Orthopaedics & Traumatology: Surgery & Research 105 (2019) 831–837

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

Shoulder arthrodesis using a vascularized scapular pillar graft: Cadaver study and surgical technique

Olivier Le Reun [a], Guillaume Anthony Odri [b], Vincent Crenn [c], Louis-Romée Le Nail [d], François Gouin [e], Mickaël Ropars [a,*]

[a] Service de chirurgie orthopédique et traumatologique, CHU Pontchaillou, université de Rennes, 2, rue Henri-Le-Guillou, 35033 Rennes, France
[b] Service de chirurgie orthopédique et traumatologique, CHU Lariboisière, 2, rue Ambroise-Paré, 75010 Paris, France
[c] Service de chirurgie orthopédique et traumatologique, CHU de Nantes, Hôtel Dieu, 1, place Alexis-Ricordeau, 44000 Nantes, France
[d] Service de chirurgie orthopédique et traumatologique, CHU de Tours, CHU Bretonneau, 2, boulevard Tonnelé, 37044 Tours, France
[e] Département de chirurgie oncologique, centre Léon-Berard, 28, rue Laënnec, 69800 Lyon, France

A R T I C L E I N F O

Article history:
Received 21 January 2019
Accepted 9 April 2019

Keywords:
Shoulder arthrodesis
Scapula
Proximal humerus reconstruction
Anatomical study

A B S T R A C T

Introduction: Whether secondary to trauma, infection or tumor invasion, a complex reconstruction procedure is required after proximal humerus resection. Among the reconstruction options, there are few published reports of a vascularized scapular pillar graft being used. The goal of our study was to describe the surgical technique for shoulder arthrodesis using a vascularized scapular pillar based on an anatomical study of this graft.
Materials and methods: This anatomical and surgical study involved both shoulders from seven separate cadavers (14 shoulders). Two shoulders were used for trials. Four shoulders were injected with latex to describe the vascularization of the composite scapular pillar graft. Five fresh shoulders were then used to define the optimal orientation of the osteotomy and rotation of the scapular pillar. Each vascularization element was then isolated and measured. The shoulder arthrodesis procedure using a composite scapular pillar graft was performed on three shoulders in order to describe the steps of this procedure.
Results: The angular branch of the thoracodorsal artery was 8.25 ± 1.5 cm long and reached the lateral angle of the scapula 1.6 ± 1.1 cm above its antero-inferior edge. The mean length of the circumflex scapular artery was 5.25 ± 1 cm with 3 cm separating the inferior edge of the glenoid and the end of the artery in question. Optimal graft positioning was achieved with a glenoid osteotomy of the pillar that was horizontal in the frontal plane and angled 20° downward and forward in the sagittal plane. This resulted in the pillar being turned 240° medially (internal rotation).
Discussion: The latex injection study confirmed that the scapular pillar always has two vascularization sources: circumflex scapular artery and angular branch of the thoracodorsal artery. While there are anatomical variations, the scapular pillar shares its vascularization with the latissimus dorsi and teres major muscles. It can be preserved when transferring the graft for reconstruction. Our anatomical description of shoulder arthrodesis using this composite graft allows surgeons to anticipate potential technical and anatomical problems that could be encountered during this complex surgical procedure.

1. Introduction

Proximal humerus resection secondary to trauma or tumor invasion leaves a challenging reconstruction problem. When the abductor mechanism is also removed, restoring abduction using a composite reverse shoulder arthroplasty (tendon sutured to allograft) or massive prosthesis (suture to synthetic reattachment tube or to implant) is not always successful. This justifies resorting to shoulder arthrodesis with addition of bone graft, especially in a younger patient. In this specific indication, only a few authors have reported using a pedicled vascularized composite scapular pillar graft instead of vascularized fibula transfer [1,2]. The aim of this study was to describe in detail this complex and little known surgical technique by performing an anatomical analysis of the muscle-bone graft from the vascularized scapular pillar (VSP) and then rehearsing the procedure on cadavers.

* Corresponding author.
E-mail address: mickael.ropars@chu-rennes.fr (M. Ropars).

