Percutaneous trans-axilla transcatheter aortic valve replacement

Atsushi Sugiura1 · Mitsumasa Sudo1 · Baravan Al-Kassou1 · Jasmin Shamekhi1 · Miriam Silaschi2 · Nihal Wilde1 · Alexander Sedaghat1 · Ulrich Marc Becher1 · Marcel Weber1 · Jan-Malte Sinning1 · Eberhard Grube1 · Georg Nickenig1 · Efstratios I. Charitos2 · Sebastian Zimmer1

Abstract
The left axillary artery is an attractive alternative access route for transcatheter aortic valve replacement (TAVR) and may provide better outcomes compared to other alternatives. Nevertheless, there remain concerns about vascular complications, lack of compressibility, and thorax-related complications. Between March 2019 and March 2021, 13 patients underwent transaxillary TAVR for severe aortic stenosis at the University Hospital Bonn. The puncture was performed with a puncture at the distal segment of the axillary artery through the axilla, with additional femoral access for applying a safety wire inside the axillary artery. Device success was defined according to the VARC 2 criteria. The study participants were advanced in age (77 ± 9 years old), and 54% were female, with an intermediate risk for surgery (STS risk score 4.7 ± 2.0%). The average diameter of the distal segment of the axillary artery was 5.8 ± 1.0 mm (i.e., the puncture site) and 7.6 ± 0.9 mm for the proximal axillary artery. Device success was achieved in all patients. 30-day major adverse cardiac and cerebrovascular events were 0%. With complete percutaneous management, stent-graft implantation was performed at the puncture site in 38.5% of patients. Minor bleeding was successfully managed with manual compression. Moreover, no thorax-related complications, hematomas, or nerve injuries were observed. Percutaneous trans-axilla TAVR was found to be feasible and safe. This modified approach may mitigate the risk of bleeding and serious complications in the thorax and be less invasive than surgical alternatives.

Keywords Transaxillary · Percutaneous · TAVR · Axilla · Distal puncture

Introduction
Transcatheter aortic valve replacement (TAVR) is now a first-line therapy in patients with aortic stenosis, and the femoral artery has been adopted as the primary access point [1, 2]. Nevertheless, the transfemoral approach is not feasible in up to 15–20% of TAVR candidates [3]. Furthermore, vascular complications can be associated with a dismal prognosis. For this reason, numerous efforts have been made to develop alternative approaches [4–6]. The left axillary artery is an attractive alternative access route and may provide better outcomes compared to the other methods, requiring thoracotomy (transapical, direct aortic). Although, the axillary artery is less affected by atherosclerosis, compared to the femoral artery, there remain concerns about vascular complications [7], lack of compressibility, thorax-related complications, and nerve injury through the intervention [8, 9]. Herein, we report our modified transaxillary TAVR approach, namely, “trans-axilla” TAVR where vascular access of the distal axillary artery is gained through the left axilla. This approach may allow us to eliminate the thorax-related complications and offer better compressibility. The puncture technique and vascular management of the puncture site for this procedure are described in the following sections.
Materials and methods

Population

Between March 2019 and March 2021, a total of 13 patients underwent transaxillary TAVR via the axilla for severe aortic stenosis at our institution. All patients were considered ineligible for the transfemoral TAVR approach because of severe peripheral artery disease, as assessed by computed tomography imaging and angiography. This study was approved by the institutional ethics committee of the University of Bonn and conducted in concordance with the Declaration of Helsinki. All patients provided written informed consent to the local TAVR registry.

Trans-axilla TAVR procedure

The TAVR procedures were performed under general anesthesia. The axillary artery is divided into three segments based on its relation to the pectoralis minor muscle. The first, second, and third segments are medial, posterior, and lateral to the pectoralis minor muscle (i.e., proximal, middle, and distal segments). The puncture was performed within the third segment of the axillary artery, considering that the anatomical relationship with the humeral head allows physicians to compress the puncture site after the procedure efficiently. Furthermore, the puncture should be performed proximal of the take-off of the anterior humeral circumflex artery and subscapular artery (Fig. 1A), given that the median nerve generally transverses in front of the transition between the axillary and brachial arteries. If

