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Comparison of Direct Aortic and Subclavian Transcatheter Aortic Valve Implantation: recent knowledge/an update from the UK Transcatheter Aortic Valve Implantation (TAVI) registry in 2013-2015.

A Myat MD \*, O Papachristofi PhD\*, U Trivedi , V Bapate,f,2, C Young, A de Belder, J Cockburn, A Baumbach, A P. Banning, D J. Blackman, P MacCarthy, M Mullen, D F. Muir, J Nolan, A Zaman, M de Belder, I Cox, J Kovac, S Brecker, M Turner,S Khogali, I Malik, S Redwood, B Prendergast, P Ludman, LD Sharples PhD<sup>3</sup>, D Hildick-Smith MD<sup>4</sup>, on behalf of the UK TAVI Steering Committee and the National Institute for Cardiovascular Outcomes Research.

\*co-primary authors

<sup>1</sup>Research Fellow, Department of Medical Statistics, London School of Hygiene and Tropical Medicine, London, WC1E 7HT, UK

<sup>2</sup> Specialist Registrar in Cardiology, Heart and Lung Centre, Royal Wolverhampton NHS Trust, Wolverhampton, WV10 0QP, UK

<sup>3</sup> Professor of Medical Statistics, Department of Medical Statistics, London School of Hygiene and Tropical Medicine, London, WC1E 7HT, UK

<sup>4</sup> Professor in Interventional Cardiology, Brighton and Sussex University Hospitals NHS Trust, UK

Corresponding author: Dr O Papachristofi, Department of Medical Statistics, London School of Hygiene and Tropical Medicine, London, WC1E 7HT, UK

Email: [olympia.papachristofi@lshtm.ac.uk](mailto:olympia.papachristofi@lshtm.ac.uk)

## Abstract

**Background:** Surgical subclavian (SC) and direct aortic (DA) access are established alternatives to the default transfemoral route for transcatheter aortic valve implantation (TAVI). We sought to find differences in survival and procedure-related outcomes after SC- versus DA-TAVI.

**Methods:** We performed an observational cohort analysis of cases prospectively uploaded to the UK TAVI registry. To ensure the most contemporaneous comparison, the analysis focused on SC and DA procedures performed from 2013 to 2015.

**Results:** Between January 2013 and July 2015, 82 (37%) SC and 142 (63%) DA cases were performed that had validated 1-year life status. Multivariable regression analysis showed procedure duration was longer for SC cases (SC  $193.5 \pm 65.8$  vs. DA  $138.4 \pm 57.7$  min;  $p < .01$ ) but length of hospital stay was shorter (SC  $8.6 \pm 9.5$  vs. DA  $11.9 \pm 10.8$  days;  $p = .03$ ). Acute kidney injury was observed less frequently after SC cases (odds ratio [OR] 0.35, 95% confidence interval [CI] 0.12–0.96;  $p = .042$ ) but vascular access site-related complications were more common (OR 9.75 [3.07–30.93];  $p < .01$ ). Procedure-related bleeding (OR 0.54 [0.24–1.25];  $p = .15$ ) and in-hospital stroke rate (SC 3.7% vs. DA 2.1%;  $p = .67$ ) were similar. There were no significant differences in in-hospital (SC 2.4% vs. DA 4.9%;  $p = .49$ ), 30-day (SC 2.4% vs. DA 4.2%;  $p = .71$ ) or 1-year (SC 14.5% vs. DA 21.9%;  $p = .344$ ) mortality.

**Conclusions:** Surgical subclavian and direct aortic approaches can offer favourable outcomes in appropriate patients. Neither access modality conferred a survival advantage but there were significant differences in procedural metrics that might influence which approach is selected.

**Aims** The direct aortic (DA) and subclavian (SC) routes are means of vascular access to undertake transcatheter aortic valve implantation (TAVI) in particularly high-risk cases. The two access route are considered to be comparable in terms of short- and long-term survival, however this has not been recently evaluated, following the gain in experience with both techniques; moreover, whether the characteristics of the patient population currently treated with each differ remains unclear. This study uses up-to-date information from the UK TAVI registry in order to describe the patient

population receiving TAVI via the DA and SC access routes, and compare these in terms of short and long-term mortality as well as other key clinical and process outcomes, adjusting for patient risk.

**Methods and Results:** All patients in the UK TAVI registry operated via the SC or DA route between January 2013 and June 2015 were included in this analysis. Mortality status was ascertained up to July 2015. Multivariate models were used to assess the effect of access route on mortality and other outcomes of interest, adjusting for patient characteristics.

**Conclusion:** The SC and DA routes for TAVI were not found to be significantly different in terms of short- and long-term mortality; nevertheless, the SC route was associated with a lower risk of bleeding and AKI. SC access significantly inflated operative duration, whereas DA access increased postoperative length-of-stay. Therefore the cost-effectiveness of the two routes merits further investigation as it may be a principal determinant in the choice between the two approaches.

**Keywords:** transcatheter aortic valve implantation, aortic valve stenosis, subclavian implantation, direct aortic implantation, heart valve.

