Transfemoral Access Assessment for Transcatheter Aortic Valve Replacement
Evidence-Based Application of Computed Tomography Over Invasive Angiography

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Background—Although computed tomography (CT) is commonly used for iliofemoral evaluation for transfemoral transcatheter aortic valve replacement, many centers worldwide use invasive angiography alone for this purpose. No study to date has evaluated the value of CT over angiography for the prediction of vascular complications. In addition, no data exist for the value of noncontrast CT.

Methods and Results—Of the 588 transcatheter aortic valve replacement patients, we reviewed 496 consecutive transfemoral cases. Vessel diameters were measured by CT or angiography. Sheath-related complication (SRC) was defined as an iliofemoral arterial injury not including a cannulation site. Receiver operating characteristic models were generated using sheath-to-iliofemoral artery ratios as a variable and SRC as an end point. In patients undergoing both contrast CT and angiography (n=283; 35 SRCs), contrast CT showed a greater predictive value than angiography by area under the curve $P<0.001$: 0.87 (95% confidence interval: 0.82–0.91) versus 0.72 (95% confidence interval: 0.66–0.77). In patients undergoing both noncontrast CT and angiography (n=103; 17 SRCs), there was no difference between noncontrast CT and angiography: 0.79 (95% confidence interval: 0.70–0.86) versus 0.73 (95% confidence interval: 0.63–0.81). Three-dimensional assessments of calcification and tortuosity provided limited additional value for SRC prediction.

Conclusions—Contrast CT has a greater predictive value for post-transcatheter aortic valve replacement vascular complications than angiography. Because these complications increase mortality, an accurate assessment of the vasculature is a critical component of proper access selection. (Circ Cardiovasc Imaging. 2015;8:e001995. DOI: 10.1161/CIRCIMAGING.114.001995.)

Key Words: angiography ■ cone-beam computed tomography ■ diabetic vascular complications

Transfemoral arterial access for transcatheter aortic valve replacement (TAVR) was introduced in 2006. Although other access sites are considered, they usually come with increased invasiveness and, if feasible, the transfemoral approach is preferred. Vascular complications (VCs) are important events which are correlated to increased mortality. On the basis of the Valve Academic Research Consortium-1 (VARC) definition, major VCs are observed in 5% to 23.3% of patients. The access site assessment for transfemoral TAVR is crucial to prevent these common and important phenomena.

See Clinical Perspective

Vessel size, calcification, and tortuosity in access vessels are thought to be important determinants for the risk for vascular injury related to sheath insertion; among these, vessel diameter in relation with sheath size is considered as the most predictive factor. Angiography or computed tomography (CT) are the main imaging modalities used to assess these factors. Single-plane angiography was previously considered a minimal requirement for evaluation of the iliofemoral system, yet this assessment yields limited information. However, CT is gaining popularity, and the increased use of CT has coincided with a reduction in VCs. CT allows 3-dimensional (3D) assessment and its use is recommended for pre-TAVR assessment. However, there is heterogeneity of practice worldwide and many centers use angiography alone for this purpose. No study to date has evaluated the value of measurements derived from CT assessment over angiography for the prediction of VC in TAVR preprocedural planning. Moreover, despite the fact that an optimal CT examination should be performed with iodinated contrast medium, noncontrast CT still allows an overall assessment. Some TAVR candidates have only noncontrast CT because of comorbidities, but the value of noncontrast CT has not yet been defined.

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Given the heterogeneity of preprocedural imaging assessment, we sought to compare the predictive value of vascular CT and angiography for VCs, to identify the optimal imaging strategy to best predict VCs and thereby streamline and provide a clear evidence base for practice.

Methods

Patient Population and Devices Used

Consecutive severe symptomatic aortic stenosis patients who had TAVR between November 2007 and February 2013 were reviewed. All were treated with balloon-expandable TAVR (Edwards Sapien/Sapien XT, Edwards Lifesciences, Irvine, CA) in a single center. Vessel diameter was measured prospectively by CT or angiography. For modality comparisons, 2 cohorts were generated: a contrast-CT cohort in which patients had both contrast CT and angiography, and a noncontrast–CT cohort in which patients had both noncontrast CT and angiography. The study was conducted with approval by the institutional review board. All patients agreed with participation in the study and written informed consents were obtained.

In this study, 3 types of the Edwards system introducer sheath were used: Retroflex 3, Novaflex, and the expandable sheath (e-sheath). The outer diameters of Retroflex system for 24 Fr and 22 Fr are 9.2 and 8.4 mm, those of Novaflex system for 19 and 18 Fr are 7.5 and 7.2 mm, and those of e-sheath system (unexpanded) for 20, 18, and 16 Fr are 8.0, 7.2, and 6.7 mm, respectively.

