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The effect of Fiber Optic RealShape technology on the reduction of radiation during complex endovascular surgery

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ABSTRACT

Objective: Despite the advantages that fenestrated endovascular aortic repair has over open repair, it is accompanied by the consequence of radiation exposure, which can result in long-term complications for both the patient and surgical staff. Fiber Optic RealShape (FORS) technology is a novel advancement that uses emitted light from a fiber optic wire and enables the surgeon to cannulate vessels in real time without live fluoroscopy. This technology has been implemented at select centers to study its effectiveness for cannulation of target vessels and its impact on procedural radiation.

Methods: We collected prospective data on physician-modified endograft (PMEG) cases before and after the introduction of FORS technology. FORS PMEGs were matched with up to three conventional fluoroscopy cases by number of target vessels, inclusion of a bifurcated device below, aneurysm extent, and patient body mass index. The procedural radiation parameters were compared between these cohorts. Within the FORS cohort, we analyzed the rate of successful target vessel cannulation for all cases done with this technology (including cases other than PMEGs), and we compared the radiation between the cannulations using only FORS with those that abandoned FORS for conventional fluoroscopy.

Results: Nineteen FORS PMEGs were able to be matched to 45 conventional fluoroscopy cases. Procedures that used FORS technology had significantly reduced total air kerma (527 mGy vs 964 mGy), dose area product (121 Gy*cm^2 vs 186 Gy*cm^2), fluoroscopy dose (72.1 Gy*cm^2 vs 132.5 Gy*cm^2), and fluoroscopy time (45 minutes vs 72 minutes). There was no difference in procedure length, total contrast, or digital subtraction angiography. Within FORS cases, 66% of cannulations were completed using only FORS. Cannulations using only FORS had significant reduction of navigation air kerma (5.0 mGy vs 26.5 mGy), dose area product (1.2 Gy*cm^2 vs 5.1 Gy*cm^2), and fluoroscopy time (0.6 minutes vs 2.3 minutes) compared with cannulations abandoning FORS for conventional fluoroscopy.

Conclusions: This study demonstrates the advantages of FORS for total procedural radiation as well as during individual cannulation tasks. The implementation of FORS for target vessel catheterization has the potential to decrease the total degree of radiation exposure for the patient and surgical staff during complex endovascular aortic surgeries. (J Vasc Surg 2024;79:954-61.)

Keywords: Fiber optics; FORS; Radiation; PMEG

After the introduction and U.S. Food and Drug Administration approval of fenestrated and branched aortic grafts, complex aortic repair became possible in many patients who would have been prohibitively high risk for open aortic surgery.[1-3] These endovascular alternatives offer numerous benefits in both morbidity and mortality, however, despite these advantages they are accompanied by the unique consequence of radiation exposure.[4] This is especially true during complex aortic repair, which is associated with higher radiation dosing and contrast use than standard infrarenal endovascular aneurysm repair.[5-11] Many practices have been implemented to reduce the degree of radiation during these cases, but fluoroscopy has remained an

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integral and unavoidable part of endovascular aortic surgery.[12,13]

The detrimental long-term effects of radiation exposure are well-known and, unfortunately, apply to both the patient and surgical staff.[5,14-17] Despite the use of lead coverings and other protective gear, exposure to harmful radiation still occurs routinely.[18,19] Fiber Optic RealShape (FORS) technology is a novel advancement that seeks to mitigate this exposure by drastically reducing the degree of radiation required during endovascular surgery. The technology is predicated on using emitted light from a fiber optic wire to generate a reconstructed image of the wire position overlayed on a radiographic image. This is a dynamic technology that allows instantaneous three-dimensional visualization of the wire position, which enables the surgeon to cannulate vessels in real time without the use of live fluoroscopy.

In 2021, FORS was introduced at select international centers to investigate its effectiveness for cannulation of target vessels and its impact on procedural radiation. The previously published data on this topic have shown promising initial results with regard to vessel catheterization and radiation reduction.[20,21] In this study, we add to the limited prior data and report our initial institutional experience with this technology and the way that it has impacted our complex aortic repair practice.

ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective cohort study using prospectively collected institutional data on a novel technology
- **Key Findings:** Compared with cases using only conventional fluoroscopy, physician-modified endograft cases that used Fiber Optic RealShape (FORS) technology had decreased procedural radiation dosing without a difference in the length of procedure or volume of contrast used. Additionally, target vessel cannulations which used only FORS used less radiation than those cannulations that reverted to conventional fluoroscopy.
- **Take Home Message:** Implementation of FORS technology is feasible at high-volume aortic centers and can decrease the radiation associated with complex endovascular aortic surgery without sacrificing the speed at which it is done.