Fig. 1 Angiography, schematic illustration, and access site of trans-axilla TAVR

A The axillary artery begins at the lateral border of the first rib, as a continuation of the subclavian artery. The axillary artery is divided into three segments based on its relation to the pectoralis minor muscle. The first, second, and third segments (i.e., proximal, middle, and distal segments) are medial, posterior, and lateral of the pectoralis minor muscle. The puncture site should be within the third segment of the axillary artery, considering the anatomical relationship to the humeral head. The access point at the third segment of the axillary artery can be compressed against the neighboring osseous structures to control bleeding during sheath removal; B angiography of the subclavian and axillary arteries, showing a puncture needle (triangle arrowheads) pointing at the third segment of the axillary artery, which is normally proximal of the take-off of the anterior humeral circumflex artery asterisk and subscapular artery double asterisk; C a long J-tip wire is advanced into the axillary artery as a landmark for the puncture and kept in place as a safety measure in case of bleeding complications. A roadmap overlap-view technique as well as ultrasound guidance can be helpful in guiding the puncture site; D this technique is performed via the “axilla.” The puncture site is located in front of the humeral head, thereby allowing for better compressibility and manual hemostasis if bleeding is observed.
available, a roadmap overlap-view technique as well as an ultrasound guidance can be helpful for targeted axillary artery puncture.

First, a 6F sheath was placed into a femoral artery, and a diagnostic JR 4.0 was placed in the subclavian artery. Contrast dye was injected through the catheter to visualize the access route, and a long (260 cm) J-tip wire was advanced into the axillary artery. Second, using fluoroscopy with a landmark of the inserted wire, the distal axillary artery was punctured through the left axilla (Fig. 1B). A roadmap overlap-view technique (Fig. 1C) as well as an ultrasound guidance proved to be helpful for targeted axillary artery puncture. This technique is performed via the “axilla” (Fig. 1D). The puncture site is located in front of the humeral head, thereby allowing for better compressibility and manual hemostasis if bleeding is observed. A “pre-suture” using two ProGlide® devices as the closure system was utilized in most patients (10 out of 13 patients). A MANTA vascular closure device was applied in the remaining three patients. While placing the pre-suture ProGlide system, temporarily pulling the J-tip landmark wire back to the subclavian artery was recommended in order to avoid trapping the wire between the ProGlide® system and the vessel wall. A 9F sheath was subsequently inserted into the axillary artery.

The short femoral 6F sheath was exchanged for an 8F long sheath. A length of 70–80 cm allowed to maintain a safety wire in the left axillary artery while simultaneously advancing a 5F pig-tail catheter for contrast dye injection to aid valve placement. The tip of the sheath was placed at the transition of aortic arch to the descending aorta (Fig. 2). A stiff guidewire was then inserted via the left axillary artery into the left ventricle and the 9F sheath was exchanged for a 14–16F guiding sheath, depending on the type of transcatheter heart valve (THV) used. After the THV implantation, an angioplasty balloon was advanced into the proximal subclavian artery via the femoral access, while the THV guiding sheath was carefully pulled back. The 8F long sheath was carefully advanced into the left subclavian artery (Fig. 3A). After removal of the THV guiding sheath, the angioplasty balloon was inflated to minimize antegrade blood flow while the J-tip wire (via the femoral artery) remained in the axillary artery to secure an access route for potential stent implantation, in case of significant bleeding, perforation, or flow-limiting dissection (Fig. 3B). After the two sutures of the ProGlide® system were tied down, control angiography was performed through the 8Fcm sheath via the femoral artery. Out of 13 patients, the MANTA vascular closure devise was utilized in three patients instead of the Proglide system.

Fig. 2  Schematic illustration of trans-axilla TAVR set-up shown is the set-up for a trans-axilla TAVR. A pig-tail catheter is placed through an 8F long sheath via the femoral artery for the injection of dye. Also, a safety wire is placed in the axillary artery through the femoral sheath.
Periprocedural antithrombotic regimen

All patients were loaded with 500 mg aspirin intravenously and received unfractionated heparin 70 IU/kg body weight at the beginning of the procedure. Activated clotting time was measured after 15 min and additional heparin administered if required. During the procedure, activated clotting time was maintained at more than 250 s. Heparin reversal with protamine was performed at the end of the procedure. After the procedure, all patients received continuous intravenous unfractionated heparin at 100 IU/h for prevention of deep vein thrombosis. In patients with indications for permanent oral anticoagulation, oral anticoagulation was stopped before the procedure, and bridging with intravenous heparin was performed during the first 48 h after the procedure.

