3**

Mortality and major adverse events (MAEs) of 44 patients treated by FB-EVAR with overhead upper extremity position

All patients <i>n</i> = 44	
<i>n</i> (percent) or mean $\pm$ SD (median, IQR)	
30-day or in-hospital mortality	1 (2)

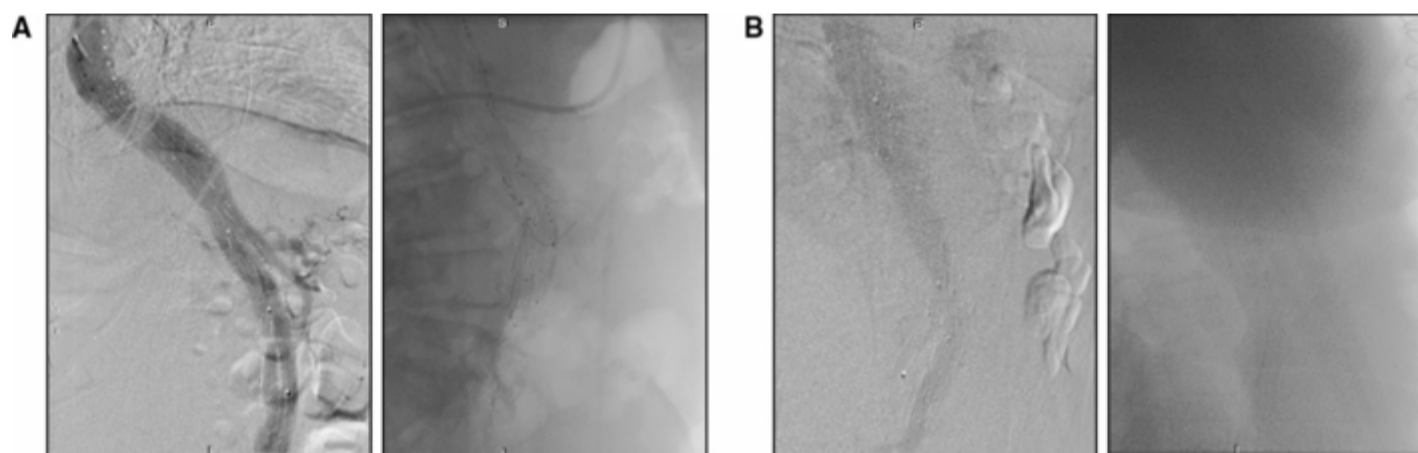
All patients <i>n</i> = 44	
<i>n</i> (percent) or mean ± SD (median, IQR)	
Length of hospital stay, days	7 ± 5.9 (5, 3–8)
Any MAE	6 (14)
Spinal cord injury (Grade 3a–3c)	3 (7)
Acute kidney injury (RIFLE criteria)	2 (5)
Bowel ischemia requiring resection	2 (5)
Respiratory failure	1 (2)
Other adverse events	
Estimated blood loss > 1L	6 (14)
Minor stroke	1 (2)
Vascular complication	2 (5)
Any reintervention	4 (9)
Aortic or branch related reintervention	2 (5)
Access complication requiring reintervention	0 (0)
Dismissal to	
Home	41 (93)
Nursing facility	2 (5)
SD Standard deviation; IQR interquartile range; MAE major adverse event; RIFLE risk, injury, failure, loss, end-stage renal disease	

## Discussion

This study validates the safety of overhead upper extremity positioning for optimal visualization of the mesenteric vessels during lateral or oblique views, without compromise in surgical access of the upper extremity vessels or unintentional injury to the brachial plexus and peripheral nerves (Fig. 3). Since this pilot study, we have incorporated the technique for all patients who require complex procedures. Proper preoperative assessment by the surgical and anesthesia team is critical to identify patients with limited mobility, and in these cases, the standard position is recommended. When needed, the use of right-side brachial access provides better operator ergonomics and potentially reduces radiation exposure [16].

