SPINE An International Journal for the study of the spine Publish Ahead of Print

DOI: 10.1097/BRS.0000000000002150

Pedicled vascularized clavicular graft for anterior cervical arthrodesis: cadaveric feasibility study, technique description, and case report

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Acknowledgment: November 22, 2016
Accept: February 10, 2017

The manuscript submitted does not contain information about medical device(s)/drug(s).

The Barrow Neurological Foundation and the Newsome Family Endowed Chair of Neurosurgery grant funds were received in support of this work.

Relevant financial activities outside the submitted work: grants.

ABSTRACT

Study Design: Cadaveric feasibility study.

Objectives: To assess the anatomic and technical feasibility of rotating a clavicular segment on a sternocleidomastoid muscle (SCM) pedicle into the ventral cervical spine using a cadaveric model and to provide the first clinical case description of performing this procedure.

Summary of Background Data: Reconstruction of the anterior cervical spine in patients with a high risk of pseudoarthrosis may require the use of a vascularized bone graft (VBG). A vascularized clavicular graft rotated on an SCM pedicle would afford all the benefits of a VBG without the added morbidity of free-tissue transfer; however, this technique has not been described.

Methods: A multidisciplinary team hypothesized that it would be anatomically and technically feasible to rotate a pedicled clavicular bone graft from the bottom of C2 to the top of T2 via an anterior approach. Five cadavers underwent bilateral anterior neck dissections for a total of 10 clavicular graft assessments. A case report describes the use of a clavicular VBG in a patient with a 3-level corpectomy defect and a history of failed fusion.

Results: Ten clavicles were rotated on an SCM pedicle. The grafts were either harvested as an entire segment or as the superior two-thirds of clavicle, leaving the inferior one-third in situ with pectoralis attachments intact. All grafts reached from the bottom of C2 to the top of T2. When the entire length of exposed clavicle was mobilized, it could cover 5-6 levels. The case report highlights technical challenges of this procedure in a living patient and provides clinical context for its potential utility in reconstruction of the ventral cervical spine.

Conclusions: This surgical technique is best suited for patients with long-segment cervical defects and an increased risk of pseudarthrosis. Further clinical experience with this technique is required before definitive conclusions can be made.

Key Words: Augmenting fusion rates; pedicled bone graft; posterior cervical fusion; vascularized bone graft

Level of Evidence: 5

ABBREVIATIONS: C-VBG, clavicular vascularized bone graft; SCM, sternocleidomastoid muscle; VBG, vascularized bone graft

INTRODUCTION

Successful arthrodesis is critical for achieving a favorable outcome in patients undergoing reconstructive surgery of the anterior cervical spine. Rates of successful arthrodesis in patients who require multilevel anterior cervical corpectomies range from 47% to 84% when expandable cages or structural allograft are used, with the success rate varying inversely with the number of levels being treated and number of patient comorbidities.[1-4] Certain high-risk patients with numerous risk factors for pseudarthrosis require an alternative surgical strategy. These patients generally include those who require a 3-level or longer corpectomy and who have additional risk factors for pseudarthrosis, such as history of prior failed fusion attempts; irradiation to the fusion bed; infection in the fusion bed; or the presence of numerous medical, metabolic, or social risk factors known to impede arthrodesis.[5] Many in the literature have reported on the use of free-fibula vascularized autograft in these patients, with numerous small case series reporting acceptable complication rates and near 100% arthrodesis rates with this technique.[5-12]

Vascularized bone grafts (VBGs) have numerous benefits over allografts and non-vascularized autografts. By grafting viable autologous bone into a corpectomy site, one is able to achieve primary bone healing at the host-graft interface, precluding the long and slow process of creeping substitution that is required to incorporate necrotic bone tissue into a fusion mass. This reduces the amount of time required for healing and improves biomechanical stability of the graft because remodeling and hypertrophy take place more quickly and without an intervening period of instability, as is seen in grafts that undergo substitution. Maintaining a vascular supply to the graft furthermore provides the graft with greater resistance to infection, which is especially important when treating patients with osteomyelitis and discitis. This technique also permits placement of the graft in poorly vascularized tissue beds, such as those that have been previously irradiated or are chronically infected. Numerous animal and laboratory studies have demonstrated that, compared to non-vascularized grafts, VBGs demonstrate superior bone hypertrophy, union rates, and bone density with increased graft stiffness and stability at both 3 months and 6 months postoperatively.[13-19] Clinical experience with VBGs furthermore suggests that they afford decreased healing times, more robust fusions, and decreased graft-associated morbidity as compared to non-vascularized grafts.[20-27] Despite these advantages, the use of VBG in reconstruction of the ventral cervical spine has yet to receive widespread acceptance among orthopedic surgeons and neurosurgeons, likely secondary to the added donor site morbidity, operative time, and increased technical complexity of performing these procedures.