### Endpoint

The primary endpoint for efficacy was device success. Secondary endpoints were 30-day major adverse events (i.e., death and disabling stroke) and periprocedural complications. These endpoints were assessed according to the VARC2 criteria [3].

### Statistical analysis

Categorical variables are reported as percentages and continuous variables are reported as the mean ± standard deviation (SD) or as medians and interquartile ranges (IQRs), as appropriate.

### Results

#### Study participants

Overall, the study participants were at advanced age (77 ± 9 years old) and 53.8% were female, with an intermediate risk for surgery (STS risk score: 4.7 ± 2.0%) (Table 1). The mean transvalvular aortic pressure gradient was...
39.0 ± 21.8 mmHg, and the aortic valve area was 0.73 ± 0.20 cm². In all patients, trans-axilla TAVR was performed using the left axillary artery. At the time of the preprocedural computed tomography imaging, the average diameter was 7.6 ± 0.9 mm for the first segment of the axillary artery, 6.7 ± 1.0 mm for the second segment, and 5.8 ± 1.0 mm for the third segment. Mild calcification was observed in 10 (76.9%) patients, while none of the patients had severe calcification in these arteries.

**Procedural outcome**

Device success was achieved in all patients (Table 2). There were no periprocedural deaths, emergency surgery, or 30-day major adverse events (i.e., death and disabling stroke). They exhibited no subsequent neurological complications (e.g., restricted arm movement). Moreover, no major vascular complications occurred. One patient underwent the procedure with a puncture in the second segment due to the small vessel size of the third segment (4.1 mm). Stent-graft implantation was performed at the puncture site in five (38.5%) patients with persistent extravasation after the vascular closure device, whereas there was no significant difference in the vessel diameters between patients with and those without stent-graft implantation (first segment: 7.5 ± 1.2 mm vs. 7.6 ± 0.8 mm, p = 0.78; second segment: 6.7 ± 1.1 mm vs. 6.7 ± 1.0 mm, p = 0.37; third segment: 5.7 ± 1.1 mm vs. 6.1 ± 1.0 mm, p = 0.37). Otherwise, minor periprocedural bleeding was successfully managed with the administration of protamine and manual compression. Also, no pneumothorax or hemothorax were observed. Of the two patients who received multiple blood transfusions, one had a baseline hemoglobin level of 9.0 g/dl due to macrocytic anemia, which declined to 7.3 g/dl after the procedure. The other patient had gastrointestinal bleeding after the procedure, which required transfusion of 4 packs of red blood cell transfusion. Therefore, they were classified as having major bleeding and life-threatening bleeding, respectively. In one patient, the puncture site was surgically corrected because the J-tip wire was trapped by the ProGlide® knot loop. All patients were extubated in the hybrid operating room.

**Table 2 Procedural findings**

| Category                                           | Value(s)                |
|----------------------------------------------------|-------------------------|
| General anesthesia                                 | 13 (100)                |
| THV devices used                                   |                         |
| Evolut R/PRO                                       | 12 (92.3)               |
| Sapien 3                                            | 1 (7.7)                 |
| Predilatation                                      | 1 (7.7)                 |
| Postdilatation                                     | 2 (15.4)                |
| Contrast volume, ml                                | 134.8 ± 39.2            |
| Fluoroscopy time, min                              | 29.7 ± 13.8             |
| Procedural time, min                               | 107.3 ± 46.8            |
| Successful THV implantation                        | 13 (100)                |
| Conversion to surgery                              | 0                       |
| Closure devices used                               |                         |
| ProGlide                                           | 10 (76.9)               |
| Manta                                              | 3 (23.1)                |
| Stent implantation in the axillary artery           | 5 (38.5)                |
| Bail-out surgical cutdown                          | 1 (7.8)                 |
| 30-day outcomes                                    |                         |
| Mortality                                          | 0                       |
| Disabling stroke                                   | 0                       |
| Myocardial infarction                              | 0                       |
| Major bleeding                                     | 1 (7.8)                 |
| Major vascular complication                        | 0                       |
| Multiple blood transfusions                        | 2 (15.6)                |
| Acute kidney injury                                | 0                       |
| Paravalvular leakage moderate or more              | 0                       |

Values are the mean ± SD or n (%)

THV transcatheter heart valve

**Discussion**

In this study, we describe a modified trans-axilla TAVR and its procedural results.