https://doi.org/10.1016/j.otsr.2019.04.022

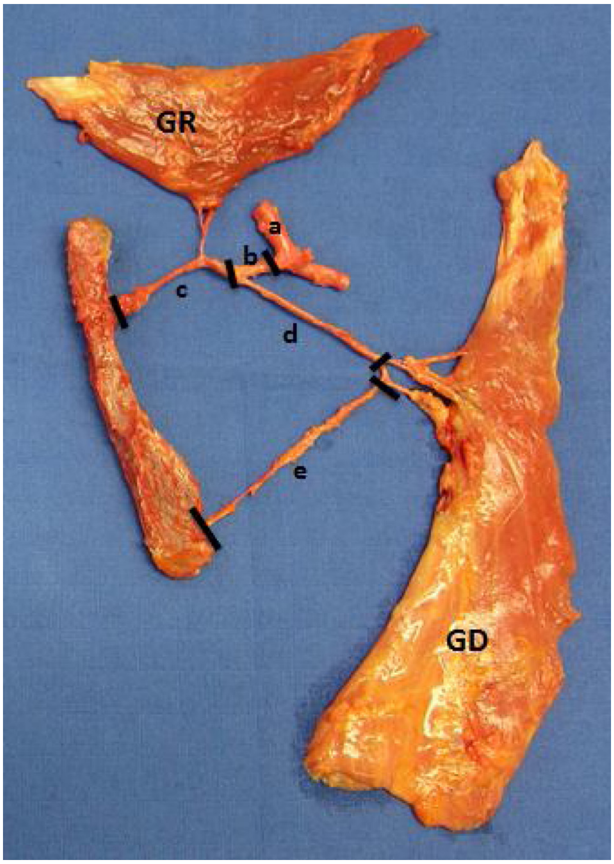

Fig. 1. Arterial segments arising from the axillary artery: (a) that vascularize the scapular pillar and the latissimus dorsi (LD) and teres major (TMa) muscles: subscapular artery (b), circumflex scapular artery (c), thoracodorsal artery (d) and its angular branch (e).

2. Material and methods

This cadaver study involved seven shoulders from different donors. Two shoulders were used for trials.

2.1. Vascularization study

Latex was injected into the subclavian artery in four shoulders, which were subsequently dissected to describe this graft's vascularization. Each artery segment that vascularized the scapular pillar was measured: the angular branch of the thoracodorsal artery was measured from its termination on the pillar to the first upstream arterial junction; the subscapular artery was measured from its origin at the axillary artery to its 1st division; the circumflex scapular artery was measured from its origin on the subscapular artery to its termination on the pillar. Lastly, the thoracodorsal artery was measured from its origin on the subscapular artery to its division into the angular branch and branch to the latissimus dorsi (LD) muscle (Fig. 1).

2.2. Geometry study

The second portion involved five fresh scapula samples (Caucasian donors, 3 men, 2 women, age 72 to 88 years). The scapulae were placed in a metering box in a standardized manner. Based on the anatomical orientation of the scapula in space, the axis of the scapular body was anteverted 30° in the axial plane, with the medial (vertebral) border and the major axis of the glenoid being vertical. In this orientation, two orthogonal photographs of each scapula were taken from the lateral and posterior sides (Fig. 2). The anatomical angles of the scapular pillar were measured. The axillary angle (α) was defined as the angle between a vertical line and a line passing through the inferior edge of the glenoid and the lateral edge of the scapula in the frontal plane. The sagittal angle (β) was defined as the angle between the pillar axis and a vertical line in the sagittal plane (Fig. 2). The osteotomy's orientation and the scapular pillar's rotation were determined for a theoretical final arthrodesis position of 30° abduction, 30° anteflexion and 30° internal rotation [3]. The final orientation was determined based on the orientation of the glenoid osteotomy cut and the rotation of the scapular pillar: level or angled cut upward and forward, 180° or 240° internal rotation (results in Table 1). The contact area of the osteotomy after fixation was determined for these different cut configurations.

2.3. Surgical technique

Three arthrodesis procedures were carried out on three cadaver specimens in order to describe the surgical technique. The sequence of steps for this technique is presented in the results, from harvesting to graft fixation.

3. Results

3.1. Vascularization study

The subscapular artery, which arose from the axillary artery, provided vascularization to the scapular pillar. In our study, two vascularization sources were found in every specimen: circumflex scapular artery that feeds the body of the scapular pillar and angular branch that feeds the inferior angle of the pillar (Fig. 3). The mean length of the circumflex scapular artery was 5.5 ± 1.4 cm with 3 cm separating the inferior edge of the glenoid and the end of the artery in question. The angular branch was 8.25 ± 1.5 cm long and reached the lateral aspect of the scapula 1.6 ± 1.1 cm above and in front of its inferior angle (Table 2).

In the four injected specimens, the circumflex scapular artery arose from the subscapular artery, 2.6 ± 0.2 cm from its origin on the axillary artery. The subscapular artery is called the thoracodorsal artery at the point it emerges from the circumflex artery. The angular branch was always issued from a division of the thoracodorsal artery, which provided the angular branch and an arterial branch to the LD muscle. In three of the four specimens, the artery to the teres major came from the circumflex scapular artery and in the other specimen, from the thoracodorsal artery. The VSP had a mean length of 13.8 ± 1.2 cm.

3.2. Scapular angles and orientation

The α angle can be considered constant, with a mean value of $33° \pm 1.5$. The β angle can also be considered constant, with a mean value of 26 ± 1.4.