METHODS

Data source. This study was composed of prospectively collected institutional data from January 2018 through March 2023. These data include patients who underwent a physician-modified endograft (PMEG) using standard fluoroscopy, as well as patients who underwent a PMEG using FORS technology. Additionally, the dataset includes iliac branch device, embolization, and infrarenal endovascular aneurysm repair cases that were performed with FORS technology. These non-PMEG cases were used only for the individual task success analysis that was conducted within the FORS cohort.

We chose 2018 as the starting point for data inclusion to obtain an adequate sample of standard fluoroscopy patients and also to provide a fair temporal comparison to the FORS cohort, which was introduced at our institution in late 2021. Additionally, by excluding cases before 2018 we are excluding our early PMEG experience (which began in 2012); therefore, the cases included in this study are thought to be most consistent with our contemporary practice. PMEG cases that use standard fluoroscopy are present in the database before and after the introduction of FORS technology.

This study was approved by the Beth Israel Deaconess Medical Center IRB under protocol number 2021-P-000219. All patients who underwent a FORS procedure have signed informed consent for inclusion in this study and for use of this technology. The standard fluoroscopy cohort includes PMEG cases from before and after an Investigational Device Exemption (IDE) trial was begun at our institution in May 2021 (NCT# 04746677). The pre-IDE trial patients were submitted to the U.S. Food and Drug Administration in support of the IDE trial.

Patient cohorts and matching. Cohorts were defined by whether the case was performed entirely with standard fluoroscopy, or whether the case used FORS at any point. For instance, if a case using FORS was unable to complete an aspect of the procedure with FORS technology (and reverted to standard fluoroscopy), that case was still included within the FORS cohort.

To obtain the cohorts of PMEG patients to be used in the study, we used a standard matching scheme that matched to the type of aneurysm (thoracoabdominal aortic aneurysm [TAAA] vs AAA), the number of fenestrations of the PMEG ($\leq$3 vs $\geq$4), the inclusion of a bifurcated device below the PMEG (yes vs no), and the patient body mass index (BMI) (which required the matches to be within $\pm$1 unit of each other). This method was preferred over propensity score matching owing to the desire to match on only four specific procedural parameters. FORS cases were matched with up to three conventional fluoroscopy cases without replacement, as able.

The analysis of individual cannulation tasks was performed for all cases that used FORS technology. Here, the cohorts were defined by whether the task was completed entirely with FORS, or if the task abandoned FORS in favor of standard fluoroscopy. Accordingly, it is possible for a single patient to have their individual cannulation tasks distributed between both cohorts.

Definitions and variables. For all patients, we assessed age, sex, race, BMI, and smoking status. Additionally, we collected data on the aneurysm diameter, the type of