Figure 1. Diameter measurement of iliofemoral vasculature by each modality. A, Comparison of angiography and contrast computed tomography (CT). B, Comparison of angiography and noncontrast CT. Angiography (i), CT with antero-posterior view (ii), CT with lateral view (iii).

Figure 2. Detailed assessments of iliofemoral vasculature. A, Three-dimensional (3D) angle is measured on the 3D center line of iliofemoral vasculature. B, The cross-sectional view is generated and minimal diameter, mean diameter, and perimeter of the vasculature are measured.

Figure 3. Flow chart of patient selection and vascular complications. CT indicates computed tomography; SRC, sheath-related complication; TAVR, transcatheter aortic valve replacement; and VARC, Valve Academic Research Consortium.
CT and Angiography Acquisition

Preprocedural CT was performed with a Siemens Somatom Sensation 64 scanner (Siemens Medical Solution USA, Inc., Malvern, PA) with a 32×0.6 mm detector configuration using a flying z-focal spot technique. After a gated cardiac scan with a pitch of 0.65, a chest, abdominal, and pelvic scan were performed with a pitch of >1. A dedicated protocol was formulated with 120 kV and tube current modified according to patient size. A standard convolution kernel of B35f was applied with a gantry rotation time of 330 ms. Injection of 30 to 60 mL of Iovue 370 (Bracco Diagnostics Inc. Princeton, NJ) was performed for the contrast CT with a flow rate of 1.5 mL/s. The contrast dose was modified based on renal function; if the glomerular filtration rate was <60 mL/min, the maximum dose used was 2× the glomerular filtration rate. Noncontrast CT was performed when patients had contraindication of contrast usage (e.g., severely impaired renal function or allergy for contrast). Multiplanar reconstruction images were reconstructed with a section thickness of 1.0 mm and section spacing of 0.7 mm.

Single plane angiography was performed at the time of pre-TAVR coronary artery assessment using the system of GE Healthcare Bioscience (GE Healthcare Biosciences, PA). Patients underwent distal aortography with bilateral iliopelvic run-off in the anteroposterior projection. Contrast of 30 to 40 mL was injected by a power injector at a rate of 10 mL/s through a marker pigtail catheter placed above the iliac bifurcations.

Iliofemoral Vasculature Measurement

The diameter of iliofemoral vessels was prospectively assessed from the common iliac artery to the common femoral artery at the level of the femoral head. The smallest measurement at the side used for access was recorded as the vessel diameter.

CT and Angiography for TAVR Vascular Complications

![Venn diagram showing study population. Of 496 patients treated transfemorally, 370 had contrast computed tomography (CT) and 103 noncontrast abdomino-pelvic CT. Only patients with concurrent angiography were studied (283 contrast CT and 103 noncontrast CT).](image)