3.3. Glenoid osteotomy cut and VSP rotation

A horizontal sagittal cut resulted in the graft being positioned in 53° abduction, 48° forward flexion and 35° anteversion after rotating the graft 180°. However, the two osteotomy surfaces had the smallest contact area with 180° rotation. With 240° rotation, the two glenoid surfaces could be superimposed (Fig. 4). After a horizontal sagittal cut and 240° rotation, the scapular pillar was oriented in 69° anteversion, 15° abduction and 56° forward flexion. A level cut angled downward and forward of the glenoid reduced the excess anteversion when the graft was rotated 240°. With the

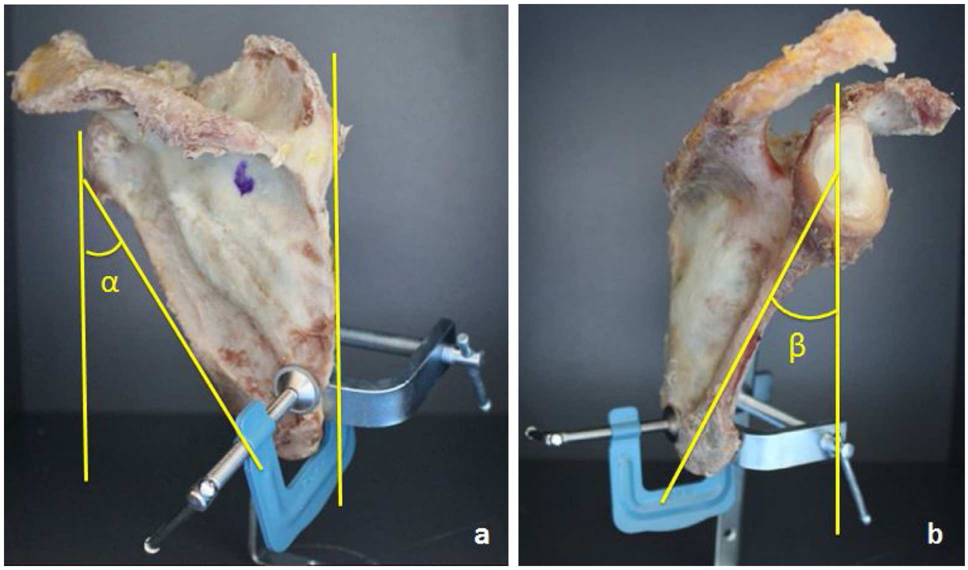

Fig. 2. Posterior view of the scapula and axillary angle α (a); lateral view of scapula and sagittal angle β of the pillar (b). The body of the scapula is anteverted 30°.

Table 1
Final orientation in three dimensions of scapular pillar once secured according to the type of glenoid cut (horizontal or angled) and the internal rotation placed on the pillar before fixation.

Cut/final position	Horizontal cut, 180° rotation	Horizontal cut, 240° rotation	Angled cut, 180° rotation	Angled cut, 240° rotation
Anteversion	35°	69°	−4°	33°
Abduction	53°	15°	63°	34°
Anteflexion	48°	56°	−12°	32°

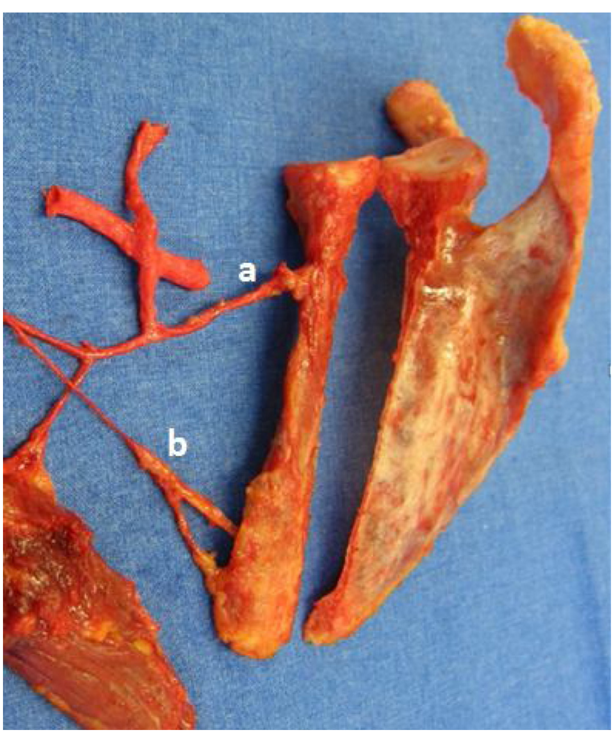

Fig. 3. Dual vascularization of the scapular pillar by the circumflex scapular artery (a) and the angular branch of the thoracodorsal artery (b).

glenoid osteotomy cut being horizontal in the frontal plane and angled 20° downward and forward in the sagittal plane (Fig. 5), the resulting pillar position was 32° anteflexion, 34° abduction and 33° anteversion after the graft was rotated 240° (Fig. 5).

3.4. Surgical technique

3.4.1. Proximal humeral resection

The donor was placed on their lateral side. To reproduce proximal humeral bone loss conditions, 14 cm of the proximal humerus was removed through a wide deltopectoral anterior surgical approach. The humeral attachments of the pectoralis major, supraspinatus, subscapularis, teres major and LD were cut. An oscillating saw was used to cut through the humeral shaft. Any posterior muscle insertions were released from the posterior surface of the humerus from bottom to top.