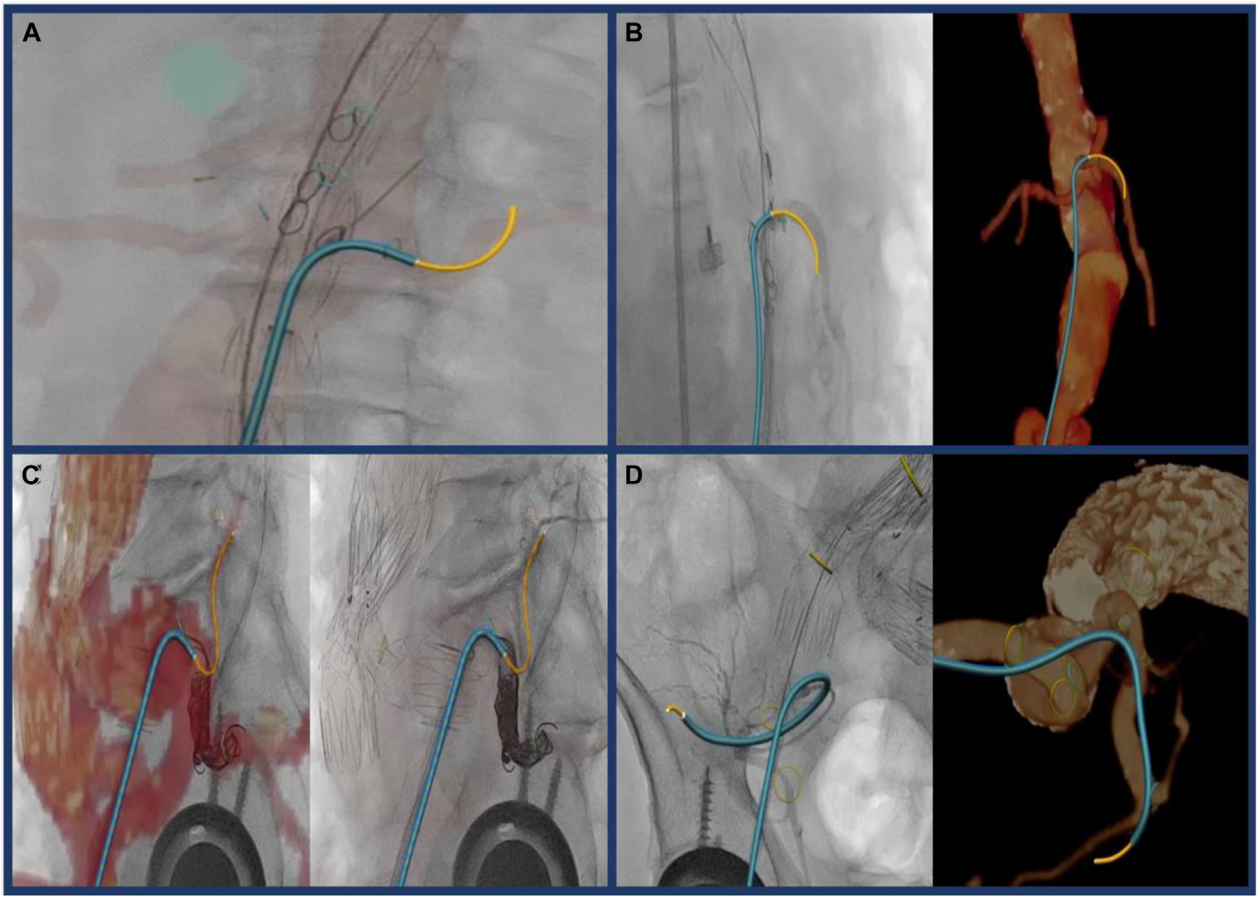

Fig. Representative images of fiber optic RealShape (FORS) use. **(A)** Navigation through left renal fenestration of physician-modified endograft (PMEG) into distal portion of artery using FORS wire and catheter in conjunction with live fluoroscopy and image overlay. **(B)** Navigation through superior mesenteric artery fenestration of PMEG with FORS wire and catheter in conjunction with live fluoroscopy with hand injection of contrast and three-dimensional computed tomography (CT) reconstruction. **(C)** Navigation into hypogastric branch for embolization using fluoroscopy with image fusion and hand injection of contrast. **(D)** Navigation into distal hypogastric using FORS wire and catheter with live fluoroscopy with hand injection of contrast and three-dimensional CT reconstruction.

aneurysm, number of vessels involved, and whether the case included placement of a bifurcated device below the PMEG, as previously described for our matching scheme.

For the comparison between conventional fluoroscopy and FORS, our primary outcomes were the overall procedural parameters. These included total procedure time (minutes), total contrast volume (mL), total air kerma (mGy), total dose area product (DAP, Gy*cm2), total digital subtraction angiography (DSA, Gy*cm^2), total fluoroscopy dose (Gy*cm^2), and total fluoroscopy time (minutes). These variables were collected at the end of each case by trained research personnel.

With regard to the task analysis within the FORS cases, we collected similar data for the navigational component of each individual cannulation task. The navigation targets included the visceral vessels, internal iliac vessels, external iliac vessels, and the contralateral gate. The navigational data that we collected included air kerma (mGy), DAP (Gy*cm^2), fluoroscopy time (minutes), and total cannulation time (minutes). Additionally, we analyzed the success rate of catheterizations that used only FORS and conducted a subanalysis of the visceral vessel (celiac artery, superior mesenteric artery, right renal artery, and left renal artery) and iliac vessel (bilateral internal iliac, bilateral external iliac, and contralateral gate) success rates. Data collection was started once the FORS wire was visible on screen and ended when the FORS wire (or conventional wire for those cases that abandoned FORS) was replaced with a stiff guidewire to begin the treatment component. These data were collected at the time of the case by trained research personnel.