## Introduction

The retrograde trans-femoral (TF) route is the established default vascular access for trans-catheter aortic valve implantation (TAVI) [1,2]. In some patients, however, the trans-femoral approach is not possible because of significant atherosclerotic disease and/or unsuitable iliofemoral anatomy, such as tortuosity or small calibre. Alternatives include the trans-apical (TA), direct aortic (DA), subclavian or axillary (SC), carotid and trans-caval access sites. With the miniaturisation of TAVI delivery systems and the relative invasiveness of surgical thoracotomy in often multi-morbid patients, TA access is now performed less frequently in the United Kingdom (UK). Consequently the SC and DA routes have become the predominant alternative surgical approaches, both performed under general anaesthetic. Either approach mandate a surgical cut down – the former to the subclavian artery and the latter via an upper partial sternotomy or small right anterior thoracotomy. Both were originally developed for the Medtronic CoreValve (Medtronic, Dublin, Ireland) due to its longer profile, which made a TA approach problematic. The DA access can also be used for the Edwards Lifesciences Sapien (Irvine, CA, USA) valve.

There is a lack of data directly comparing outcomes after SC versus DA access TAVI. Hence we analysed the UK TAVI national registry to determine whether there was a difference in short- and medium-term survival and other important procedure-related outcomes between these two alternative vascular access approaches.

## **Methods**

### **Overview of the UK TAVI registry**

The UK TAVI registry has recorded baseline demographics, procedural characteristics, complications and clinical outcomes for every patient treated with TAVI since January 2007. It is mandatory to complete the dataset for every individual undergoing attempted TAVI in the UK. The data are collated and the process quality controlled by the National Institute of Cardiovascular Outcomes Research (NICOR) [1,3,4].

The current study is an observational cohort analysis of all procedures prospectively uploaded to the NICOR servers from January 2007 to December 2015. A Heart Team in each centre determined patient eligibility for TAVI, selected prosthesis type and corresponding access route according to size and degree of tortuosity, calcification, and atheroma of the aorto-iliofemoral arterial tree. All patients provided written informed consent at the time of their TAVI procedure as per standard institutional protocols. We identified all those who had TAVI performed via the SC versus DA access route and compared them according to patient and procedural characteristics, clinical outcomes and survival. Missing data were excluded from the analyses.

DA access has only been used from 2013 onwards, whereas SC access was available from 2007. To ensure a more contemporaneous and statistically more robust comparison of SC versus DA access outcomes, we focussed our analyses on procedures performed from January 2013 to July 2015. We used multivariable regression to adjust for remaining confounding.

The primary analysis looked at 30-day and 1-year all-cause mortality after SC versus DA access TAVI up to July 2015. The secondary analysis was designed to investigate important process measures and postoperative complications including: procedure duration, postoperative length-of-stay (LoS), vascular access site and related complications, in-hospital permanent pacemaker implantation (PPI), pericardial tamponade, valve embolization, further valve intervention before discharge, stroke, bleeding, aortic valve regurgitation, acute kidney injury (AKI) and requirement for new renal replacement therapy.

### **Data Cleaning**

Registry results are presented to the British Cardiovascular Intervention Society (BCIS) annually, ensuring continual validation and verification of data integrity. All data, inclusive of peri- and postprocedural complications up to hospital discharge are reported by each participating TAVI centre in accordance with the definitions outlined by the national dataset. Range checks to expose extreme values and assessments of internal consistency are applied when individual records are uploaded to the central NICOR server. Centres uploading records with missing, extreme, or inconsistent values are contacted and asked to ratify records if necessary.

### **Mortality Tracking**

Patients undergoing TAVI in England and Wales (comprising the vast majority of procedures in the registry), are linked to the Office of National Statistics by the National Health Service (NHS) Central Register via a unique NHS number. This provides a robust system for tracking all-cause mortality. Validated life status data were available for patients up to July 2015. This was used for survival analyses at 30 days and 1 year for the current investigation. NICOR has support under section 251 of the NHS Act 2006. According to NHS research governance arrangements, formal ethics approval was not required for this study [1,3]. This study was conducted in accordance with the Declaration of Helsinki and good clinical practice.

### **Statistical analysis**

Continuous variables are summarised as mean and standard deviation, or as median and interquartile ranges (IQR) where appropriate. Unadjusted differences were assessed with the two-sample *t*-test, or two-sample Wilcoxon rank-sum test. Categorical variables are presented as absolute numbers and percentages, and comparison between groups was undertaken by the  $\chi^2$ , or Fisher exact tests (the latter for variables with five events or less per group); ordinal categorical variables were compared using the linear-by-linear association test, taking into account their ordered nature. A Kaplan-Meier survival curve was produced to illustrate the percentage survival of all patients undergoing SC versus DA TAVI from 2013 to 2015 with log-rank test *p*-values additionally

obtained. Survival was examined as a time-to-event outcome, using the Cox proportional hazards model. The proportional hazards assumption was assessed using scaled Schoenfeld residuals.

Linear regression models were employed for continuous outcomes (considering logarithmic transformations to address non-normality issues where necessary), and binary outcomes analysed using logistic regression. In order to adjust for selection bias, candidate co-variables considered for risk-adjustment were age at operation, sex, body mass index (BMI), Canadian Study of Health and Aging (CSHA) clinical frailty score, diabetes, history of pulmonary disease, previous myocardial infarction (MI), previous percutaneous coronary intervention (PCI), previous cardiac surgery, elective procedure (or not), extensive calcification of ascending aorta, aortic balloon valvuloplasty, and year of operation; these were selected based on group consensus and the existing literature.