Our main findings are as follows:

1. Trans-axilla TAVR with complete percutaneous management is feasible and safe in patients who are not eligible for a transfemoral approach, with a 100% success rate for device implantation.
2. There were no 30-day major adverse events. Moreover, no thorax-related complications, hematomas, or nerve injuries were observed.
3. In addition to the TAVR access site, only one femoral 8F sheath is required for contrast dye injection and to maintain a safety wire inside the axillary artery.

Transaxillary TAVR is increasingly popular among interventional cardiologists for patients ineligible for transfemoral arterial access [4–6]. In general, the arteries of the upper extremities are more likely to be free of atherosclerosis and calcification, even if the iliofemoral arteries are diseased [10]. Axillary access offers less invasiveness and several advantages over the transapical or transaortic approaches, which include a lower risk of periprocedural bleeding, swift recovery after the procedure, and reduced mortality [11]. Given the risk of major bleeding or wound complications through surgical cut-down approaches [12], fully percutaneous management is a safe, feasible, and attractive way to perform transaxillary TAVR [13]. Nevertheless, there still remains concerns for this procedure with regard to periprocedural bleeding, hemotoma, pneumothorax, and hemothorax, as the proximal part of the axillary artery is surrounded...
by relatively soft tissues and is located on the thorax [14].
Moreover, difficulties in effecting hemostasis, given the lack
of compressibility of this artery due to the surrounding bone
structures, may explain why transaxillary access is often not
selected.

Herein, we have illustrated a modified approach to this


technique, namely, trans-axilla TAVR. The major advan-

tage of our technique is that it allows the artery to easily be



compressed at the puncture point, as is in the transfemoral









approach. Very much like transfemoral TAVR, it allows for


a complete percutaneous access of the THV and provides


vascular complications occurred in the current study. In line with


our findings, Tayal et al. reported that the axillary artery


was normally large enough to accommodate a sheath with


up to 18 French [15] and yielded vascular complications


of 0%. Another advantage of our technique is to be able to


eliminate the risk of pneumothorax or hemothorax. Coupled


with earlier knowledge [16–18], our findings suggest that


implantation of a THV was achieved in all patients, with no incidence


of major bleeding complications related to the access site.


Not surprisingly, the distal section of the axillary artery was


smaller than the proximal part, however, no major vascular


complications occurred in the current study. In line with


our findings, Tayal et al. reported that the axillary artery


was normally large enough to accommodate a sheath with


up to 18 French [15] and yielded vascular complications


of 0%. Another advantage of our technique is to be able to


eliminate the risk of pneumothorax or hemothorax. Coupled


with earlier knowledge [16–18], our findings suggest that


trans-axilla TAVR serves as a safe alternative for patients


who are ineligible for transfemoral arterial access.


Patient selection is a critical step for successful trans-


axilla TAVR. One important concern of this technique might


be related to the diameter of the axillary artery. Although


the third segment of the axillary is preferable for the punc-


ture site, in the current cohort, one patient underwent a


trans-axilla TAVR with a puncture in the second segment


of the axillary artery owing to the small diameter in the third


segment (4.1 mm). In patients with a history of coronary


artery bypass graft using the left internal mammary artery,


the diameter of the artery at the take-off of the mammary


artery should be greater than 5.5 mm [19]. The presence of


an atrial-venous shunt for dialysis on the TAVR access is


regarded as a relative contraindication, although we believe


that a trans-axilla TAVR could be performed with a large


enough diameter of the axillary artery. Also, severe calci-


fication, excessive tortuosity, steep angulation of the artery


should be precluded. As in trans-subclavian TAVR, both the


left and right axillary approaches can be used, whereas the


left is preferred due to better alignment with the native anu-


lus. Also, the trans-axilla TAVR can be performed without


any femoral access but with bilateral radial accesses [20].


Moreover, our modified approach “trans-axilla TAVR” with


percutaneous access site management could also be per-

formed under local anesthesia instead of general anesthesia.


Further investigations are needed to validate our preliminary


findings and explore these issues.