FORS equipment and technique. There are three permanent devices that are necessary in the endovascular suite for the use of this technology. The first is a

computer with the FORS software, the second is the FORS engine, which contains much of the hardware where the image reconstruction is processed, and third is the bedside docking station that connects to the FORS enabled wires and catheters. At present, there are three such wires and catheters available; a 120-cm, 0.035-inch diameter nonbackloadable AltaTrack guidewire, an 80-cm 5.5F Berenstein catheter, and an 80-cm 5.5F C2 catheter. These are used exclusively during the navigational phase of the procedure because the wire is nonbackloadable and, therefore, cannot be used for the treatment portion (such as stent deployment).

During the case, the dynamic three-dimensional position of the FORS wire is fused with static radiographic imaging, which is used as a roadmap. The prevailing FORS catheterization technique at our institution is to use a deflecting tip sheath with the FORS catheter advanced to the tip of the sheath, allowing visualization. Once the PMEG is inserted, we use the FORS wire and catheters with a combination of saved fluoroscopy images to cannulate the fenestrations and then use saved fluoroscopy runs and image fusion to observe the interaction of the wire and catheter with the visceral arterial anatomy. Preoperative computed tomography (CT) angiography fusion, DSA, and hand injection under fluoroscopy can all be used to facilitate FORS cannulations (Fig). Additionally, we can rotate the three-dimensional roadmap into positions that are not available with the c-arm alone. Once the vessel has been cannulated, the FORS wire is exchanged for a stiff guidewire to begin the treatment portion. If unable to complete the cannulation solely with the FORS devices, conventional catheters and wires are used in lieu of, or in addition to, the FORS devices.

Before the implementation of FORS, we have routinely used CT image fusion for all endovascular aortic cases. We continue to use CT image fusion for endovascular aortic cases when we are not using FORS.

Statistical analysis. Continuous variables were compared using the *t* test (when normality was assumed) or Wilcoxon rank-sum test (when normality was not assumed) and are presented as mean (standard deviation) or median (interquartile range), respectively. Binary and categorical variables were compared using Pearson's χ^2 test and are presented as percentages. A *P* value of $<.05$ was considered statistically significant. The cohorts were generated through a standard matching program which matched exactly on the binary variables (TAAA vs AAA, whether there were ≥ 4 fenestrations, and whether there was a bifurcated device below), and within one unit for patient BMI. From these parameters, we matched up to three conventional fluoroscopy cases to each FORS PMEG without replacement. All statistical analysis was performed using Stata version 17.0 (StataCorp, College Station, TX).

RESULTS

Patient cohort and characteristics. We were able to successfully identify at least 1 match for 19 of the 24 PMEGs that had been performed using FORS. For 11 of the 19 cases, we identified three matches, for 4 of the cases we identified 2 matches, and for the final 4 cases we identified 1 match. This process resulted in a total of 45 matched conventional fluoroscopy cases.

With regard to baseline characteristics, there was no significant difference between the FORS and non-FORS cohorts for age (77.8 years vs 74.6 years), proportion male (84% vs 80%), race (84% White vs 89% White), BMI (27.8 vs 27.1), and aneurysm diameter (69.2 mm vs 63.7 mm) (Table I). The cohorts did differ in terms of smoking status, where the FORS cases were less likely to be current smokers (21% vs 49%; $P = .008$).

Overall procedural characteristics. Comparing FORS cases to non-FORS cases, we found no significant difference in the total procedure time (192 minutes vs 177 minutes; $P = .17$), total contrast volume (140 mL vs 108 mL; $P = .11$), and total DSA (42.5 Gy*cm^2 vs 51.1 Gy*cm^2; $P = .26$) (Table II). FORS was significantly favorable with regards to total air kerma (527 mGy vs 965 mGy; $P = .002$), total DAP (121 Gy*cm^2 vs 186 Gy*cm^2; $P = .006$), total fluoroscopy dose (72.1 Gy*cm^2 vs 132.5 Gy*cm^2; $P = .003$), and total fluoroscopy time (45.1 minutes vs 72.0 minutes; $P < .001$) (Table II).