Multivariable regression analysis was undertaken to examine the association of access route with the co-primary outcomes, adjusted for patient characteristics. Multivariable models were further used for all other continuous outcomes, and binary outcomes with a sufficient number of events to allow for modelling. Note that procedure-related bleeding and AKI were modelled as binary variables if these occurred, but not their gravity. Relevant predictors for each outcome of interest were identified by first performing univariable regression analyses; those variables found significant (i.e. with 2-sided  $p$ -value  $<.05$ ) were subsequently assessed simultaneously in multivariable models.

Additional sensitivity analysis to assess the impact of selection bias was undertaken. Propensity score matching was performed but the results obtained were similar to those in the adjusted regression analysis so were therefore omitted. A 2-sided  $p$ -value  $<.05$  was considered significant for all statistical tests. Data handling and analysis were performed with R (v3.3.2).



## Results

From January 2007 to December 2015 a total of 9903 TAVI procedures were recorded in the UK TAVI registry. Of the 2473 procedures reported in 2015, the TF approach was the default vascular access strategy ( $n = 2073$ , 83.8%). TA access was the next most common ( $n = 163$ , 6.6%) followed by DA ( $n = 56$ , 2.3%) and SC ( $n = 43$ , 1.7%) routes. In the primary analysis, there were 4033 TAVI procedures undertaken from January 2013 up to July 2015. Of these 296 (7.3%) were performed via the DA and SC access routes (192 [64.9%] and 104 [35.1%] respectively) (see Online Supplement Fig. 1). After exclusion of cases with missing information on mortality (short or long-term, 27 cases) or other outcomes of interest (e.g. procedure duration, 14 cases), and key covariates examined (e.g. age, 31 cases), the final analysis cohort included 224 cases, 142 (63.4%) by DA and 82 (36.6%) by the SC route. Follow-up ranged from 35 to 920 days (median follow-up amongst survivors 545 days).

### Patient and operative characteristics by vascular access route

The median age of patients was 81 (IQR 75–85) years and 54.9% were male. DA access patients were marginally older. Significantly more men were approached via the SC route (Table 1). The BMI distribution was comparable. SC access was almost exclusively used for the CoreValve (93.9%, 77 of 82) prosthesis, whereas the majority of DA cases were for a Sapien valve (64.1%, 91 of 142).

### Unadjusted Outcomes by vascular access route

Unadjusted 30-day mortality (post-TAVI) for the full cohort was 3.6%. In-hospital, 30-day and 1-year post-TAVI survival did not significantly differ between groups, although more DA deaths occurred overall (Table 2). Long-term survival did not differ significantly between those individuals exposed to SC versus DA access (Fig. 1).

Median procedure time was approximately 1 h longer for SC cases, although SC cases were associated with earlier hospital discharge. A higher proportion of SC patients required a permanent pacemaker post TAVI though this was not statistically significant. The SC route was associated with significantly more vascular access complications and aortic regurgitation compared to the DA

approach. Conversion to full sternotomy, bailout valve in valve intervention, further valve intervention and renal replacement therapy prior to discharge were rarely required for either access route.

### **Adjusted associations of access route with outcomes**

The only significant predictor for long-term mortality after an adjusted Cox regression analysis was patient frailty as assessed by the CSHA frailty score (hazard ratio [HR] 1.68, 95% confidence interval [CI 1.35, 2.09];  $p < .01$ ). The SC route was associated with a comparatively lower all cause mortality risk (HR 0.71 [0.39, 1.29];  $p = .258$ ) although this did not reach statistical significance.

Multivariable logistic regression showed that the two access routes differed in certain key outcomes (Table 3). The SC cases were associated with a 38% longer mean procedure time yet resulted in a 29% shorter mean length of hospital stay compared to DA cases. It is worthwhile noting that the overall time in theatre reduced by 10% per calendar year. The SC approach significantly reduced the odds of AKI (odds ratio [OR] 0.35, [0.12, 0.96];  $p = .042$ ). However, the SC route was also associated with a doubling in the odds of aortic regurgitation (OR 2.08 [1.11, 3.91];  $p = .023$ ) and a nearly tenfold increase in vascular access site-related complications (OR 9.75 [3.07, 30.93];  $p < .01$ ).

## Discussion

The TF approach remains the default vascular access strategy for TAVI. It is minimally invasive and allows performance of TAVI under conscious sedation. However, roughly 10% of patients require an alternative access route [1,5].

The TA route is associated with more postoperative bleeding and a higher mortality than the TF approach [6,7]. This led to the development of subclavian/axillary access, first described in 2008 [8].

A surgical cut down is usually required, although a fully percutaneous method has been more recently described [9] along with a move to perform appropriate cases under local anaesthetic.