Table 1. Patient Populations and Clinical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Total Patients (n=386)</th>
<th>Contrast-CT cohort (n=283)</th>
<th>Noncontrast–CT cohort (n=103)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>167 (43.3)</td>
<td>128 (45.2)</td>
<td>39 (37.9)</td>
<td>0.20</td>
</tr>
<tr>
<td>Age</td>
<td>84.3±8.7</td>
<td>83.9±8.5</td>
<td>85.0±9.3</td>
<td>0.17</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.4±5.4</td>
<td>26.4±5.5</td>
<td>26.4±5.4</td>
<td>0.92</td>
</tr>
<tr>
<td>Height, cm</td>
<td>165.9±10.6</td>
<td>165.3±10.4</td>
<td>167.7±10.9</td>
<td>0.04</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>72.6±15.8</td>
<td>72.0±15.6</td>
<td>74.3±16.5</td>
<td>0.42</td>
</tr>
<tr>
<td>Baseline creatinine, mg/dL</td>
<td>1.3±1.0</td>
<td>1.2±1.0</td>
<td>1.7±0.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Creatinine clearance, mL/min</td>
<td>39.7±18.6</td>
<td>42.8±19.5</td>
<td>31.3±12.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>NYHA class III or IV</td>
<td>359 (93.0)</td>
<td>264 (93.3)</td>
<td>95 (92.2)</td>
<td>0.72</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>137 (35.5)</td>
<td>91 (32.2)</td>
<td>46 (44.7)</td>
<td>0.023</td>
</tr>
<tr>
<td>Hypertension</td>
<td>338 (87.6)</td>
<td>251 (88.7)</td>
<td>87 (84.5)</td>
<td>0.27</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>340 (88.1)</td>
<td>248 (87.6)</td>
<td>92 (89.3)</td>
<td>0.65</td>
</tr>
<tr>
<td>Peripheral artery disease</td>
<td>170 (44.0)</td>
<td>137 (48.4)</td>
<td>33 (32.0)</td>
<td>0.004</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>60 (15.5)</td>
<td>46 (16.3)</td>
<td>14 (13.6)</td>
<td>0.52</td>
</tr>
<tr>
<td>Percutaneous coronary intervention</td>
<td>133 (34.5)</td>
<td>93 (32.9)</td>
<td>40 (38.8)</td>
<td>0.28</td>
</tr>
<tr>
<td>Coronary artery bypass grafting</td>
<td>109 (28.2)</td>
<td>86 (30.4)</td>
<td>23 (22.3)</td>
<td>0.12</td>
</tr>
<tr>
<td>Balloon aortic valvuloplasty</td>
<td>57 (14.8)</td>
<td>40 (14.1)</td>
<td>17 (16.5)</td>
<td>0.56</td>
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<tr>
<td>Cerebrovascular disease</td>
<td>81 (21.0)</td>
<td>67 (23.8)</td>
<td>14 (13.6)</td>
<td>0.03</td>
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<tr>
<td>Hemodialysis</td>
<td>6 (1.6)</td>
<td>4 (1.4)</td>
<td>2 (1.9)</td>
<td>0.71</td>
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<tr>
<td>Pulmonary disease</td>
<td>197 (51.0)</td>
<td>147 (51.9)</td>
<td>50 (48.5)</td>
<td>0.56</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>150 (38.9)</td>
<td>114 (40.3)</td>
<td>36 (35.0)</td>
<td>0.34</td>
</tr>
<tr>
<td>Permanent pacemaker implantation</td>
<td>55 (20.1)</td>
<td>37 (18.6)</td>
<td>18 (24.3)</td>
<td>0.29</td>
</tr>
<tr>
<td>Echocardiographic findings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitral regurgitation≥moderate</td>
<td>60 (15.5)</td>
<td>46 (16.3)</td>
<td>14 (13.6)</td>
<td>0.52</td>
</tr>
<tr>
<td>Left ventricular ejection fraction (%)</td>
<td>58.1±14.8</td>
<td>59.0±14.5</td>
<td>55.7±15.4</td>
<td>0.043</td>
</tr>
<tr>
<td>Mean pressure gradient, mm Hg</td>
<td>47.0±12.3</td>
<td>47.5±12.7</td>
<td>45.7±10.9</td>
<td>0.21</td>
</tr>
<tr>
<td>Aortic valve area, cm²</td>
<td>0.6±0.2</td>
<td>0.6±0.2</td>
<td>0.6±0.2</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Values are n (%) or mean±SD. BMI indicates body mass index; CT, computed tomography; NYHA, New York Heart Association; and STS score, The Society of Thoracic Surgeons’ risk score.
CMPR views were applied for measurement. Measurements were performed by an imaging technologist with >20-year experience in assessment of peripheral vasculature and were cross checked by a physician. For the invasive angiography, measurements were performed with PICOM PowerConsole software (SciImage, Los Altos, CA) using preprocedural iliofemoral angiograms. Calibration was done with the use of a marker pigtail and vasculature diameter was measured (Figure 1). Sheath-to-iliofemoral artery ratio (SIFAR) was defined as sheath outer diameter divided by access-side vasculature diameter.6

### Detailed 3D Assessment by CT

CT allows detailed 3D assessment of tortuosity and a cross-sectional measurement which are not available in angiography. To understand the best way to evaluate the iliofemoral vasculature, repeated reconstructions from raw Digital Imaging and Communications in Medicine data were generated and these 3D assessments were performed retrospectively in the consecutive 131 cases of the contrast-CT cohort using 3mensio Structural Heart software (3mensio Medical Imaging B.V., Bilthoven, The Netherlands).

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**Table 2. Procedural Characteristics**