Individual task outcomes. Looking within all FORS cases, we identified 157 total individual vessel cannulations. Of these 157 cannulations, 103 were performed using only FORS, a 66% success rate. The remaining 54 tasks were started with FORS, but then reverted to standard fluoroscopy. We found that, for every metric studied, the tasks completed using only FORS were superior to those that used standard fluoroscopy. This included total navigation time (5 minutes vs 9 minutes; $P < .001$), navigation fluoroscopy time (0.6 minutes vs 2.3 minutes; $P < .001$), navigation air kerma (5.0 mGy vs 26.5 mGy; $P < .001$), and navigation DAP (1.2 Gy*cm^2 vs 5.1 Gy*cm^2; $P < .001$) (Table III).

Upon subanalysis of the visceral vessel cannulations, we found success rates of 42%, 47%, 57%, and 56% for the celiac, superior mesenteric, right renal, and left renal arteries, respectively. There was no significant difference in likelihood of success between the visceral vessels ($P = .75$) (Table IV). Analysis of the iliac system revealed success rates of 92%, 88%, 100%, 73%, and 56% for the contralateral gate, right common iliac, left common iliac, right internal iliac, and left internal iliac arteries, respectively. Although it approached significance, the likelihood of success between the iliac vessels did not reach the 0.05 threshold ($P = .057$) (Table IV). Last, we compared the two systems as a

Table I. Baseline characteristics for matched patients

Characteristics	Non-FORS	FORS	*P* value
No.	45	19	
Age, years	74.6 ± 6.5	77.8 ± 8.4	.11
Sex	36 (80)	16 (84)	.69
Race			
White	40 (89)	16 (84)	.60
Black	1 (2)	0 (0)	
Other/unknown	4 (9)	3 (16)	
Smoking			
Never	6 (13)	0 (0)	.01
Former	17 (38)	15 (79)	
Current	22 (49)	4 (21)	
BMI	27.1 ± 4.7	27.8 ± 6.0	.59
Aneurysm diameter	63.7 ± 10.8	69.2 ± 33.7	.35
Fenestrations	4.0 ± 0.4	4.0 ± 0.3	.65
TAAA	6 (13)	4 (21)	.44
Included bifurcated graft	44 (98)	18 (95)	.52

BMI, Body mass index; *FORS*, fiber optic RealShape; *TAAA*, thoracoabdominal aortic aneurysm.
Vales are mean ± standard deviation or number (%).

whole and found a success rate of 51% for visceral vessel cannulations and a success rate of 83% for iliac system cannulations. Here, we found that the iliac system cannulations were significantly more likely to be successful ($P < .001$) (Table IV).

DISCUSSION

Since the implementation of FORS technology at our institution, we have noted many positive impacts to radiation dosing during complex endovascular surgery. With regard to the overall procedural parameters, we found that cases using FORS had significantly less radiation while having minimal difference in length of the operation or volume of contrast used. When looking at the success of individual vessel cannulations, we found that the target could be cannulated using only FORS in approximately 66% of the attempts. Additionally, when cannulations were completed with only FORS, they used approximately five times less radiation than those cannulations that reverted to standard fluoroscopy.

The results that we have identified are not surprising. The fact that a low radiation alternative to standard fluoroscopy is associated with less radiation is not exactly a shocking statement. Instead, what we find most impactful from our experience is that the implementation of this technology was feasible and that it resulted in minimal differences in operative time and contrast use. When new technology becomes available, there is often a tradeoff between the benefits that it offers and the difficulties associated with its adoption. With FORS, the benefits are clear in terms of decreased radiation dosing for both the patient and surgical team. The difficulties with its implementation can be thought of as falling into one of two categories: the cost of new equipment and the technical issues that accompany that new equipment.

With regard to cost, the initial investment in a new technology is an unavoidable but necessary expense for the advancement of practice. With FORS, this investment comes in the form of the compatible wires and catheters, and the cost of the FORS engine and docking station (the main hardware components necessary for use of the technology). A prior study by Kang et al[22] identified that the endovascular graft itself was the largest driver of the increased cost associated with endovascular repairs. Although FORS wires and catheters may have an increased cost relative to those used with standard fluoroscopy, the largest component of the procedural cost is unchanged between these two techniques. The permanent equipment (ie the FORS engine and the docking station) represents an up-front investment, but with each subsequent case performed the cost per use of the equipment decreases, similar to other permanent fixtures in operating suites (like in room CT and high-resolution displays). Further, and at the crux of the value of this technology, there are likely to be future cost benefits of lower radiation in the form of less radiation induced disease, which may become evident in the years to come.