The SC approach has been shown to have equivalent procedural success and medium term results when compared with TF access using a propensity-matched analysis of the Italian CoreValve Registry [10]. Equivalence in survival was also demonstrated against TA access in a small multicentre study comprising 202 procedures, despite the TA access causing significantly more bleeding and a trend towards greater in-hospital mortality [11]. Use of the SC approach, however, can be restricted by anatomical features such as tortuosity or small vessel calibre. Those with a pre-existing left internal mammary artery bypass graft may also be exposed to the risk of ischemia during instrumentation [12]. Moreover the relative lack of a muscular component to the wall of the subclavian artery makes it more susceptible to dissection.

The DA approach was first reported in 2010. It offers direct delivery within close proximity to the aortic annulus, a high level of control and enhanced accuracy when positioning the prosthesis. A surgical incision via an upper partial sternotomy or small right anterior thoracotomy means invasiveness is relatively high. Risk is further exacerbated by the need for general anaesthesia and mechanical ventilation [13,14].

A suprasternal DA approach, performed under general anaesthesia but avoiding sternotomy and thoracotomy, has also been reported [15]. DA access is a safe and feasible alternative to a TF strategy, when the latter cannot be used [16–19]. DA access appears to have at least equivalent or better rates of long- and short-term mortality, stroke and bleeding when previously compared to the

TA route [20–23]. Much of the observational data used to support these comparisons, however, are limited to predominantly high surgical risk individuals. Further validation in intermediate and lower risk cohorts are required in response to the inevitable broadening of the eligibility criteria for TAVI. There is a paucity of data directly comparing the SC and DA routes for TAVI. In the absence of randomised controlled trial data, prospectively collected observational data offer the best alternative for such a comparison. In a prior analysis of the UK TAVI registry from January 2007 to December 2012, SC access demonstrated a similar 1-year survival rate to TF. The TA and DA approaches were, however, found to have significantly higher mortality both at 1 and 2 years. The investigators concluding that a SC strategy may represent the safest non-femoral access route for TAVI [24].

The present study directly compared the SC and DA approaches and showed no survival advantage in favour of either strategy with respect to in-hospital, 30-day and 1-year all-cause mortality, although deaths after the DA approach were numerically higher. The SC route was associated with significantly more vascular access site complications and aortic regurgitation. The latter may be explained by the fact almost all SC procedures were performed using the Medtronic CoreValve prosthesis [25,26]. The numerically higher rate of permanent pacemaker implantation after SC procedures are also likely to be associated with CoreValve use [27]. Moreover, in a recent propensity-matched analysis of the FRANCE-TAVI nationwide registry from treated with balloon-expandable prostheses ( $n = 3910$ ) were matched 1:1 with individuals treated with self-expandable heart valves ( $n = 3910$ ), use of the latter device was found to cause significantly more post-procedural paravalvular regurgitation ( $p < .0001$ ) and the need for permanent pacemaker implantation ( $p < .0001$ ) [28]. The true extent of our findings, therefore, require further validation in a larger cohort as the respective confidence intervals were relatively wide (Table 3).

Some UK centres no longer use DA access as the recovery from a thoracotomy was found to be slow and patients were susceptible to chest infections, post-operative renal dysfunction and had a longer hospital stay. Further reports from the UK TAVI registry encompassing all procedural reports from

2016 and 2017 appear to echo this trend. The reports show an increasing trend towards use of SC over DA access (2016, SC 94 vs. DA 65 procedures, 2017, SC 107 vs. DA 53 procedures) [29,30].

Future studies will incorporate this data to further delineate whether there is a survival advantage of SC over DA access.

### **Limitations**

The current work suffers from all the limitations inherent to observational analyses of clinical registry data, thus the results should be interpreted with caution. The data were prospectively collected by each TAVI centre but there was no event adjudication committee for this study. This exposes our analysis to potentially significant under-reporting of complications, though mortality tracking avoided this issue with regard to life status.

The number of SC and DA cases available for the analysis were relatively small. This is a product of both the truncated period in which there was validated life status available and that the predominant vascular access strategy remains the TF route in the UK. Regrettably we were unable to utilise data from 2016 and 2017 in our primary analysis due to a lack of validated life status during this time period. The relatively small size of our study cohort may have resulted in limited power to detect significant associations between route and outcomes, and to identify potentially important covariates.

There was a notable amount of missing data primarily related to in-hospital outcomes. Multiple imputation, however, was not pursued given the proportions involved was almost equitable between access routes (21% SC vs. 25% DA). Furthermore the clinical nature of the cohort examined allowed for thorough risk-adjustment in model building in order to account for differences in patient profiles treated via either strategy. Nevertheless, residual confounding cannot be excluded.

### **Conclusions**

Surgical subclavian (or transaxillary) and direct aortic vascular access routes are established, feasible and comparatively safe alternative strategies to the default retrograde transfemoral access for TAVI. We found no significant difference in short- or medium-term survival between the two. However, in

more recent years, there has been an increase in the use of the transaxillary route (including percutaneous approaches performed under local anaesthetic) and a corresponding decline in DA access. As with any operative technique, however, the decision to select a specific approach will be determined by varying combinations of patient comorbidity, vascular anatomy, transcatheter heart valve preference and the skill mix and expertise of the Heart Team.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j-ijcard.2020.03.059>.

### **Ethics approval**

This study is in compliance with the Declaration of Helsinki. Data collection was mandated by UK national cardiac audit, and all patient identifiers were removed from the dataset prior to any analysis. The TAVI registry forms part of NICOR that has support under the National Health Service (NHS) Act 2006 (section 251); under NHS research arrangements, formal ethical approval was not required.