Another concern is nerve injury associated with interven-


tions. Even though, in general, nerve injuries after interven-


tions are rare and usually transient [8], caution should be


cared for to prevent significant functional impairment. In the


present study, no nerve injury or hematoma occurred after


the intervention. An appropriate puncture site is an essen-


tial factor to prevent nerve injury. The previously reported


higher rate of nerve complications is likely due to a more
distal puncture site as we performed in the current manage-


ment [9]. The puncture should be performed proximal of in


the proximal to the take-off of the anterior humeral circum-


flex artery and subscapular artery (Fig. 1), given that the


median nerve generally transverses in front of the transition


between the axillary and brachial arteries [21, 22]. In addi-


tion to fluoroscopic guidance using a roadmap overlap-view


technique, ultrasound guidance will be helpful for targeted


axillary artery puncture. Also, optimal vascular management


at the puncture site (i.e., safety wire, stent-graft implanta-


tion) is paramount since nerve injury more often results from


hematoma or pseudoaneurysm formation and less commonly


through direct damage from the needle puncture or manual


compression [8].


The major limitations of this study are derived from the


retrospective nature with a small sample size. Patients were


not randomized to several alternative approaches. Furth-


more, although no patients reported brachial plexus injury,


longer follow-up data beyond 30 days were not evaluated.


Our preliminary findings should be validated in further stud-


ies with larger cohorts and long-term clinical outcome data.


Conclusions

The present analysis showed that percutaneous trans-axilla


TAVR was safe and feasible, with no thorax-related com-


plications, hematomas, or nerve injuries. This modified


approach may mitigate the risk of bleeding and serious com-


plications related to the thorax.


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Declarations

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References

1. Popma JJ, Deeb GM, Yakubov SJ, Mumtaz M, Gada H, O’Hair D, Bajwa T, Heiser JC, Merhi W, Kleiman NS, Askew J, Sorajja P, Rovin J, Chetcuti SJ, Adams DH, Teirstein PS, Zorn GL, Forrest JK, Tchétché D, Resar J, Walton A, Piazza N, Ramlawi B, Robinson N, Petrossian G, Gleason TG, Oh JK, Bouliwre MJ, Qiao H, Mugglin AS, Reardon MJ, Evolut low risk trial investigators (2019) Transcatheter Aortic-Valve Replacement with a Self-Expanding Valve in Low-Risk Patients. N Engl J Med 380:1706–1715

2. Mack MJ, Leon MB, Thourani VH, Makkar R, Kodali SK, Russo M, Kapadia SR, Malaisrie SC, Cohen DJ, Pibarot P, Leipsic J, Hahn RT, Blanke P, Williams MR, McCabe JM, Brown DL, Babaliaros V, Goldman S, Szeto WY, Genevreux P, Pershad A, Pocock SJ, Ali MC, Webb JG, Smith CR, PARTNER 3 Investigators (2019) Transcatheter Aortic-Valve Replacement with a Balloon-Expandable Valve in Low-Risk Patients. N Engl J Med 380:1695–1705

3. Biasco L, Ferrari E, Pedrazzini G, Faletra F, Moccetti M, Moccetti M (2018) Access sites for TAVI: patient selection criteria, technical aspects, and outcomes. Front Cardiovasc Med 5:88

4. Amat-Santos IJ, Rojas P, Gutiérrez H, Vera S, Castrodeza J, Tobar J, Goncalves-Ramirez LR, Carrasco M, Catala P, San Román JA (2018) Transsubclavian approach: a competitive access for transcatheter aortic valve implantation as compared to transfemoral. Catheter Cardiovasc Interv 92:935–944

5. Doshi SN, George S, Kwock CS, Mechery A, Mamas M, Ludman PF, Townend JN, Bhabra M (2018) A feasibility study of transaxillary TAVI with the lotus valve. Catheter Cardiovasc Interv 92:542–549

6. Lee H-A, Su I-L, Chen S-W, Wu VC-C, Chen D-Y, Chu P-H, Chou A-H, Cheng Y-T, Lin P-J, Tsai F-C (2020) Direct aortic route versus transaxillary route for transcatheter aortic valve replacement: a systematic review and meta-analysis. PeerJ 8:e9610

7. van der Wulp K, Thijs I, van Wely M, Loverbos A, Gehlmann H, Verkroost M, Van Garsse L, Kievit P, Vart P, El Messaoudi S, Bosboom D, Morshuis W, van Royen N (2020) Incidence and predictors of vascular complications in transaxillary TAVI. Euro Intervention 15:e1325–e1331