### Fig. 3

Rotational angiography captured in a hybrid operating room with GE IGS 740 Discovery imaging equipment (GE Healthcare, Chicago, IL) from a lateral view during final technical assessment. Standard acquisition technique utilizes 90 mL of 50% Visipaque contrast agent and 200-degree rotation with 7-s spin. Female patient, 73 years old, body mass index (BMI) 22 kg/m<sup>2</sup> treated by fenestrated-branched endovascular aortic repair (FB-EVAR) with the overhead upper extremity position (A). Male patient, 71 years old, BMI 25 kg/m<sup>2</sup> treated by FB-EVAR with the standard arms by the side position (B)



The anatomical position has been widely used to reduce risk of inadvertent nerve compression or stretch injuries during operations. For years, we have used this position during a variety of complex endovascular procedures and accepted suboptimal imaging resolution during lateral or oblique views, which were needed during catheterization of the mesenteric vessels. We conducted this pilot study because of initial concern from the anesthesia team that prolonged operations with overhead upper extremity elevation could be associated with risk of nerve injury. Cadaver dissection studies have found that elevation of the elbows with limited arm abduction to less than 90° reduces brachial plexus stretching [11, 17, 18]. The use of upward upper extremity positioning has been previously described during cardiovascular procedures to reduce risk of brachial plexus injury from sternal retraction [19, 20, 21, 22]. Tomlinson and associates reported on 335 patients who had cardiovascular operations via median sternotomy with elevation of both upper extremities without peripheral nerve or brachial plexus injury [21]. In fact, the rate of neurologic symptoms was lower than that observed for patients who had the extremities tucked to the side. In our cohort, we excluded nearly one third of the patients because of limited mobility. It is possible that some of these patients may tolerate overhead upper extremity positioning.

The use of neuromonitoring on the upper extremities can be a useful resource to identify neurological changes that can result from brachial plexus stretching or compression [23]. Kamel and colleagues retrospectively analyzed 929 patients who had neuromonitoring during

repositioning [24]. Although the authors have not described in their series overhead upper extremity position, none of the patients with sensory changes developed postoperative deficit. In our study, two of the 44 patients (5%) had reversible upper extremity sensory changes during the procedure which immediately resolved with repositioning. None of the patients developed permanent deficit. The most recent ASA clinical practice guidelines did not find conclusive evidence that brachial plexus neuropathy is associated with overhead upper extremity positioning during operations, provided arm abduction is limited to  $\leq 90^\circ$  [12]. Although the guidelines do not comment on use of neuromonitoring, we continue to recommend neuromonitoring in patients at increased risk of spinal cord injury due to aortic coverage.

Improving image quality and reducing radiation exposure should be primary goals for any operator conducting complex endovascular repairs. This should start in the preoperative phase with proper acquisition of CTA using modern helical scanners. Proper imaging is needed for onlay fusion techniques. CTAs are usually performed with the upper extremities elevated whenever possible, except for specific indications where patient mobility is compromised or a muscle-skeletal or spinal injury is suspected. Compared to lateral arm position, CTA with upper extremity elevation significantly decreases radiation dose and image noise while improving diagnosis capability, especially in the abdominal region [25, 26, 27, 28]. Following the ALARA principles (“as low as reasonably achievable”) is essential, while avoiding use of digital subtraction angiography and using other adjuncts such as collimation, digital zoom and fluoroscopic loops [5]. The effective radiation dose in this study ( $1.3 \pm 0.6$  Gy) was substantially less than that reported in our prior reports ( $2.1 \pm 1.8$  Gy), but this may reflect a number of other improvements in technique and imaging technology [10].

This study has several limitations that need to be discussed. The small patient cohort may have limited the ability to identify subtle and uncommon neurological injuries. Although imaging quality was prospectively analyzed, this was not directly compared to patients who had similar procedures with the arms tucked to the side. **AQ3** Nonetheless, evaluation by the primary operator identified satisfactory imaging in lateral or oblique views using overhead upper extremity positioning, while these are almost always compromised when upper extremities are tucked to the side. Finally, comparisons of radiation exposure with our historical results should take into consideration a number of factors including evolution of imaging technology, differences in procedure complexity and increasing clinical experience [1, 10].

## Conclusion

This pilot study demonstrates the safety of FB-EVAR using overhead upper extremity position to optimize visualization of the mesenteric vessels during lateral or oblique views. There were no brachial plexus or peripheral nerve injuries observed in the study cohort.

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## Funding

This study was not supported by any funding.