An alternative to free-transfer VBG that has yet to be described in the anterior cervical literature is pedicled VBG, in which a locally harvested piece of bone is rotated into the ventral cervical defect on an exiting vascular pedicle. This technique precludes the need for multiple surgical sites and tying of microvascular anastomoses, and when done appropriately can provide an osseous graft with equal or greater vascularity than a free-transfer graft. Pedicled VBG may therefore achieve all the benefits of VBG without the added morbidity and challenges of free-tissue transfer. Pedicled rib grafts have previously been reported for posterior thoracic spinal reconstruction,[28,29] with promising operative results. Pedicled VBG has yet to be described, however, for anterior cervical reconstructive spine surgery. Given its proximity to the ventral cervical spine, the clavicle seems to be a good candidate for a pedicled VBG donor site. Numerous studies have previously described harvest of autologous bone from the sternum and clavicle for use in the ventral cervical spine, but none have described the rotation of these bones on a vascular pedicle.[30-33] There are also numerous studies in the oral-maxillofacial literature that describe the rotation of vascularized clavicle on a pedicle of sternocleidomastoid muscle (SCM) for treatment of temporomandibular pathology.[34-37]

The purpose of this study was to assess the anatomic and technical feasibility of rotating a segment of clavicle on a pedicle of SCM into the ventral cervical spine using a cadaveric model, and to provide the first technique description for performing this procedure. A single case report is provided to highlight certain technical challenges of performing this procedure that were not recognized in the cadaveric dissections, and to provide further clinical context for the potential utility of pedicled bone grafting into the ventral cervical spine.

METHODS

A multidisciplinary team of plastic surgeons and neurosurgeons hypothesized that it is feasible to rotate pedicled clavicular bone graft (C-VBG) from C2 to T2 via an anterior approach. Using 5 cadaveric torsos with intact crania, 10 clavicular bone grafts were harvested and mobilized into the ventral cervical spine. The dimensions of each graft were measured, as were the spine levels reached and covered by each graft. Photographs were taken to demonstrate key anatomical features.

Graft dimensions are reported as mean (SD) in length × width × thickness. The average spine level reached is rounded to the nearest whole level and reported as mean (range). The spine levels covered by the clavicular grafts are reported as mean (range).

Exposure and Graft Mobilization

With the cadaver in a supine position and neck slightly extended, an incision was made along the medial edge of the SCM muscle from the level of the hyoid bone to the sternal notch. The platysma was dissected parallel to the incision, exposing the underlying contents of the anterior cervical triangle (Fig. 1A). A standard approach to the anterior cervical spine was then performed, exposing the ventral cervical vertebrae from the inferior endplate of C2 to the superior endplate of T2 (Fig. 1B-C). The SCM was then dissected out, exposing the medial and lateral borders, as well as the sternal and clavicular heads. The ventral surface of the clavicle was then exposed subperiosteally from the lateral edge of the sternoclavicular joint to the lateral extent of exposure, taking care not to disrupt the inferior pectoralis attachments or the superior SCM attachments (Fig. 1A). Using a high-speed drill, the superior two-thirds of the clavicle was cut while preserving the sternoclavicular joint and the inferior one-third of the clavicle to avoid cosmetic or functional deformity. Alternatively, the entire exposed segment of clavicle may be removed for a more robust structural graft. The SCM vascular supply arises segmentally from 3 primary sources: occipital artery branches, superior thyroid branches, and supraclavicular branches, respectively from superior to inferior. Adequate mobilization of the C-VBG requires disruption of the supraclavicular supply, but should be possible without disrupting superior thyroid or occipital artery branch feeders. The graft was mobilized with intact periosteum and muscle attachments from the clavicular head of the SCM. The graft was then rotated inferior to the sternal head of the SCM and placed in the ventral cervical defect (Fig. 1D). The angle of the clavicle can be positioned such that it conforms well to the desired cervical lordosis.

Each graft was measured in length, width, and thickness. The superior and inferior limits of graft mobilization were recorded, as well as the number of spinal levels that each graft was capable of covering.