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### **References**

- [1] P F Ludman, N Moat, M A De Belder, et al., Transcatheter aortic valve implantation in the United Kingdom: temporal trends, predictors of outcome, and 6-year follow-up: a report from the UK transcatheter aortic valve implantation (TAVI) registry, 2007 to 2012, *Circulation* 131 (2015) 1181–1190.
- [2] H Baumgartner, V Falk, J J Bax, et al., ESC/EACTS guidelines for the management of valvular heart disease, *Eur. Heart J.* 38 (2017) 2739–2786.

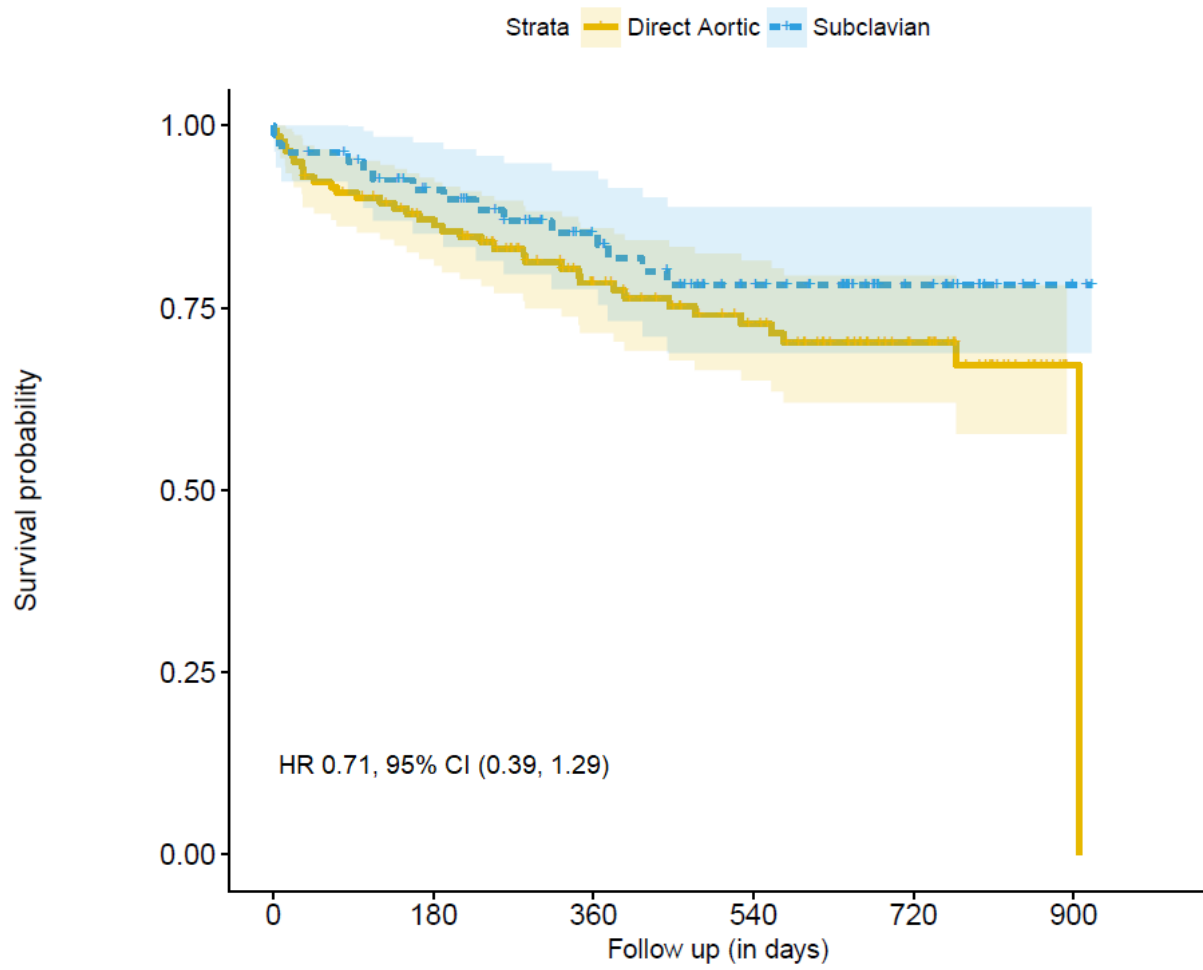
- [3] P F Ludman, The UK transcatheter aortic valve implantation registry; one of the suite of registries hosted by the National Institute for Cardiovascular Outcomes Research (NICOR), *Heart* 98 (2012) 1787–1789.
- [4] N E Moat, P Ludman, M A de Belder, et al., Long-term outcomes after transcatheter aortic valve implantation in high-risk patients with severe aortic stenosis: the U.K. TAVI (United Kingdom transcatheter aortic valve implantation) registry, *J. Am. Coll. Cardiol.* 58 (2011) 2130–2138.
- [5] M Gilard, H Eltchaninoff, P Donzeau-Gouge, et al., Late outcomes of Transcatheter aortic valve replacement in high-risk patients: the FRANCE-2 registry, *J. Am. Coll. Cardiol.* 68 (2016) 1637–1647.
- [6] S Kodali, V H Thourani, J White, et al., Early clinical and echocardiographic outcomes after SAPIEN 3 transcatheter aortic valve replacement in inoperable, high-risk and intermediate-risk patients with aortic stenosis, *Eur. Heart J.* 37 (2016) 2252–2262.
- [7] R M van der Boon, B Marcheix, D Tchetché, et al., Transapical versus transfemoral aortic valve implantation: a multicenter collaborative study, *Ann. Thorac. Surg.* 97 (2014) 22–28.
- [8] H Ruge, R Lange, S Bleiziffer, et al., First successful aortic valve implantation with the CoreValve ReValving™ system via right subclavian artery access: a case report, *Heart Surg Forum* 11 (2008) E323–E324.
- [9] U Schäfer, Y Ho, C Frerker, et al., Direct percutaneous access technique for transaxillary transcatheter aortic valve implantation: “the Hamburg Sankt Georg approach”, *J. Am. Coll. Cardiol. Interv.* 5 (2012) 477–486.
- [10] A S Petronio, M De Carlo, F Bedogni, et al., 2-year results of CoreValve implantation through the subclavian access: a propensity-matched comparison with the femoral access, *J. Am. Coll. Cardiol.* 60 (2012) 502–507.
- [11] C Ciuca, G Tarantini, A Latib, et al., Trans-Subclavian versus Transapical access for Transcatheter aortic valve implantation: a multicenter study, *Catheter. Cardiovasc. Interv.* 87 (2016) 332–338.