3.4.2. VSP harvesting

A skin incision was made from the spine and free edge of the scapula to its inferior angle. The inferior angle was a good landmark to avoid making the cut too lateral. After incision of the skin and fascia, the LD was broadly detached from the subcutaneous plane. The posterior head of the deltoid was reflected upward and outward. The LD and teres major muscles were reflected laterally after their scapular attachments were cut, which exposed the inferior angle of the pillar (LD and teres minor were no longer attached). Dissection of the LD pedicle upstream led to the thoracodorsal artery where the angular branch emerged on the deep side of the teres major muscle (Fig. 6). The arterial dissection leaved the angular branch near the pillar on its deep side (anterior). The common terminal of the LD and teres major muscles was retrieved posteriorly. After going around the inferolateral edge of the subscapularis muscle, the circumflex vessels issued from the subscapular pedicle became posterior at their emergence from the medial axillary space. They reached the scapular pillar 3 cm below the inferior edge of the glenoid. At 2 cm from its free edge, the attachments of the pillar muscles were roughened with a bone rasp, while preserving the scapular attachment of the long head of the triceps brachiii on the free edge of the pillar. An osteotomy of the pillar was done next

Table 2
Mean length of the various artery segments dissected near the scapular pillar.

Artery	Angular branch	Circumflex scapular	Latissimus dorsi	Subscapular	Thoracodorsal
Mean length (cm)	8.25 ± 1.5	5.5 ± 1.4	3.5 ± 0.7	2.6 ± 0.2	5.3 ± 0.4

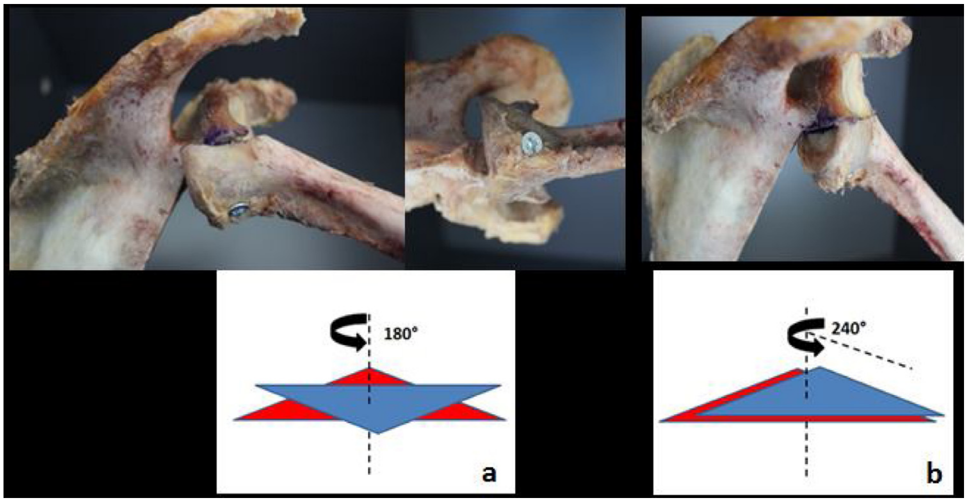

Fig. 4. Bone contact area after rotating the pillar by 180° (a) and 240° (b).