RESULTS

Each of 5 cadavers underwent bilateral anterior cervical dissections for a total of 10 C-VBGs. Mean graft dimensions were 5.7 cm (1.64 cm) long □ 1.2 cm (0.21 cm) wide □ 0.9 cm (0.30 cm) thick. All 10 C-VBGs reached the inferior endplate of C2 to the superior endplate of T2. The C-VBGs were capable of covering 5 (3-6) levels (Table 1).

CASE REPORT

A 69-year-old woman with cervical myeloradiculopathy previously underwent a C5-C6 corpectomy and C4-C7 anterior cervical plating for revision treatment following a remote single anterior cervical discectomy and fusion. An expandable cage was used in place of the 2-level corpectomy defect. Approximately 2-weeks after her procedure, she had recurrence of her neck pain, and imaging showed collapse of the C7 vertebral body and dislodging of the expandable cage (Fig. 2A). Given that she would require a third revision procedure and expansion of her corpectomy defect to 3 levels, it was believed that a vascularized clavicular graft followed by posterior fixation would provide her with the best chance of a stable long-term outcome.

The patient's previous incision was reopened and extended in a J-shape along her ipsilateral clavicle. After exposing her ventral cervical spine, the previously placed hardware was removed, and the corpectomy defect was expanded to include the C7 level. Her bone was noted at this time to be very soft. Once an adequate bony decompression from C4-T1 had been accomplished, attention was turned to harvesting the C-VBG. The ventral surface of the clavicle was exposed subperiosteally, starting 1 cm distal from the sternoclavicular joint and extending laterally. Based on the patient's poor bone quality, the decision was made intraoperatively to mobilize the entire clavicular graft to provide greater biomechanical stability. Using a reciprocating saw, proximal and distal cuts were made in the clavicle, taking care not to injure the underlying subclavicular vessels. The pectoral muscle attachments were then separated from the C-VBG. The sternal and clavicular heads of the SCM were then separated, and the graft was mobilized on its intact periosteum and clavicular SCM head attachments. Once mobilized, the C-VBG was then rotated deep to the sternal head of the SCM and into the ventral cervical corpectomy defect. The C-VBG was trimmed to the appropriate length and placed in the corpectomy defect with the angle of the clavicle matching the desired cervical lordosis. A 4-level ventral cervical plate was then bent to the appropriate angle, and affixed with 2 screws each into the C4 vertebral body, the C-VBG, and the T1 vertebral body. The clavicular defect was repaired using a cadaveric fibular strut graft and clavicular plate. The anterior cervical incision was then closed, and the patient was repositioned prone for C2-T2 posterior segmental fixation and posterolateral fusion (Fig. 2B).

Postoperatively the patient suffered a contralateral vocal cord palsy, leading to dysphagia and need for a feeding tube. She also required 1 month of acute inpatient rehabilitation following her procedure, from which she was discharged home. Approximately 2-months postoperatively she began complaining of shoulder pain, and was found on imaging to have a dislodged clavicular plate and fibular allograft. She was taken to the operating room for removal of the allograft and clavicular plate. Postoperatively, she reported resolution of her shoulder pain with retained shoulder mobility, and was discharged home the same day. Three-month postoperative computed tomography imaging of her cervical spine showed evidence of bony incorporation of her clavicular graft into the host site (Fig. 2C). A 4-month postoperative swallow study revealed no aspiration of barium at all consistencies tested.

DISCUSSION

This study is the first to describe a technique for rotating a pedicled VBG, specifically clavicle on an SCM pedicle, into a ventral cervical spine defect, and, furthermore, provides the first case report of this procedure being used in an anterior cervical reconstruction. Important points noted during dissection included the finding that long segments of clavicle contained a curve that could be closely approximated to the desired cervical lordosis. Furthermore, long grafts could be cut in half while maintaining the periosteal vascular supply such that double-barreled C-VBGs could be placed into a shorter ventral cervical corpectomy defect. It was necessary in each dissection to transect the omohyoid muscle to provide adequate exposure for C-VBG rotation and placement into the ventral cervical spine. Harvest of the C-VBG will likely put the subclavian vessels at some risk of injury, and so it is critical to protect these vessels when performing this procedure in a living patient. There is an extensively published experience with using clavicular grafts in the oral-maxillofacial and plastic surgery literature. The method described above is very similar to that described by Chen et al.[34] These reports describe minimal to no cosmetic or functional deformity when C-VBG is harvested in this method.