8. Kuo F, Park J, Chow K, Chen A, Walsworth MK (2019) Avoiding peripheral nerve injury in arterial interventions. Diagn Interv Radiol 25:380–391

9. Smith DC, Mitchell DA, Peterson GW, Will AD, Mera SS, Smith LL (1989) Medial brachial fascial compartment syndrome: anatomic basis of neuropathy after transaxillary arteriography. Radiology 173:149–154

10. Rogers T, Lederman RJ (2018) Percutaneous transaxillary access for TAVR: another opportunity to stay out of the chest. Catheter Cardiovasc Interv 91:157–158

11. Price J, Bob-Manuel T, Tafur J, Jouy A, Aymond J, Duran A, Almusawi H, Cloninger A, Parrino P, Ramee S (2021) Transaxillary TAVR leads to shorter ventilator duration and hospital length of stay compared to transapical TAVR. Curr Probl Cardiol 46:100624

12. Southmayd G, Hoque A, Kaki A, Tayal R, Rab ST (2020) Percutaneous large-bore axillary access is a safe alternative to surgical approach: a systematic review. Catheter Cardiovasc Interv 96:1481–1488

13. Costa G, Bieliasauskas G, Fukutomi M, Ihlemann N, Sondergaard L, De Backer O (2021) Feasibility and safety of a fully percutaneous transcatheter aortic valve replacement program. Catheter Cardiovasc Interv 97:E418–E424

14. Deby N, Trimech TR, Gandet T, Vincent F, Hysi I, Delhaye C, Cayla G, Koussa M, Juthier F, Leclercq F, Pécheux M, Ghostine S, Labreuche J, Modine T, Van Belle E, Collaborators, (2020) Transaxillary versus transcarotid access for TAVR: a propensity-matched comparison from a French multicentre registry. EuroIntervention 16:842–849

15. Tayal R, Htikhar H, LeSaar B, Patel R, Tyagi N, Cohen M, Wasty N (2016) CT angiography analysis of axillary artery diameter versus common femoral artery diameter: implications for axillary approach for transcatheter aortic valve replacement in patients with hostile aortoiliac segment and advanced lung disease. Int J Vasc Med 2016:3610705

16. Schäfer U, Deuschl F, Schofer N, Frerker C, Schmidt T, Kuck KH, Kreliezel, F. Schirmer J, Mizote I, Reichenschurner H, Blankenberg S, Treede H, Conradi L (2017) Safety and efficacy of the percutaneous transaxillary access for transcatheter aortic valve implantation using various transcatheter heart valves in 100 consecutive patients. Int J Cardiol 232:247–254

17. Sacha J, Krawczyk K, Gwoźdź W, Bugajski J, Perkowski T, Hobot J, Gierlotka M (2020) Fully percutaneous transaxillary aortic valve replacement with effective bailout plan for vascular complications. JACC Cardiovasc Interv 13:2811–2812

18. Zhan Y, Toomey N, Ortolova J, Kawabori M, Weintraub A, Chen FY (2020) Safety and efficacy of transaxillary transcatheter aortic valve replacement using a current-generation balloon-expandable valve. J Cardiothorac Surg 15:244

19. Harloff MT, Percy ED, Hirji SA, Yazdchi F, Shim H, Chowdhury M, Malarczyk AA, Sobieszczyk PS, Sabe AA, Shah PB, Kaneko T (2020) A step-by-step guide to trans-axillary transcatheter aortic valve replacement. Ann Cardiothorac Surg 9:510–521

20. Ooms JF, Van Wiechen MP, Hokken TW, Goudzwaard J, De Backer O, De Ronden-Tillmans J, Daenen J, Mattace-Raso F, De Jaegere P, Van Mieghem NM (2021) Simplified trans-axillary aortic valve replacement under local anesthesia—a single-center early experience. Cardiovasc Revasc Med 23:7–13

21. Okwumabua E, Thompson JH (2022) Anatomy, shoulder and upper limb, axillary nerve. StatPearls Publishing, Treasure Island

22. Thiel R, Munjal A, Daly DT (2022) Anatomy, shoulder and upper limb, axillary artery. StatPearls Publishing, Treasure Island