<table>
<thead>
<tr>
<th>Total Patients (n=386)</th>
<th>Contrast-CT cohort (n=283)</th>
<th>Noncontrast-CT cohort (n=103)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 mm TAVR valve</td>
<td>187 (48.4)</td>
<td>137 (48.4)</td>
<td>50 (48.5)</td>
</tr>
<tr>
<td>26 mm TAVR valve</td>
<td>181 (46.9)</td>
<td>132 (46.6)</td>
<td>49 (47.6)</td>
</tr>
<tr>
<td>29 mm TAVR valve</td>
<td>13 (3.4)</td>
<td>10 (3.5)</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>Right femoral approach</td>
<td>231 (59.8)</td>
<td>176 (62.2)</td>
<td>55 (63.4)</td>
</tr>
<tr>
<td>Retroflex 24 Fr</td>
<td>135 (35.0)</td>
<td>94 (33.2)</td>
<td>41 (39.8)</td>
</tr>
<tr>
<td>Retroflex 22 Fr</td>
<td>131 (33.9)</td>
<td>93 (32.9)</td>
<td>38 (36.9)</td>
</tr>
<tr>
<td>Novaflex 19 Fr</td>
<td>29 (7.5)</td>
<td>22 (7.8)</td>
<td>7 (6.8)</td>
</tr>
<tr>
<td>Novaflex 18 Fr</td>
<td>44 (11.4)</td>
<td>37 (13.1)</td>
<td>7 (6.8)</td>
</tr>
<tr>
<td>e-sheath 20 Fr</td>
<td>17 (4.4)</td>
<td>13 (4.6)</td>
<td>4 (3.9)</td>
</tr>
<tr>
<td>e-sheath 18 Fr</td>
<td>17 (4.4)</td>
<td>14 (4.9)</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>e-sheath 16 Fr</td>
<td>13 (3.4)</td>
<td>10 (3.5)</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>Percutaneous closure</td>
<td>328 (85.0)</td>
<td>244 (86.2)</td>
<td>84 (81.6)</td>
</tr>
<tr>
<td>SRC</td>
<td>52 (13.5)</td>
<td>35 (12.4)</td>
<td>17 (16.5)</td>
</tr>
<tr>
<td>Percutaneous closure failure or cannulation site complications</td>
<td>32 (8.3)</td>
<td>20 (7.1)</td>
<td>12 (11.7)</td>
</tr>
<tr>
<td>Major SRC by VARC-1</td>
<td>45 (11.7)</td>
<td>31 (11.0)</td>
<td>14 (13.6)</td>
</tr>
<tr>
<td>Major SRC by VARC-2</td>
<td>16 (4.1)</td>
<td>12 (4.2)</td>
<td>4 (3.9)</td>
</tr>
<tr>
<td>Total Major VC by VARC-1</td>
<td>55 (14.2)</td>
<td>39 (13.8)</td>
<td>16 (15.5)</td>
</tr>
<tr>
<td>Total Major VC by VARC-2</td>
<td>30 (7.8)</td>
<td>22 (7.8)</td>
<td>8 (7.8)</td>
</tr>
</tbody>
</table>

Values are n (%). CT indicates computed tomography; SRC, sheath-related complication. TAVR, transcatheter aortic valve replacement; VARC, Valve Academic Research Consortium; and VC, vascular complication.
For the tortuosity assessment, once a CMPR center line is generated, the method uses a center line with a given point and 2 equidistant points that generate arms extending along the center line in opposite directions of the former given point. The angle between the 2 arms is the 3D angle as it takes into account antero-posterior and medio-lateral tortuosity. The given point can be scrolled up and down the center-line to identify the maximal tortuosity. For the assessment of vasculature size, minimum diameter, mean diameter, and perimeter were measured in the cross-sectional view (Figure 2). These vasculature-size variables were analyzed in the ratio to the sheath outer diameter. For the calcification assessment, conventional scoring of calcification in whole iliofemoral vasculature was performed as follows: 0, no calcification; 1, mild calcification; 2, moderate calcification; and 3, severe calcification.\(^{6}\) Also circumferential extent of calcification was assessed in the cross-sectional view at the minimal lumen diameter level, and scored as follows: 0, no calcification; 1, <30% of vessel is covered by calcium; 2, ≈30% to 60% of vessel is covered by calcium; 3, 60% to 100% vessel is covered by calcium.

### End Point Definitions

Vascular access site and access-related complications were collected and categorized based on the VARC-1\(^{11}\) and VARC-2\(^{16}\) definitions. Both were included as, despite the large size of the study, we saw few VCs by the less stringent VARC-2 definition, which diminished the value of the model because of a lack of end points. For the further specific end points, predicted by iliofemoral vasculature assessment, a sheath-related complication (SRC) was defined as an iliofemoral artery injury caused by sheath manipulation not including cannulation site complications; the latter can be more multifactorial including percutaneous closure device failure and are most probably less related to vessel caliber. This SRC was collected by review of procedural note and fluoroscopy. If vascular injury was detected, then the place was compared with the puncture site for cannulation and SRC was recorded when injury was not same place as the puncture site.

### Statistical Analysis

All the analyses were performed with data from the as-treated population. Quantitative variables are expressed as means±SD, and qualitative variables as number and percentage. Normality of distributions for continuous variables was tested using Shapiro–Wilks test and data were analyzed appropriately thereafter. In comparison across independent groups, \(\chi^2\) test was used for qualitative variables; independent sample \(t\) test was used for normally distributed qualitative variables; and Mann–Whitney \(U\) test was used for non-normally distributed quantitative variables. For inter/intraobserver reproducibility assessment, Bland–Altman analysis was performed. For intra-group comparisons, a paired \(t\) test was used for quantitative variables. Receiver operating characteristic (ROC) curves were generated using VCs as the end points and vasculature measurements as the variables. Areas under the curves (AUC) were compared using the method of DeLong et al\(^{17}\) Specific upper cut-offs of SIFAR were defined using ROC curves based on the SIFAR corresponding to the highest sum of sensitivity and specificity. A logistic regression analysis including variables with \(P\leq0.2\) in the univariable analysis was performed to determine the independent predictor for SRCs. A \(P\leq0.05\) is considered statistically significant. All data were analyzed with SPSS software (PASW v18, SPSS Inc., Chicago, IL) except ROC comparison by DeLong method with MedCalc version 12.7 (MedCalc Software bvba, Ostend, Belgium).