## Declarations

**Conflict of interest** Gustavo Oderich MD has received consulting fees and grants from Cook Medical, W. L. Gore, and GE Healthcare (all paid to Mayo Clinic with no personal income). Other co-authors declare that they have no conflict of interest.

**Ethical Approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This is a retrospective review of a prospective maintained database of patients treated by FB-EVAR conducted under the US Food and Drug Administration (FDA) PS-IDE G130030 and G130266 and registered under *ClinicalTrials.gov* NCT01937949 and NCT02089607. The study was approved by the Institutional Review Board at University of Texas Health Science Center at Houston and Mayo Clinic Rochester.

**Consent for Publication** For this type of study, consent for publication is not required.

**Informed Consent** Informed consent was obtained from all individual participants included in the study.

## References

1. Mirza AK, Tenorio ER, Kärkkäinen JM, Hofer J, Macedo T, Cha S, et al. Learning curve of fenestrated and branched endovascular aortic repair for pararenal and thoracoabdominal aneurysms. *J Vasc Surg.* 2020;72(2):423-34.e1.
2. Oderich GS, Greenberg RK, Farber M, Lyden S, Sanchez L, Fairman R, et al. Results of the United States multicenter prospective study evaluating the Zenith fenestrated endovascular graft for treatment of juxtarenal abdominal aortic aneurysms. *J Vasc Surg.* 2014;60(6):1420–8.
3. Schneider DB, Agrusa CJ, Ellozy SH, Connolly PH, Meltzer AJ, Graham AR, et al. Analysis of the learning curve and patient outcomes of endovascular repair of thoracoabdominal aortic aneurysms using fenestrated and branched stent grafts: prospective, nonrandomized, Single-center physician-sponsored investigational device exemption clinical study. *Ann Surg.* 2018;268(4):640–9.
4. Hertault A, Maurel B, Sobocinski J, Martin Gonzalez T, Le Roux M, Azzaoui R, et al. Impact of hybrid rooms with image fusion on radiation exposure during endovascular aortic repair. *Eur J Vasc Endovasc Surg Off J Eur Soc Vasc Surg.* 2014;48(4):382–90.