- [12] T Modine, A Sudre, F Collet, et al., Transcatheter aortic valve implantation using the axillary/subclavian access with patent left internal thoracic artery to left anterior descending artery: feasibility and early clinical outcomes, *J. Thorac. Cardiovasc. Surg.* 144 (2012) 1416–1420.
- [13] V Bapat, M Thomas, J Hancock, et al., First successful trans-catheter aortic valve implantation through ascending aorta using Edwards SAPIEN THV system, *Eur. J. Cardiothorac. Surg.* 38 (2012) 811–813.
- [14] V Bapat, M Z Khawaja, R Attia, et al., Transaortic transcatheter aortic valve implantation using Edwards SAPIEN valve: a novel approach, *Catheter. Cardiovasc. Interv.* 79 (2012) 733–740.
- [15] A C Kiser, W W O’Neill, E de Marchena, et al., Suprasternal direct aortic approach transcatheter aortic valve replacement avoids sternotomy and thoracotomy: first-in-man experience, *Eur. J. Cardiothorac. Surg.* 48 (2015) 778–784.
- [16] H Amrane, F Porta, A V Van Boven, et al., A meta-analysis on clinical outcomes after transaortic transcatheter aortic valve implantation by the heart team, *EuroIntervention* 13 (2017) e168–e176.
- [17] H Amrane, F Porta, A J van Boven, et al., Transcatheter aortic valve implantation using a direct aortic approach: a single-Centre heart team experience, *Interact. Cardiovasc. Thorac. Surg.* 19 (2014) 777–781.
- [18] D P O’Hair, T K Bajwa, J J Popma, et al., Direct aortic access for Transcatheter aortic valve replacement using a self-expanding device, *Ann. Thorac. Surg.* 105 (2018) 484–490.
- [19] R Cocchieri, R Petzina, M Romano, et al., Outcomes after transaortic transcatheter aortic valve implantation: long-term findings from the European ROUTE, *Eur. J. Cardiothorac. Surg.* 55 (2019) 737–743.
- [20] V H Thourani, H A Jensen, V Babaliaros, et al., Transapical and Transaortic Transcatheter aortic valve replacement in the United States, *Ann. Thorac. Surg.* 100 (2015) 1718–1727.
- [21] T Arai, M Romano, T Lefèvre, et al., Direct comparison of feasibility and safety of transfemoral versus transaortic versus transapical transcatheter aortic valve replacement, *J. Am. Coll. Cardiol. Interv.* 9 (2016) 2320–2325.



- [22] N Bonaros, R Petzina, R Cocchieri, et al., Transaortic transcatheter aortic valve implantation as a first-line choice or as a last resort? An analysis based on the ROUTE registry, *Eur. J. Cardiothorac. Surg.* 51 (2017) 919–926.
- [23] V Bapat, D Frank, R Cocchieri, et al., Transcatheter aortic valve replacement using Transaortic access, *J. Am. Coll. Cardiol. Interv.* 9 (2016) 1815–1822.
- [24] G M Fröhlich, P D Baxter, C J Malkin, et al., Comparative survival after Transapical, direct aortic, and Subclavian Transcatheter aortic valve implantation (data from the UK TAVI registry), *Am. J. Cardiol.* 116 (2015) 1555–1559.
- [25] S Lerakis, S S Hayek, P S Douglas, Paravalvular aortic leak after transcatheter aortic valve replacement: current knowledge, *Circulation* 127 (2013) 397–407.
- [26] J M Sinning, M Vasa-Nicotera, D Chin, et al., Evaluation and management of paravalvular aortic regurgitation after transcatheter aortic valve replacement, *J. Am. Coll. Cardiol.* 62 (2013) 11–20.
- [27] M Z Khawaja, R Rajani, A Cook, et al., Permanent pacemaker insertion after CoreValve transcatheter aortic valve implantation: incidence and contributing factors (the UK CoreValve collaborative), *Circulation* 123 (2011) 951–960.
- [28] E Van Belle, F Vincent, J Labreuche, et al., Balloon-expandable versus self-expanding Transcatheter aortic valve replacement: a propensity-matched comparison from the France-TAVI registry, *Circulation* 141 (2019) 243–259.
- [29] P. Ludman British Cardiovascular Intervention Society TAVI Audit <http://www.bcis.org.uk/wp-content/uploads/2018/02/TAVI-slide-deck-to-2016-data-forweb-as-11-02-2018.pdf> 2016 11 July 2019
- [30] P. Ludman British Cardiovascular Intervention Society TAVI Audit <http://www.bcis.org.uk/wp-content/uploads/2018/11/TAVI-slide-deck-to-2017-data-15-11-2018.pdf> 2017 11 July 2019