Beyond the initial increased costs, new technology is often accompanied by technical difficulties that require adjustment and adaptation. With FORS, these technical difficulties were most often related to the current wires and catheters that are compatible with the system. The FORS AltaTrack guidewire is both stiffer and shorter than the navigational wires that are preferred at our institution. Additionally, this wire is tethered to the docking station which has implications for maneuverability and tactile feel during cannulation attempts. Similarly, the available catheters (Berenstein and C2) are also stiffer and have different functionality than our more commonly used catheters. Last, the current system is limited in use by the need to be joined to the docking station. As such, vessel cannulation is possible with FORS, but vessel treatment (such as stent deployment) necessitates reversion to conventional wires and fluoroscopy use.

Despite these difficulties, we still prefer the FORS system over standard fluoroscopy. We expect many of these issues to improve or resolve with the subsequent development and release of additional FORS-compatible devices. This will offer a more diverse range of wires and catheters, as well as the possibility of backloadable devices, which will enable an even greater portion of the procedure to be accomplished without fluoroscopy. As a corollary to this point, we found that visceral vessel cannulations were completed with FORS only 51% of the time. Often, this failure was due to tortuous or calcified

Table II. Overall procedural outcomes of matched cohorts

	Non-FORS		FORS		*P* value
No.	45		19		
Procedure time, minutes	177.0	(145.0-232.0)	192.0	(160.0-271.0)	.17
Total contrast, mL	108.0	(50.0-188.0)	140.0	(110.0-165.0)	.11
Total air kerma, mGy	964.0	(651.0-1469.0)	527.0	(327.0-893.0)	.002
Total DAP, Gy*cm^2	186.1	(126.9-310.5)	121.0	(84.0-165.0)	.006
Total DSA, Gy*cm^2	51.1	(34.8-82.9)	42.5	(30.0-64.4)	.26
Total fluoro dose, Gy*cm^2	132.5	(82.4-226.5)	72.1	(45.7-97.9)	.003
Total fluoro time, minutes	72.0	(56.0-90.0)	45.1	(34.7-49.0)	<.001

DAP, Dose area product; *DSA*, digital subtraction angiography; FORS, fiber optic RealShape.
Values are median (interquartile range).

Table III. Individual task outcomes stratified by successful fiber optic RealShape (FORS) use

	Unsuccessful		Successful		*P* value
No.	54		103		
Total navigation time, minutes	9	(5.0-14.0)	5	(3.0-8.0)	<.001
Navigation fluoro time, minutes	2.3	(1.3-4.7)	0.6	(0.2-1.4)	<.001
Navigation fluoro time, normalized[a] (%)	28.5	(20.0-41.3)	12.5	(6.7-20.0)	<.001
Navigation air kerma, mGy	26.5	(12.0-51.0)	5	(2.4-12.0)	<.001
Navigation DAP, Gy*cm^2	5.1	(2.3-10.9)	1.2	(0.6-2.4)	<.001

DAP, Dose area product.
Values are median (interquartile range).
[a]Normalized represents the navigation fluoro time as a percentage of the total navigation time.

vessels, as well as the previously described stiffness and functionality of the FORS equipment. Although the successful proportion is expected to increase with improved comfort with presently available equipment, the attending surgeon is also more likely to allow the trainee to struggle with cannulation when minimal radiation is being delivered and there is less concern of causing a dissection with the FORS wire. These points suggest that the true benefit of FORS may be attenuated despite the already significant differences that have been identified, and we plan to compare our early and more recent experiences in a subsequent study. With additional FORS wires and catheters that are more like the preferred conventional counterparts, and with increased experience and comfort with the technology, we believe the success rate of FORS cannulations could increase. This in turn may lead to an even further reduction in procedural radiation.

Despite the benefits that we have identified while using this novel technology, our study is not without limitations. First, our FORS cohort is relatively small, with only 19 cases. Although we have performed >19 FORS cases, we felt it was imperative to restrict the cohort to complex aneurysm cases to conduct a fair comparison of our primary outcomes. For instance, we have performed infrarenal AAA repairs using FORS, but felt it would be inappropriate to include a case such as that along with complex visceral aneurysms that necessitated four-vessel PMEGs. The radiation dose during an endovascular case has been shown to increase with the degree of complexity or number of fenestrations; therefore, including these less complicated cases would have added confusion to the interpretation of our primary outcomes.[8,9] Despite restricting the cohort to PMEGs, we obtained significant results even with this relatively small cohort. Additionally, because this study is ongoing, our cohort numbers (both FORS and conventional cases) will continue to increase and become more robust once current FORS equipment supply chain issues resolve.