5. Tenorio ER, Oderich GS, Sandri GA, Ozbek P, Kärkkäinen JM, Macedo TA, et al. Impact of onlay fusion and cone beam computed tomography on radiation exposure and technical assessment of fenestrated-branched endovascular aortic repair. *J Vasc Surg.* 2019;69(4):1045-58.e3.
6. Tenorio ER, Oderich GS, Sandri GA, Ozbek P, Kärkkäinen JM, Vrtiska T, et al. Prospective nonrandomized study to evaluate cone beam computed tomography for technical assessment of standard and complex endovascular aortic repair. *J Vasc Surg.* 2020;71(6):1982-93.e5.
7. Howells P, Eaton R, Patel AS, Taylor P, Modarai B. Risk of radiation exposure during endovascular aortic repair. *Eur J Vasc Endovasc Surg Off J Eur Soc Vasc Surg.* 2012;43(4):393–7.
8. Shah A, Das P, Subkovas E, Buch AN, Rees M, Bellamy C. Radiation dose during coronary angiogram: relation to body mass index. *Heart Lung Circ.* 2015;24(1):21–5.
9. Madder RD, VanOosterhout S, Mulder A, Ten Brock T, Clarey AT, Parker JL, et al. Patient body mass index and physician radiation dose during coronary angiography. *Circ Cardiovasc Interv.* 2019;12(1):e006823.
10. Sen I, Tenorio ER, Pitcher G, Mix D, Marcondes GB, Lima GBB, et al. Effect of obesity on radiation exposure, quality of life scores and outcomes of fenestrated-branched endovascular aortic repair of pararenal and thoracoabdominal aortic aneurysms. *J Vasc Surg.* 2020;73:1156-1166.e2.
11. Jackson L, Keats AS. Mechanism of brachial plexus palsy following anesthesia. *Anesthesiology.* 1965;26:190–4.
12. Neuropathies ASoATFoPoPP. Practice advisory for the prevention of perioperative peripheral neuropathies 2018: an updated report by the American society of anesthesiologists task force on prevention of perioperative peripheral neuropathies. *Anesthesiology.* 2018;128(1):11–26.
13. Oderich GS, Forbes TL, Chaer R, Davies MG, Lindsay TF, Mastracci T, et al. Reporting standards for endovascular aortic repair of aneurysms involving the renal-mesenteric arteries. *J Vasc Surg.* 2020;73:4S-52S.
14. Tenorio ER, Ribeiro MS, Banga PV, Mendes BC, Kärkkäinen J, DeMartino RR, et al. Prospective assessment of a protocol using neuromonitoring, early limb reperfusion, and selective temporary aneurysm sac perfusion to prevent spinal cord injury during fenestrated-branched endovascular aortic repair. *Ann Surg.* 2021. <https://doi.org/10.1097/SLA.0000000000004624>.
15. Bellomo R, Kellum JA, Ronco C. Defining and classifying acute renal failure: from advocacy to consensus and validation of the RIFLE criteria. *Intensive Care Med.* 2007;33(3):409–13.
16. Mirza AK, Tenorio ER, Marcondes GB, Lima GBB, Macedo TA, Mendes BC, et al. Comparison of cerebral embolic events between right and left upper extremity access during fenestrated/branched endovascular aortic repair. *J Endovasc Ther Off J Int Soc Endovasc Spec.* 2020. <https://doi.org/10.1177/1526602820953511>.
17. Kwaan JH, Rappaport I. Postoperative brachial plexus palsy. A study on the mechanism. *Arch Surg (Chicago, Ill: 1960).* 1970;101(5):612–5.
18. Winfree CJ, Kline DG. Intraoperative positioning nerve injuries. *Surg Neurol.* 2005;63(1):5–18.
19. Vander Salm TJ, Cereda JM, Cutler BS. Brachial plexus injury following median sternotomy. *J Thorac Cardiovasc Surg.* 1980;80(3):447–52.
20. Roy RC, Stafford MA, Charlton JE. Nerve injury and musculoskeletal complaints after cardiac surgery: influence of internal mammary artery dissection and left arm position. *Anesth Analg.* 1988;67(3):277–9.
21. Tomlinson DL, Hirsch IA, Kodali SV, Slogoff S. Protecting the brachial plexus during median sternotomy. *J Thorac Cardiovasc Surg.* 1987;94(2):297–301.
22. Jellish WS, Blakeman B, Warf P, Slogoff S. Hands-up positioning during asymmetric sternal retraction for internal mammary artery harvest: a possible method to reduce brachial plexus injury. *Anesth Analg.* 1997;84(2):260–5.
23. MacDonald DB, Dong C, Quatrone R, Sala F, Skinner S, Soto F, et al. Recommendations of the international society of intraoperative neurophysiology for intraoperative somatosensory evoked potentials. *Clin Neurophysiol Off J Int Federation Clin Neurophysiol.* 2019;130(1):161–79.

24. Kamel IR, Drum ET, Koch SA, Whitten JA, Gaughan JP, Barnette RE, et al. The use of somatosensory evoked potentials to determine the relationship between patient positioning and impending upper extremity nerve injury during spine surgery: a retrospective analysis. *Anesth Analg*. 2006;102(5):1538–42.
25. Brink M, de Lange F, Oostveen LJ, Dekker HM, Kool DR, Deunk J, et al. Arm raising at exposure-controlled multidetector trauma CT of thoracoabdominal region: higher image quality, lower radiation dose. *Radiology*. 2008;249(2):661–70.
26. Kahn J, Grupp U, Maurer M. How does arm positioning of polytraumatized patients in the initial computed tomography (CT) affect image quality and diagnostic accuracy? *Eur J Radiol*. 2014;83(1):e67-71.
27. Karlo C, Gnannt R, Frauenfelder T, Leschka S, Brüesch M, Wanner GA, et al. Whole-body CT in polytrauma patients: effect of arm positioning on thoracic and abdominal image quality. *Emerg Radiol*. 2011;18(4):285–93.
28. Bayer J, Pache G, Strohm PC, Zwingmann J, Blanke P, Baumann T, et al. Influence of arm positioning on radiation dose for whole body computed tomography in trauma patients. *J Trauma*. 2011;70(4):900–5.