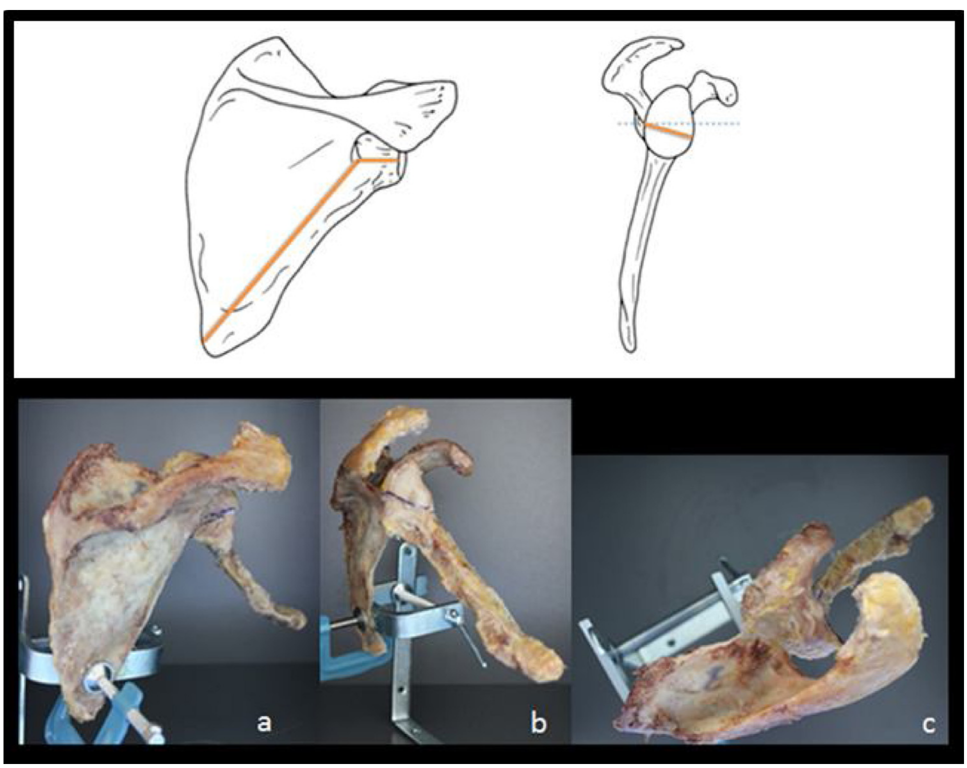

Fig. 5. Posterior (a), lateral (b) and superior (c) views (scapula anteverted 30°) of the arthrodesis construct after a glenoid osteotomy that is horizontal in the frontal plane, and angled 20° downward and forward in the sagittal plane.

using an oscillating saw. Special attention was placed on the distal cut which had to capture the entire inferior angle of the scapula, thus a width of at least 2 cm to avoid harvesting a graft without the angular branch (Fig. 7). The osteotomy cut was extended parallel to the free edge of the pillar, up to the foot of the acromion. Proximally, resection of the posteroinferior capsule allowed us to look at the posterior edge of the glenoid and made it easier to mobilize the VSP proximally. The glenoid osteotomy was perpendicular to the glenoid and angled 20° downward and forward (Fig. 5). The pillar was then rotated internally 240° (which releases the tension on the vascular network) and passed in front of the triceps. The proximal end of the pillar was screwed to the glenoid perpendicular to the glenoid osteotomy cut. The inferior end of the pillar was then embedded into the humeral shaft after identifying the radial nerve. The incision along the axillary (lateral) border of the scapula was extended upward and inward, along the spine of the scapula. Here,

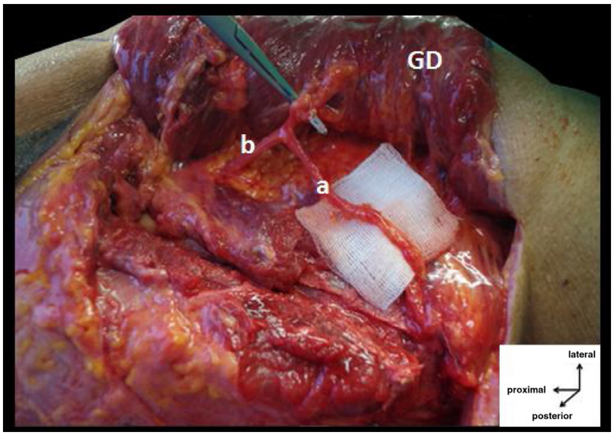

Fig. 6. By lifting the latissimus dorsi (LD) flap, the angular branch (a) and thoracodorsal artery (b) can be viewed on its deep side.

the muscles were detached by releasing the superior bundle of the trapezius to the spinal edge. The construct was stabilized with a curved plate resting in the supraspinatus fossa and slid under the acromion and deltoid muscle (Fig. 8). The teres major and LD muscle flaps could be mobilized together to cover the arthrodesis plate and the pillar in cases where the deltoid is resected; this helps restore the shape of the shoulder (Fig. 9).

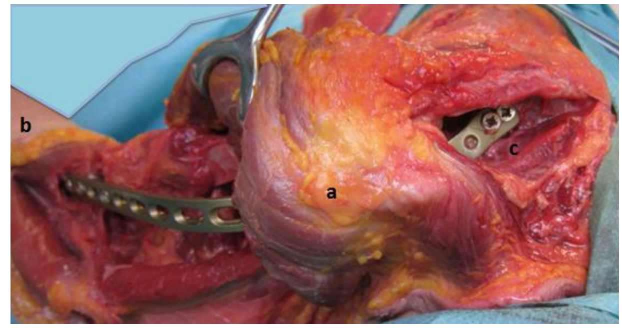

Fig. 8. Superior view of a right shoulder: deltoid (a), arm (b) and supraspinatus fossa (c).

4. Discussion

The first description of a free scapular pillar bone graft harvested with the circumflex scapular artery was made by Gilbert and Teot in 1981 [4]. The subsequent description of the angular branch to the scapula arising from the thoracodorsal artery that vascularizes the inferior angle of the scapular pillar means that the VSP has two sources of vascularization [5]. This graft has been used as a free flap or composite graft during head and neck surgery [6] and for proximal humerus reconstruction after trauma-related bone loss [7,8]. More often, the bone loss occurs after proximal humerus resection due to tumor invasion. The most common are chondrosarcoma, osteosarcoma and metastasis of kidney cancer. The latter are less suited to addition of pedicled vascularized bone because of the frequent need for embolization [9]. Other options for