**Figure 1:** Kaplan-Meier curves (unadjusted) and 95% confidence intervals to compare survival between the SC and DA routes; the hazard ratio (HR) from the Cox regression model (adjusted for the CSHA frailty score) is also provided.



	Number at risk					
	0	180	360	540	720	900
Direct Aortic	142	112	78	58	32	1
Subclavian	82	66	50	33	14	2

**Table 1:** Patient and procedural characteristics for the primary analysis dataset by access route (n=224). The figures given are number and percentage of cases unless otherwise specified.

<i>Variables</i>	<i>Subclavian route</i>	<i>Direct aortic route</i>	<i>p-value</i>
	<i>(n=82, 36.6%)</i>	<i>(n=142, 63.4%)</i>	
<i>Patient characteristics</i>			
Mean(SD) <sup>†</sup> Age at operation (years)	78.3 (6.8)	80.0 (8.9)	0.139
Median (IQR) <sup>†</sup> Age at admission (years)	79.5 (73, 84)	81.5 (76, 85)	0.028*
Male	54 (65.9)	69 (48.6)	0.018*
Mean(SD) BMI <sup>†</sup> (kg/m <sup>2</sup> )	27.6 (5.4)	27.2 (6.7)	0.609
Median(IQR) BMI (kg/m <sup>2</sup> )	26.7 (24.1,31.7)	26.8 (22.7,29.6)	0.407
Diabetic	24 (29.3)	37 (26.1)	0.716
Current/Ex smoker	59 (72.0)	85 (59.9)	0.178
CSHA <sup>†</sup> frailty score (range 1 to 7)			0.117
Very fit (1)	2 (2.4)	2 (1.4)	
Well (2)	6 (7.3)	13 (9.2)	
Well (with treated co-morbid disease) (3)	28 (34.2)	29 (20.4)	
Apparently vulnerable (4)	19 (23.2)	33 (23.2)	
Mildly frail (5)	12 (14.6)	30 (21.2)	
Moderately frail (6)	12 (14.6)	33 (23.2)	
Severely frail (7)	3 (3.7)	2 (1.4)	
History of pulmonary disease			0.223
No pulmonary disease	48 (58.6)	94 (66.2)	
COAD <sup>†</sup> /emphysema	27 (32.9)	43 (30.3)	
Asthma	6 (7.3)	3 (2.1)	
Other significant pulmonary disease	1 (1.2)	2 (1.4)	

Previous cardiac surgery 0.067<sup>•</sup>

	None	59 (72.0)	116 (81.7)	
	Previous CABG <sup>†</sup>	21 (25.6)	19 (13.4)	
	Other	2 (2.4)	7 (4.9)	
Previous TAVI		1 (1.2)	0 (0)	
Previous PCI <sup>†</sup>		24 (29.3)	25 (17.6)	0.062 <sup>•</sup>
Previous MI <sup>†</sup>		11 (13.4)	34 (23.9)	0.085 <sup>•</sup>
Aortic balloon valvuloplasty (prior to valve deployment)				<0.0001*
	Completed	64 (78.0)	72 (50.7)	
	Not done	18 (22.0)	70 (49.3)	
Extracardiac arteriopathy		47 (57.3)	77 (54.2)	0.757
Extensive calcification of ascending aorta (grade 3 or 4)		16 (19.5)	20 (14.1)	0.381
Critical pre-operative status		3 (3.7)	5 (3.5)	1
Elective		77 (93.9)	122 (85.9)	0.108
Left ventricular ejection fraction (LVEF) <sup>††</sup>				0.747
	≥50%	41 (50.0)	84 (59.1)	
	(30-49%]	36 (43.9)	43 (30.3)	
	<30%	4 (4.9)	15 (10.6)	

*Procedural characteristics*

Valve manufacturer				0.001*
	Boston Scientific	0 (0)	10 (7.0)	
	Edwards Lifesciences	1 (1.2)	93 (65.5)	
	Medtronic	80 (97.6)	39 (27.5)	
	Unknown	1 (1.2)	0 (0)	
Valve model				
	CoreValve	77 (93.9)	37 (26.1)	