### Results

#### Study Population and Baseline and Procedural Characteristics

From the 588 patients undergoing TAVR, 496 patients were performed with the transfemoral approach (84.4%), with 84 (14.3%) transapical TAVR and 8 (2.78%) transaortic TAVR. Of the tranfemoral TAVR patients, a total of 370 had contrast

### Table 3. Comparison of AUC for Each End Point by Each Modality: Contrast-CT Cohort

<table>
<thead>
<tr>
<th>End point</th>
<th>Contrast CT</th>
<th>Angiography</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRC</td>
<td>0.87</td>
<td>0.72</td>
<td>0.001</td>
</tr>
<tr>
<td>Major SRC by VARC-1</td>
<td>0.85</td>
<td>0.73</td>
<td>0.001</td>
</tr>
<tr>
<td>Major SRC by VARC-2</td>
<td>0.91</td>
<td>0.77</td>
<td>0.001</td>
</tr>
<tr>
<td>Major VC by VARC-1</td>
<td>0.75</td>
<td>0.68</td>
<td>0.001</td>
</tr>
<tr>
<td>Major VC by VARC-2</td>
<td>0.73</td>
<td>0.69</td>
<td>0.001</td>
</tr>
</tbody>
</table>

AUC indicates area under the curve; CI, confidence interval; CT, computed tomography; SRC, sheath-related complication; VARC, Valve Academic Research Consortium; and VC, vascular complication.
CT and 103 noncontrast abdomen-pelvis CT. Only patients who had an angiographic comparator were analyzed (ie, 283 with contrast CT and 103 with noncontrast CT; Figures 3 and 4). Baseline characteristics for these groups are shown in Table 1. In the contrast-CT cohort, 67 cases of VCs were found, and of this group, 52% (35/67) of patients exhibited SRC complications. In the noncontrast–CT cohort, 28 cases of VCs were found, and of this group, 61% (17/28) of patients exhibited SRC complications (Table 2; Figure 3).

Reproducibility of CT and Angiography Assessment
Repeated reconstructions from Digital Imaging and Communications in Medicine data were generated for the subset of 20 randomly selected patients from both cohorts and vasculature diameter was measured for analysis of intra- and interobserver variability. For contrast CT, intraobserver variability was 0.13 mm (95% limits of agreement: −0.88 to 0.62 mm) and interobserver variability was 0.21 mm (95% limits of agreement: −1.22 to 0.80 mm). For noncontrast CT, intraobserver variability was 0.01 mm (95% limits of agreement: −0.58 to 0.99 mm) and interobserver variability was 0.00 mm (95% limits of agreement: −1.10 to 1.09 mm).

For angiography, the same subset of 20 randomly selected patients for contrast-CT analysis was applied. Intraobserver variability was 0.18 mm (95% limits of agreement: −1.07 to 1.43 mm) and interobserver variability was 0.06 mm (95% limits of agreement: −1.35 to 1.47 mm). Each modality showed high reproducibility (Figure 5).

Differences and Correlations of Vasculature Diameter Between CT and Angiography
In the contrast-CT cohort, CT showed average vessel diameter of 7.7±1.1 mm and angiography showed that of 7.2±1.3 mm. Contrast-CT measurement was larger than angiography by 0.51±1.05 (r=0.67; P<0.001). Both contrast and noncontrast CT showed slightly larger measurement than angiography.

ROC Curve Analyses for VCs and Thresholds of SIFAR
In the contrast-CT cohort, contrast CT showed a greater predictive value for SRC than angiography by area under the curve (P<0.001): 0.87 (95% confidence interval: 0.82–0.91; P<0.001) versus 0.72 (95% confidence interval: 0.66–0.77; P<0.001). However, there was no significant difference between noncontrast CT and angiography (P=0.19); 0.79 (95% confidence interval: 0.70–0.86; P<0.001) versus 0.73 (95% confidence interval: 0.63–0.81; P=0.003; Figure 6). Further analyses were performed on different end points and it revealed similar outcomes (Tables 3 and 4).