Another limitation was the inability to identify three matched conventional fluoroscopy cases for each FORS case. This was due to the stringent matching scheme that we used; specifically, how matched cases required a BMI within one unit of each other. Multiple prior studies have examined the relationship between BMI and radiation dosing and have shown that elevated BMI is associated with longer case times, increased fluoroscopy, and increased DAP, which holds true in vascular surgery as well as other specialties that use fluoroscopy.[11,23-25] Being that our primary outcomes were focused on radiation dosing, we felt it was imperative to match our cohorts with as similar BMI as possible, as has been done in prior

Table IV. Univariable analysis of successful fiber optic RealShape (FORS) use within target vessels

	No. successful	Percent successful	*P* value
Visceral artery			
Celiac	8	42	0.75
Superior mesenteric artery	9	47	
Right renal artery	13	57	
Left renal artery	15	56	
Iliac artery			
Cont. gate	23	92	0.057
Right common iliac artery	7	88	
Left common iliac artery	9	100	
Right internal iliac artery	11	73	
Left internal iliac artery	5	56	
Vessel system			
Visceral	45	51	<.001
Iliac	55	83	

studies on radiation.[25] Although widening the BMI range may have produced a more complete one to three match, we felt that this would offer a less fair comparison and would have diminished the importance of any potential results. Additionally, this is another limitation that we expect to improve as more cases are enrolled into each cohort.

One final limitation is that we did not have an ideal marker of complexity by which to compare the FORS and standard fluoroscopy cases. As a part of the matching scheme, we included the number of fenestrations, whether the aneurysm was thoracoabdominal or isolated to the abdomen, and whether the case involved placement of a bifurcated device below the graft. These factors allowed us to match similar cases, but may not have matched perfectly the more nuanced complexity of each case. For example, it would be possible to include more minute information on angulation of the target vessels, their degree of stenosis, their degree of calcification, and whether there is a prior stent in the vessel, but we do not believe that matching on these additional characteristics would have proved beneficial. If information with that level of granularity were used in the matching scheme, it would have further reduced the size of the cohorts and the ability to generate three matches for each case. As it is, we feel that the complexity of the FORS and non-FORS cases are matched to a fair, albeit not perfect, degree. Although it is certainly possible that a non-FORS case may have been more technically challenging than a FORS case, we believe that, overall, the opposite is true. Given the shortage of FORS equipment (owing to the previously referenced supply chain issues with wires and catheters), we have selectively used FORS for the cases that were deemed to be more complex based on preoperative imaging. As such, the FORS cases are assumed to represent a generally more complicated repair. Ultimately, once enough centers have familiarity with the technology, a randomized trial would be the best method to compare the radiation delivered between FORS and non-FORS cases.

The introduction of FORS technology at our institution has already had a dramatically beneficial impact on radiation dosing during complex aortic surgery. Further, the analysis of individual tasks provides specific information about the usefulness of FORS, which will allow us to later analyze the learning curve and how successful use of the technology has changed over time. Additionally, we found that the implementation of this technology was feasible and there were minimal barriers to its use. Going forward, we expect that the current barriers to use will diminish once supply chain issues are resolved and additional devices become available. Technology such as this has the potential to improve long-term patient outcomes and to decrease the risk associated with endovascular radiation for the patient and surgical team. As a field, vascular surgery has pioneered many new technologies and it is possible that radiation-free navigation such as this technique is the next breakthrough in a long line of vascular imaging innovations.

CONCLUSIONS

FORS technology decreases the radiation exposure during complex aortic surgery and during individual vessel cannulation, which has obvious benefits for both patient and practitioner. Moreover, this technology can feasibly be implemented at a high-volume aortic center with relatively few hindrances. Despite the issues that often accompany the introduction of new technology, novel methods of advanced image guidance, such as FORS, have a viable future and the potential to advance the field of vascular surgery.

AUTHOR CONTRIBUTIONS

Conception and design: AS, NS, MS
Analysis and interpretation: AS, NS, GJ, MS
Data collection: AS, NS
Writing the article: AS
Critical revision of the article: AS, NS, GJ, MS
Final approval of the article: AS, NS, GJ, MS
Statistical analysis: AS, MS
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Overall responsibility: AS

DISCLOSURES

None.

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