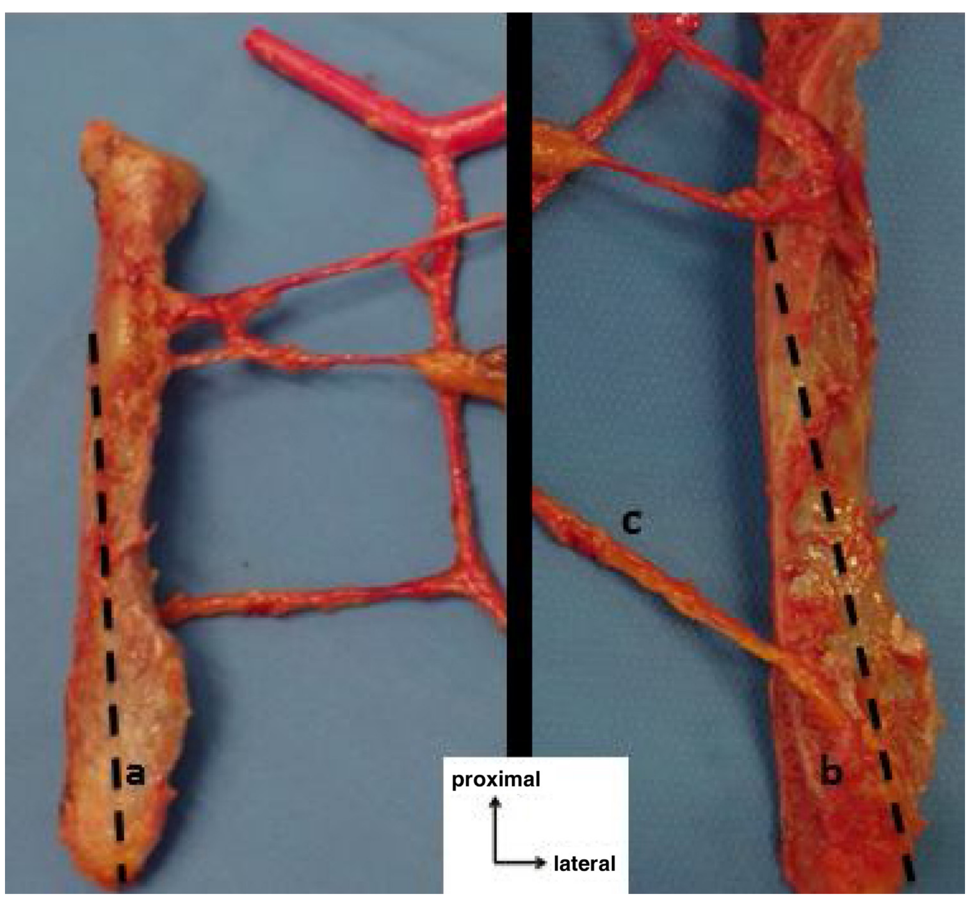

Fig. 7. Posterior (a) and anterior thoracic sides (b) of the scapular pillar with the various vascular elements isolated after latex injection. If the osteotomy cut is less than 2 cm from the lateral border of the scapula, there is a risk the angular branch will not be captured (c).

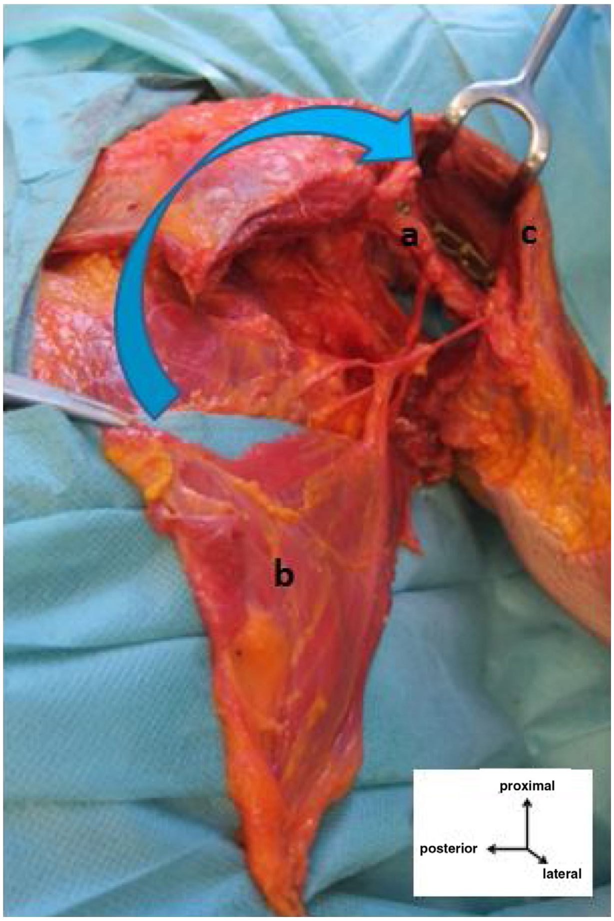

Fig. 9. Coverage of the scapular pillar graft (b) by latissimus dorsi and teres major flaps (a) in cases where the deltoid muscle is resected (c).