The above case report highlights several important factors regarding cadaveric studies and the patient population that would benefit from a pedicled VBG. First, we were able to perform the full graft mobilization in the cadavers via a straight vertical incision along the medial edge of the SCM. When performing this procedure in a living patient, however, we quickly realized that it would be necessary to “J-turn” the cervical incision over the clavicle to provide the exposure necessary for safe graft mobilization. Protection of the subclavicular tissue was furthermore more difficult in the living patient than in cadavers, likely secondary to empty subclavian vessels and or tissue necrosis in the cadavers at the time of dissection. With some additional time and care, however, we were able to mobilize the graft in our patient without causing harm to the underlying lung or subclavicular vessels.

Unfortunately our patient suffered significant dysphagia after her reconstructive procedure. Management of this was complicated by her having had a previous gastric banding procedure, which required general surgery to place a gastric tube for continued nutrition while her swallowing function recovered. Workup of her dysphagia revealed a vocal cord paralysis on the side contralateral to the anterior cervical approach and autograft harvest. It is possible that this was caused by an over-inflated endotracheal cuff that, when mobilized during surgical exposure, caused a recurrent laryngeal nerve palsy. Given that her palsy was contralateral to the surgical site, it is not felt that the pedicled VBG was to blame for this complication.

The patient additionally required revision surgery of her clavicular reconstruction secondary to non-union causing significant pain. Once the fibular allograft and clavicular plate were removed, the patient's symptoms resolved and she was able to return to home the same day. It is interesting to note that she suffered a pseudarthrosis at the structural allograft site but has thus far shown evidence of good bony healing and arthrodesis at her cervical site; we believe this provides further evidence that her ventral cervical reconstruction required the additional support of VBG as her bone was unlikely to be healthy enough to heal around an expandable cage or to incorporate a 3-level structural allograft before pseudarthrosis occurred.

As alluded to above, this study is limited by the use of cadaveric models for obtaining graft characteristic data. The cadaveric data may not closely represent what is achievable in living patients as soft and bony tissue is certain to vary, not only between cadavers, but also between cadavers and living patients. The single case report additionally provides an initial context for the clinical use of this technique, but further experience with this technique is required before any conclusions can be made regarding relative efficacy and safety as compared to free-fibula VBG or standard non-VBG techniques.

CONCLUSIONS

For patients with numerous comorbidities who require long-segment ventral cervical reconstruction, traditional techniques are likely to be insufficient for achieving arthrodesis. Rotation of a pedicled clavicular graft may afford these patients with a new surgical treatment option that combines all the benefits of a vascularized free fibula without the additional morbidity of a free-tissue transfer. Despite the increased morbidity and mortality these patients are certain to carry into any surgical procedure, many expect these patients will have better outcomes with surgical treatment as compared to conservative management alone.[38]

ACKNOWLEDGMENTS: The authors would like to acknowledge the Barrow Neurological Institute's Neuroscience Publications staff for assistance with manuscript preparation.

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FIGURE LEGENDS

Figure 1. Exposure and rotation of pedicled clavicular bone graft. **(A)** Exposure of anterior cervical triangle. **(B)** Exposure of the ventral cervical vertebrae using a standard anterior cervical approach. **(C)** Clavicular vascularized bone graft on the sternocleidomastoid muscle pedicle. **(D)** Graft rotated inferior to the sternal head of the sternocleidomastoid muscle and placed in a ventral cervical defect. Abbreviations: C-VBG, clavicular vascularized bone graft; SCM, sternocleidomastoid muscle; VBG, vascularized bone graft. *Used with permission from [institute blinded for review].*