	CoreValve Evolut R	3 (3.7)	0 (0)	
	Engager	0 (0)	1 (0.7)	
	Lotus	0 (0)	10 (7.1)	
	SAPIEN 3 model 9000TFX	0 (0)	9 (6.3)	
	SAPIEN 3 model 9600TFX	1 (1.2)	28 (19.7)	
	SAPIEN XT model 9300TFX	0 (0)	54 (38.0)	
	Unknown	1 (1.2)	3 (2.1)	
Year of Operation				0.706
	2013	40 (48.8)	77 (54.2)	
	2014	32 (39.0)	51 (35.9)	
	2015	10 (12.2)	14 (9.9)	

\*p<0.05, significant

• borderline association

†SD, standard deviation; IQR, interquartile range; BMI, Body Mass Index; CSHA, Canadian Study on Health and Aging; COPD, chronic obstructive airways disease; CABG, coronary artery bypass grafting ;TAVI, transcatheter aortic valve implantation; PCI, percutaneous intervention coronary; MI, myocardial infarction.

‡one unknown LVEF subclavian case.

Square bracket denotes number inclusive in the interval.

**Table 2:** Clinical outcomes according to vascular access route from the TK TAVI registry. The figures given are number and percentage of cases unless otherwise specified.

<i>Variables</i>	<i>Subclavian route</i> ( <i>n=82, 36.6%</i> )	<i>Direct aortic route</i> ( <i>n=142, 63.4%</i> )	<i>p-value</i>
<i>Patient characteristics</i>			
In-hospital death	2 (2.4)	7 (4.9)	0.492
Death 30 days post TAVI	2 (2.4)	6 (4.2)	0.714
Death 1 year post TAVI**	8 (14.5)	21 (21.9)	0.344
Mean(SD <sup>†</sup> ) Procedure time, in mins	193.5 (65.8)	138.4 (57.7)	<0.0001*
Median(IQR <sup>†</sup> ) Procedure time, in mins	184 (161, 227.5)	125 (96, 173.8)	<0.0001*
Mean(SD) Length-of-Stay (LOS), in days <sup>††</sup>	8.6 (9.5)	11.9 (10.8)	0.025*
Median(IQR) Length-of-Stay (LOS), in days <sup>††</sup>	6 (4,8)	7 (6,14)	0.0002*
Vascular access site and access related complications			0.001*
None	65 (79.3)	137 (96.5)	
Minor	11 (13.4)	3 (2.1)	
Major	6 (7.3)	2 (1.4)	
Permanent Pacemaker Implantation (PPI)	20 (24.4)	21 (14.8)	0.107
Tamponade	0 (0)	4 (2.8)	
Further valve intervention prior to discharge	0 (0)	1 (0.7)	

<i>Variables</i>	<i>Subclavian route</i> <i>(n=82, 36.6%)</i>	<i>Direct aortic route</i> <i>(n=142, 63.4%)</i>	<i>p-value</i>
Bailout valve in valve (non-emergency)	8 (9.8)	1 (0.7)	0.0006*
Conversion to full sternotomy during procedure			
No	82 (100)	140 (98.6)	
Yes (haemorrhage)	0 (0)	1 (0.7)	
Yes (valve surgery)	0 (0)	1 (0.7)	
CVA	3 (3.7)	3 (2.1)	0.671
Bleeding			0.181
None	72 (87.8)	117 (82.4)	
Minor	7 (8.5)	15 (10.6)	
Major	3 (3.7)	7 (4.9)	
Life threatening or disabling	0 (0)	3 (2.1)	
Aortic valve regurgitation	60 (73.2)	74 (52.1)	0.003*
AKI <sup>†</sup>			0.066•
None	77 (93.9)	116 (81.7)	
Stage 1	1 (1.2)	11 (7.8)	
Stage 2	1 (1.2)	9 (6.3)	
Stage 3	3 (3.7)	6 (4.2)	
New renal replacement therapy prior to discharge	1 (1.2)	8 (5.6)	0.16

\*p<0.05, significant

•borderline association.

\*\*Note that these figures correspond to a total of 151 patients operated before June 2014 to ensure at least 1-year of follow-up time.

<sup>†</sup>SD, standard deviation; IQR, interquartile range; CVA, cerebrovascular accident; AKI, acute kidney injury

**Table 3:** Effect of surgical subclavian versus direct access on post TAVI complications and procedural parameters obtained from multivariable logistic regression models

<i>Outcome</i>	<i>Odds Ratio</i>	<i>95% CI</i>	<i>p-value</i>
Death 1 year post TAVI	0.59	(0.23,1.57)	0.306
Permanent Pacing Implantation	1.66	(0.83,3.34)	0.154
Bleeding	0.54	(0.24,1.25)	0.149
Acute Kidney Injury	0.35	(0.12,0.96)	0.042*
Aortic valve regurgitation	2.08	(1.11,3.91)	0.023*
Ventricular access site complications	9.75	(3.07, 30.93)	<0.01
<i>Outcome</i>	<i>Mean ratio**</i>	<i>95% CI</i>	<i>p-value</i>
Operative duration (in mins)	1.38	(1.23,1.53)	<0.001*
Postoperative Length-Of-Stay (LOS)	0.71	(0.58,0.87)	0.001*

\*p-value&lt;0.05

\*\*geometric mean ratio, as outcomes have been log-transformed to improve normality.