reconstruction are suspension to the clavicle, massive prosthesis or composite arthrodesis [2,9,10]. In our study, which is the first to describe in detail the technical features of the procedure, the mean length of the pillar was 13.8 ± 1.2 cm. For arthrodesis cases, when less than 15 cm is resected, a VSP can be used instead of the fibula [9,11], as it does not require microsurgical anastomosis. Using a vascularized graft increases the vitality of the graft, improves fusion, increases the mechanical strength and improves infection resistance [10]. According to Gouin et al. [2], this technique is mainly indicated in younger patients who wish to perform labor-intensive occupations and have a good cancer prognosis. Padiolleau et al., who used the technique described here, have reported on 12 cases of shoulder arthrodesis with VSP after tumor resection with a mean follow-up of 4.9 years. The fusion rate was 87.5% with functional scores comparable to other techniques [1].

Dual vascularization of the scapular pillar was found in all our cadaver specimens, coming from the circumflex scapular artery and angular branch of the thoracodorsal artery. The pillar had the same vascularization as the LD and teres major muscles, stemming from the inferior scapular artery. The circumflex scapular artery reaches the pillar 3 cm on average below the inferior edge of the glenoid. Ebraheim found similar results, with a circumflex scapular pedicle located 2.9 cm on average below the inferior edge of the glenoid [12]. This consistency means the inferior edge of the glenoid is a reliable landmark for locating the circumflex pedicle. Despite the consistent presence of the angular branch, we found no evidence of variations in the origin of this branch, which arose from the thoracodorsal artery in all of our specimens. Nevertheless, several anatomical variations in the origin of the angular branch have been described [13,14]. In our experience, and based on the scientific literature, these variations do not necessarily justify doing CT angiography preoperatively.

The body of the pillar has a useful width of at least 2 cm [1,6,7,14]. This critical width appears sufficient not to damage the angular branch at the deep anterior surface of the pillar, since its terminal end is not visible with a posterior approach. Proximally, the osteotomy cut must be extended to the glenoid, which will be the pillar's center of rotation. The base of the scapular pillar is the best anchoring point on the scapula [3]. However, the glenoid and the two bone surfaces resulting from the osteotomy are triangular in shape. The contact area will depend on how much the pillar is rotated under the glenoid body: the final orientation of the graft and thus of the arthrodesis will depend on the orientation of the glenoid cut. The final position of the arthrodesis should match the goal of 30° abduction, 30° forward flexion and 30° internal rotation [3,15]. Padiolleau et al. made a 45° cut at the glenoid without specifying the plane it was in [1]. Rotation of 180° would be simpler, as the 30° forward flexion is restored by the initial 30° scapular anteversion and the 30° axillary angle (α) restores the 30° of pillar

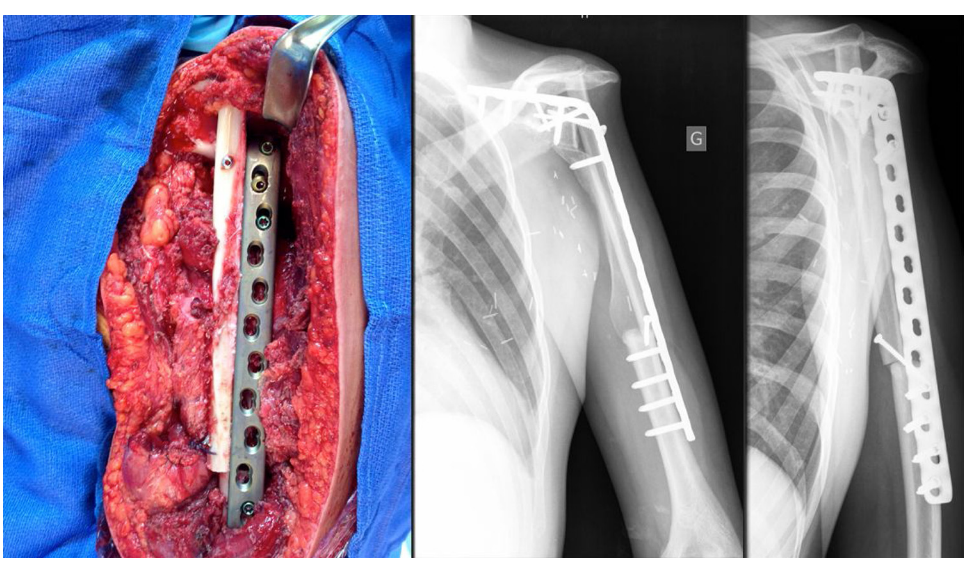

Fig. 10. Intraoperative image and 3-month postoperative radiographs of a shoulder arthrodesis performed with vascularized scapular pillar and autologous fibular graft.