SIFAR thresholds were calculated for each modality. For angiography, combined data of both cohorts (386 patients) were used for calculation. Threshold of SIFAR were 1.11 for noncontrast CT; sensitivity of 82.4% and specificity if 69.8%; 1.12 for contrast CT; sensitivity of 94.3% and specificity of 65.3%; and 1.22 for angiography; sensitivity of 65.4% and specificity of 72.5%. Numbers of patients based on CT and angiography-based SIFAR and SRC are listed in Table 5 and 6. These SIFAR were applied to sheath outer diameter and thresholds of vasculature diameter by each modality are shown (Table 7).

<table>
<thead>
<tr>
<th>SIFAR</th>
<th>SRC (P&lt;0.001)</th>
<th>No SRC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIFAR≥1.12</td>
<td>33 (27.7%)</td>
<td>86 (72.3%)</td>
<td>119</td>
</tr>
<tr>
<td>SIFAR&lt;1.12</td>
<td>2 (1.2%)</td>
<td>162 (98.8%)</td>
<td>164</td>
</tr>
</tbody>
</table>

P values are calculated by Fisher exact test. CT indicates computed tomography; SIFAR, sheath-to-iliofemoral–artery ratio; and SRC, sheath-related complication.


**Table 6. Numbers of Patients Based on CT and Angiography-Based SIFAR and SRC: Noncontrast–CT Cohort (n=103)**

<table>
<thead>
<tr>
<th>SIFAR ≥ 1.11</th>
<th>SRC</th>
<th>No SRC</th>
<th>Total</th>
<th>Angiography (P&lt;0.001)</th>
<th>SIFAR ≥ 1.22</th>
<th>SRC</th>
<th>No SRC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIFAR ≥ 1.11</td>
<td>14</td>
<td>26</td>
<td>40</td>
<td>SIFAR ≥ 1.22</td>
<td>11 (34.4%)</td>
<td>21</td>
<td>65.6%</td>
<td>32</td>
</tr>
<tr>
<td>SIFAR &lt; 1.11</td>
<td>3</td>
<td>60</td>
<td>63</td>
<td>SIFAR &lt; 1.22</td>
<td>6 (8.5%)</td>
<td>65</td>
<td>91.5%</td>
<td>71</td>
</tr>
</tbody>
</table>

*Values are calculated by Fisher exact test. CT indicates computed tomography; SIFAR, sheath-to-iliofemoral–artery ratio; and SRC, sheath-related complication.*

**Multivariable Analysis for SRCs**

Multivariable analysis showed height and SIFAR over the threshold by CT assessment because the independent predictor for SRCs in both contrast-CT cohort and noncontrast–CT cohort (Table 8). Although ROC curve analysis showed a significant correlation between SIFAR by angiography and SRCs, the significance did not remain after adjustment with other variables (P=0.303 in contrast-CT angiography cohort, and P=0.379 in noncontrast–CT angiography cohort).

**The Value of Detailed 3D Assessment by CT**

Detailed 3D assessments and conventional assessment of size, tortuosity, and calcification were performed in consecutive 131 cases of the contrast-CT cohort as previously described, and ROC models were generated using SRC as the end point. The technique of vasculature measurement in antero-postal and lateral CMPR views was compared with a cross-sectional approach using CMPR and a strong correlation of these 2 methodologies was observed (please see appendix). All tortuosity assessment including the 3D angle revealed no correlation with SRC. Calcification assessment also did not show significant value for SRC prediction. In the conventional calcification scoring of the whole iliofemoral vasculature, the rates of SRC were 12.4% in the no and mild calcification group and 11.8% in the moderate and severe calcification group (P=0.6). In the cross-sectional scoring, the rates of SRC were 10.2% in the no and mild calcification group and 18.2% in the moderate and severe calcification group (P=0.18).

**Discussion**

Careful evaluation of the patient’s iliofemoral vasculature is required for the best possible delivery site for transfemoral TAVR. This study demonstrates that contrast CT provides more predictive information than angiography for VCs during TAVR. However, this is with the important caveat that the safe iliofemoral thresholds for CT were higher than angiography.

**Value and Limitations of CT**

Multivariable analysis showed only height and CT assessment as the independent predictors for VC, and angiography did not show significance in the adjustment with other variables. Angiography has a greater spatial resolution and could better pick up focal stenoses, but the assessment is based on a 2-dimensional technique that does not take into account orthogonal dimensions. CT allows 3D assessment and CT assessment was performed in the 2 orthogonal views in this study. The greater value of contrast CT was most probably driven by this difference.