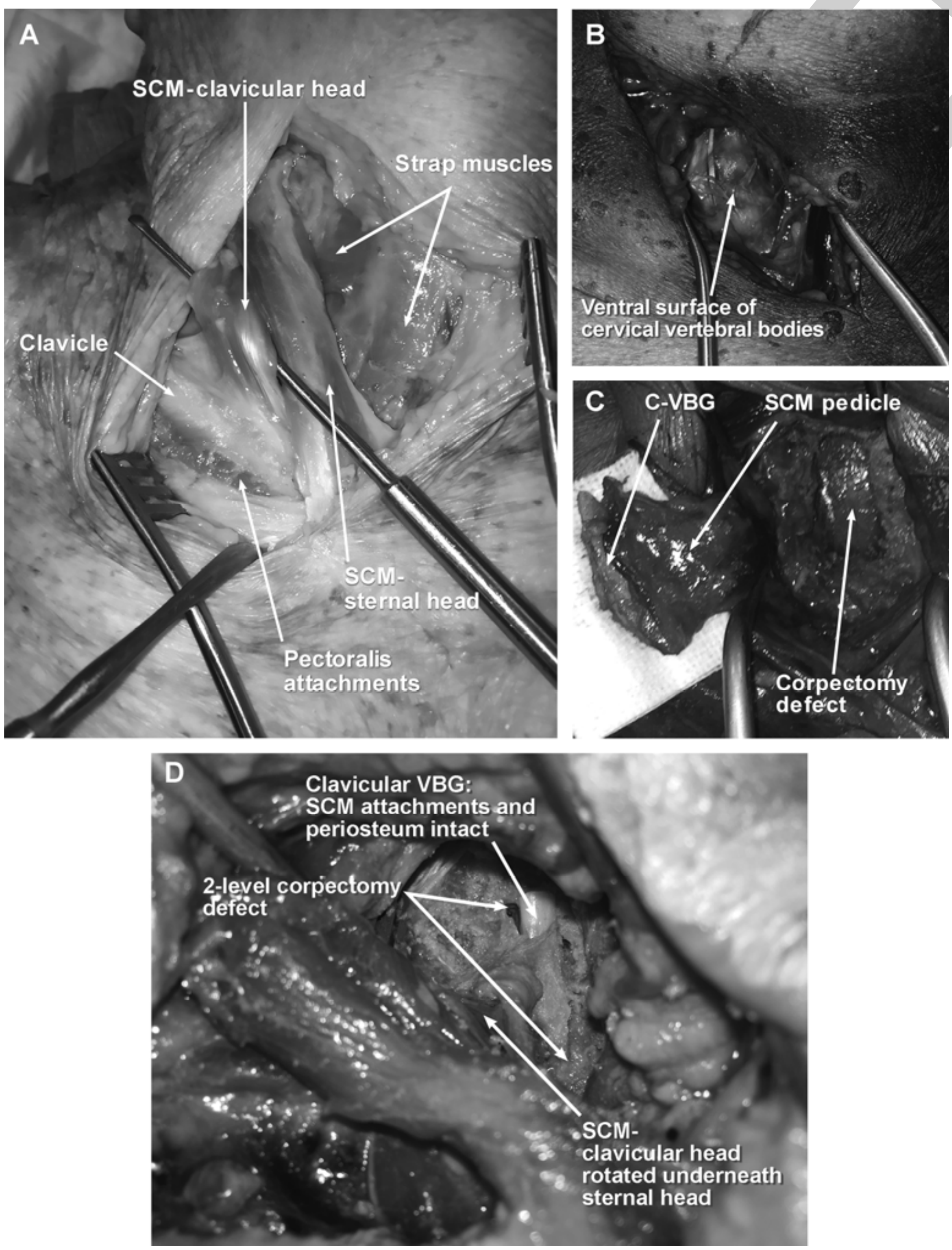

Figure 2. Computed tomograms of a 69-year-old woman with cervical myeloradiculopathy. **(A)** Collapse of the C7 vertebral body and dislodging of the expandable cage. **(B)** Immediate postoperative scan showing C-VBG and anterior cervical fixation construct. **(C)** Three-month postoperative image shows evidence of bony incorporation of clavicular graft into the host site. *Used with permission from [institute blinded for review].*

Table 1. Clavicular Graft Characteristics

	Length (cm)	Width (cm)	Thickness (cm)	Levels Reached	Levels Covered
Cadaver 1					
Right	4.5	1.1	1.0	C2-T2	4
Left	3.2	1.4	0.7	C2-T2	3
Cadaver 2					
Right	4.0	1.3	1.2	C2-T2	4
Left	6.2	1.3	0.9	C2-T2	5
Cadaver 3					
Right	4.7	1.5	0.2	C2-T2	5
Left	5.2	1.0	1.0	C2-T2	5
Cadaver 4					
Right	7.1	1.3	1.2	C2-T2	6
Left	7.0	0.9	1.0	C2-T2	6
Cadaver 5					
Right	7.5	1.1	0.7	C2-T2	6
Left	8.0	0.9	0.7	C2-T2	6
Mean (SD; range)	5.7 (1.64)	1.2 (0.21)	0.9 (0.30)	C2-T2	5 (3-6)