abduction. In reality, because of the pillar's sagittal angle (β), the combination of a horizontal cut and 180° rotation will set the graft in excessive abduction and forward flexion, resulting is less contact area. With 240° rotation, the two glenoid surfaces can be superimposed, thereby resulting in optimal contact area. Nevertheless, after a horizontal sagittal cut and 240° rotation, the scapular pillar was oriented in space in 69° anteversion, 15° abduction and 56° anteflexion; this was too much anteversion and not enough abduction relative to the 30° abduction and anteversion goal. Thus to achieve an optimal contact area, the osteotomy cut at the glenoid must be horizontal in the frontal plane and angled 20° downward and forward in the sagittal plane. The arm's 30° internal rotation does not depend on the osteotomy or the pillar rotation. Instead, it is determined by the humeral rotation at the humeral shaft during fixation of the plate to the humeral shaft. When using a VSP graft, the two bone junctions must be considered: the pillar–glenoid junction for the adduction and forward flexion position and the pillar–humeral shaft junction for the internal rotation of the arm.

The primary complication with this composite graft is nonunion or delayed union in 15 to 25% of patients [2]. A structural autologous graft can be harvested from the iliac crest, fibula or tibial head and used to supplement the bone graft initially [1,11] (Fig. 10). Amin reported that the time to union of the proximal and distal portion of the bone graft was 6 months [11].

5. Conclusion

The composite VSP graft is an option for cases of proximal humerus resection involving the shoulder's abductor mechanism. Our anatomical description of the VSP graft as it applies to shoulder arthrodesis allows surgeons to anticipate potential technical and anatomical problems that may be encountered during this complex surgical procedure.

Disclosure of interest

OL, GO, VC, LRLN, MR declare that they have no competing interest.

F. Gouin has no direct commercial links (e.g. consultancy, shareholder, etc.) that constitute a conflict of interest for the submission of this article. He is a consultant for Zimmer, Signature Orthopaedic France, Amgen SAS, Atlanta Group.

Funding sources

No financial contribution.

Author contributions

OL cowrote the article.
GO, VC, LRLN provided critical review of the article.
MR cowrote the article.
FG was the primary investigator for this study.

References

[1] Padiolleau G, Marchand JB, Odri GA, Hamel A, Gouin F. Scapulo-humeral arthrodesis using a pedicled scapular pillar graft following resection of the proximal humerus. Orthop Traumatol Surg Res 2014;100:177–81.
[2] Gouin F, Creen V. Reconstruction following shoulder resection for bone tumor. Bull Cancer 2014;101:951–7.
[3] Asfazadourian H, Teboul F, Oberlin C. Techniques d'arthrodèse de l'épaule. Encycl Med Chir 2001:44–287.
[4] Gilbert A, Teot L. The free scapular flap. Plast Reconstr Surg 1982;69:601–4.
[5] Coleman JJ, Sultan MR. The bipedicled osteocutaneous scapula flap: a new subscapular system free flap. Plast Reconstr Surg 1991;87:682–92.
[6] Bozec A, Mahdyoun P, Poissonnet G, Dassonville O. Chirurgie reconstructive cervicofaciale par lambeaux libres. Encycl Med Chir 2008:46–555.
[7] Seghrouchni H, Martin D, Pistre V, Baudet J. Composite scapular flap for reconstruction of complex humeral tissue loss: a case report. Rev Chir Orthop Reparatrice Appar Mot 2003;89:158–62.
[8] Pinsolle V, Tessier R, Casoli V, Martin D, Baudet J. The pedicled vascularised scapular bone flap for proximal humerus reconstruction and short humeral stump lengthening. J Plast Reconstr Aesthet Surg 2007;60:1019–24.
[9] Anract P, Tomeno B. Résection-reconstruction pour tumeurs osseuses malignes du membre supérieur. Encycl Med Chir 2005:44–097.
[10] Viehweger E, Gonzalez JF, Launay F, Legre R, Jouve JL, Bollini G. Shoulder arthrodesis with vascularized fibular graft after tumor resection of the proximal humerus. Rev Chir Orthop Reparatrice Appar Mot 2005;91:523–9.
[11] Amin SN, Ebeid WA. Shoulder reconstruction after tumor resection by pedicled scapular crest graft. Clin Orthop Relat Res 2002;397:133–42.
[12] Ebraheim NA, Ramineni SK, Alla SR, Biyani S, Yeasting RA. Anatomical basis of the vascular risk related to the circumflex scapular artery during posterior approach to the scapula. Surg Radiol Anat 2010;32:51–4.
[13] Seitz A, Papp S, Papp C, Maurer H. The anatomy of the angular branch of the thoracodorsal artery. Cells Tissues Organs 1999;164:227–36.
[14] Coeugniet E, Harchaoui A, Malka G, Pellerin P, Danino A. The osteomuscular latissimus dorsi scapula flap: anatomical study and 3 cases. Ann Chir Plast Esthet 2007;52:108–13.
[15] Richards RR, Waddell JP, Hudson AR. Shoulder arthrodesis for the treatment of brachial plexus palsy. Clin Orthop Relat Res 1985;198:250–8.