Although radiation exposure is important to consider with any CT acquisition, it is a lesser concern in the elderly patients currently considered for TAVR. More importantly, CT requires the addition of iodinated contrast, and it is a concern in many patients because candidates for TAVR frequently have impaired renal function. This study provides the efficacy of noncontrast CT, and this may benefit renal impaired TAVR patients; however, there is a limitation for the luminal assessment with this modality. In addition, measurement remains difficult where the iliofemoral artery is close to similar CT density soft tissue; iliofemoral vein or iliopsoas, and in thin patients with little supporting tissue or those with abdominal fluid. In consideration of the above factors and limited efficacy, noncontrast CT probably should be assessed in combination with angiography or intravascular ultrasound. Low contrast CT could be an alternative rather than the combination of noncontrast CT and angiography, but further study is required for this comparison. Advances in CT imaging including high pitch helical CT have brought both radiation levels and contrast doses dramatically down such that a whole body vascular CT may be performed with intravenous contrast doses as low as 30 cc. This may enable more patient population to be benefitted by contrast CT. On the basis of the ROC curve and multivariable analyses presented here, angiography seems to be unnecessary in patients with a good contrast-CT assessment.

**Table 7. Thresholds of Vasculature Diameter for Each Sheath by Each Modality**

<table>
<thead>
<tr>
<th>Valve Types</th>
<th>Sheath Types</th>
<th>ID, Fr</th>
<th>ED, mm</th>
<th>Recommended</th>
<th>SIFAR=1.05 (Previous Study)</th>
<th>SIFAR=1.11 (Noncontrast CT)</th>
<th>SIFAR=1.12 (Contrast CT)</th>
<th>SIFAR=1.22 (Angiography)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapien 23 mm</td>
<td>RetroFlex 3 sheath</td>
<td>22</td>
<td>8.4</td>
<td>7</td>
<td>8.0</td>
<td>7.6</td>
<td>7.5</td>
<td>6.9</td>
</tr>
<tr>
<td>Sapien 26 mm</td>
<td>RetroFlex 3 sheath</td>
<td>24</td>
<td>9.2</td>
<td>8</td>
<td>8.8</td>
<td>8.3</td>
<td>8.2</td>
<td>7.5</td>
</tr>
<tr>
<td>XT 23 mm</td>
<td>NovaFlex sheath</td>
<td>18</td>
<td>7.2</td>
<td>6.5</td>
<td>6.9</td>
<td>6.5</td>
<td>6.4</td>
<td>5.9</td>
</tr>
<tr>
<td>XT 26 mm</td>
<td>Edwards e-sheath</td>
<td>16</td>
<td>6.7</td>
<td>6</td>
<td>6.4</td>
<td>6.0</td>
<td>6.0</td>
<td>5.5</td>
</tr>
<tr>
<td>XT 29 mm</td>
<td>Edwards e-sheath</td>
<td>18</td>
<td>7.2</td>
<td>6.5</td>
<td>6.9</td>
<td>6.5</td>
<td>6.4</td>
<td>5.9</td>
</tr>
</tbody>
</table>

*CT indicates computed tomography; ED, external diameter; ID, internal diameter; and SIFAR, sheath-to-iliofemoral–artery ratio.*
Table 8. Multivariable Analysis for Prediction of Sheath-Related Complications

<table>
<thead>
<tr>
<th>Variable</th>
<th>Contrast-CT Cohort</th>
<th>Noncontrast–CT Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Value</td>
<td>Odds Ratio</td>
<td>Lower 95% CI</td>
</tr>
<tr>
<td>Age</td>
<td>0.58</td>
<td>0.937</td>
</tr>
<tr>
<td>Female</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>Height, cm</td>
<td>0.004</td>
<td>32.226</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>0.64</td>
<td>0.93</td>
</tr>
<tr>
<td>Creatinine clearance, mL/min</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>Hemodialysis</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>e-sheath</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Sheath diameter, mm</td>
<td>0.13</td>
<td>0.93</td>
</tr>
<tr>
<td>SIFAR over threshold by CT</td>
<td>&lt;0.001</td>
<td>0.30</td>
</tr>
<tr>
<td>SIFAR over threshold by Angiography</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

CI indicates confidence interval; CT, computed tomography; and SIFAR, sheath-to-iliofemoral artery ratio.

Thresholds of the SIFAR
Hayashida et al reported that sheath-to-femoral artery ratio of ≥1.05 is predictive of major VCs, yet our data showed a more lenient cut-off is appropriate: ≥1.11 for noncontrast CT, ≥1.12 for contrast CT, and ≥1.22 for angiography. This difference in the 2 studies may be driven from the use of different software and the measurement methodologies, and may also reflect the specific end point, the learning curve of iliofemoral approach, and the devices used. The earlier study defined major VCs by VARC-1 as end points, which includes not only the iliofemoral artery but also other access route complications, whereas our study defined the specific end point of an iliofemoral arterial injury not including the cannulation site. Early center experience is an independent risk factor for major VCs. This study had a relatively large number, and included cases conducted later in the learning curve. Finally, our study included patients treated with the Edwards expandable sheath (e-sheath), which was not available in the previous study.

As is seen in the annulus assessment with CT and echocardiogram for TAVR-valve sizing, there is some discrepancy of measurement between different modalities. This study revealed a significant difference between CT and angiographic measurement, and specific threshold for each modality allows more accurate preprocedure assessment.

Study Limitations
This is a single-center study with small number of events and without validation of SIFAR cut-offs either by split sample or by cross-validation. Performance features of ROC analyses and logistic models might be attenuated in a replication/validation sample. The study is limited to Edward Lifesciences devices although other devices are commercially available worldwide. The assessed population is an as-treated group of transfemoral TAVR and did not include TAVR candidates in whom TAVR was aborted. The used software for CT assessment is InSight, which is not widely used but is similar to other commercially available software. The angiography was performed with the limited method of a single projection without the digital subtraction angiography technique. Although tortuosity and calcification did not seem to predict VCs, the study was insufficiently powered to assess the extremes of these 2 parameters. This study was performed retrospectively and is limited by potential bias introduced by specific referral patterns. Patients were not randomized by each modality usage.

Conclusions
Access route selection for TAVR is an important aspect of preprocedural planning, and iliofemoral vasculature assessment is particularly crucial. Vessel diameter assessment by contrast CT provides a greater predictive value for VCs after TAVR than angiography. This finding suggests that access route selection should be based on the contrast-CT assessment whenever possible.

Acknowledgments
We acknowledge the efforts of our research team, including our research coordinator, Dr Mitch Gheorghiu, and nurse practitioners, Jasminka Stegic and Tracy Salseth.

Disclosures
Dr Makkar and Dr Jilaihawi are consultants to Edwards Lifesciences. The other authors report no conflicts.

References


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**CLINICAL PERSPECTIVE**

Iliofemoral assessment is a crucial factor for preprocedural transcatheter aortic valve replacement planning because vascular complications have been associated with adverse outcome. There is variability in the imaging modalities used to screen for vascular complications. At many sites, screening is empirical, with some following a contrast computed tomography protocol while others support the use of contrast angiography alone. Despite established practices, there remains no data to support either strategy. For the first time, this study revealed that contrast computed tomography has a greater predictive value than invasive angiography by area under the curve (*P*<0.001): 0.87 (95% confidence interval: 0.82–0.91; *P*<0.001) versus 0.72 (95% confidence interval: 0.66–0.77; *P*<0.001). This new evidence emphasizes the need to standardize the approach to iliofemoral evaluation before transcatheter aortic valve replacement and our preliminary data raises the possibility that contrast computed tomography could be the appropriate imaging modality for transcatheter aortic valve replacement patients.
Transfemoral Access Assessment for Transcatheter Aortic Valve Replacement: Evidence-Based Application of Computed Tomography Over Invasive Angiography

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SUPPLEMENTAL MATERIAL

Supplemental table. Three-dimensional and conventional assessment of vasculature by computed tomography

<table>
<thead>
<tr>
<th>Vasculature Size Assessment</th>
<th>AUC</th>
<th>SE</th>
<th>p</th>
<th>Lower/Upper 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIFAR by minimum diameter in AP and lateral CMPR views</td>
<td>0.83</td>
<td>0.045</td>
<td>&lt; 0.001</td>
<td>0.74/0.90</td>
</tr>
<tr>
<td>SIFAR by minimum diameter in cross-sectional view</td>
<td>0.82</td>
<td>0.044</td>
<td>&lt;0.001</td>
<td>0.73/0.90</td>
</tr>
<tr>
<td>SIFAR by mean diameter in cross-sectional view</td>
<td>0.76</td>
<td>0.051</td>
<td>0.001</td>
<td>0.66/0.86</td>
</tr>
<tr>
<td>SIFAR by perimeter in cross-sectional view</td>
<td>0.71</td>
<td>0.06</td>
<td>0.006</td>
<td>0.56/0.83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vasculature Tortuosity Assessment</th>
<th>AUC</th>
<th>SE</th>
<th>p</th>
<th>Lower/Upper 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle in 3-dimensional assessment</td>
<td>0.51</td>
<td>0.079</td>
<td>0.9</td>
<td>0.35/0.67</td>
</tr>
<tr>
<td>Angle in AP CMPR view</td>
<td>0.51</td>
<td>0.084</td>
<td>0.9</td>
<td>0.35/0.68</td>
</tr>
<tr>
<td>Angle in lateral CMPR view</td>
<td>0.5</td>
<td>0.081</td>
<td>1</td>
<td>0.34/0.66</td>
</tr>
</tbody>
</table>

AUC = area under the curve. AP = antero-posterior. CMPR = curved multi planar reconstruction. CI = confidence interval. MLD = minimal lumen diameter. SE = standard error. SIFAR = sheath-to-ilifemoral ratio.