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Ventral cervical fusion at multiple levels using free vascularized double-islanded fibula – a technical report and review of the relevant literature

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Abstract Reconstruction of the cervical spine using free vascularized bone flaps has been described in the literature. The reports involve either one level or, when multiple levels, they describe en bloc resection and reconstruction. Stabilization of different levels with a preserved intermediate segment with a single vascularized flap has not been described. We report on the case of a 55-year-old man, who had been operated several times using conventional techniques for cervical myelopathy and instability, who presented to us with severe neck pain. Diagnostic procedures showed pseudarthrosis of C3/4 and stress-overload of the C3/4 and C5/6 segments. The C4/5 fusion was adequately rigid, but avascular. We performed anterior cervical fusion at the C3/4 and C5/6 levels with a vascularized fibula flap modified as a double island. The rigidly fused C4/5 block was preserved and vascularized with the periosteum bridging the two fibular islands. The method and technique are described in detail. Fu-

sion was adequate. Donor site morbidity was minimal and temporary. The patient is symptom free to date (25 months). The suggested method provides the possibility of vertebral fusion at different levels using a single vascularized flap. The indications for this procedure are (1) repeated failure of conventional methods, (2) established poor bone healing and bone non-union with avascular grafts and (3) a well-fused or preserved intermediate segment. The relevant literature is reviewed.

Keywords Cervical vertebral fusion · Free vascularized bone flap · Fibula · Periosteum blood supply · Failed anterior fusion

Introduction

Various methods of spinal stabilization, ranging from multiple wire fixation to complex reconstruction with vascularized bone struts, are described in the literature [21]. The choice of method depends on the specific indications posed by the clinical and morpho-physiological situation. Like any surgical method, each spinal fusion technique has its own pitfalls. Graft resorption, collapse, sequestra-

tion and pseudarthrosis formation are some of the common complications in using non-vascularized autogenous and allogeneous bone grafts, especially in the old and in patients with compromised healing [7, 13]. Screw loosening and plate or rod migration are some problems associated with stabilization using implants [7, 8]. It has been suggested that vascularized bone flaps do not undergo resorption, and maintain twice the bone density of non-vascularized grafts [28]. The mechanical stability of vascularized bone used in spinal surgery, both initially and in

Fig. 1 Functional X-ray diagnosis of the patient before stabilization with plate and screws. Note the sequestration of the bone graft at C3/4 and increased mobility at C3/4 and C5/6. He presented with severe neck pain

later stages of healing, is superlative, and bone fusion is rapid [27]. Owing to its vitality, the vascularized bone flap is subject to hypertrophic changes under mechanical stress, and is also resistant to bacterial invasion.

The transplantation of a free vascularized bone, especially fibula, for achieving spinal stability is a very aggressive modality of treatment in itself, which is also associated with extensive donor site trauma. Thus, this method should be reserved for selected cases where well-established customary methods have failed to produce results and/or where the patient exhibits known disability towards bone fusion.

Several reconstruction techniques using vascularized bone for attaining spinal stability have been described [10, 17, 22, 24, 27, 28]. These reports concentrate either on the fusion of one segment, or, when of several segments, they describe the resection of several segments en bloc (i.e., contiguous segments) and replacement using one long vascularized bone strut.

In this report we describe a method of reconstruction of two different levels (non-contiguous) of the cervical spine using two islands of vascularized fibula that are connected through a periosteal sheath that provides vascularity. The surgical technique, the possible pitfalls, the indications and justification for the usage of this invasive treatment modality are discussed.

Case report

Last year, a 55-year-old man presented with severe neck pain that had recurred five times in the past 3 years. His initial complaints, 4 years previously, were weakness, numbness and intermittent pain in both arms, severe neck pain and intermittent stiffness of lower extremities. Cervical myelopathy and instability were diagnosed.

The patient had undergone ventral fusion, at the C4/5 level at first and later at the C3/4 level using conventional iliac crest grafting, in two different operations that had been conducted elsewhere. He was symptom free for 4 months, after which he presented himself at our clinic with severe neck pain. Functional radiographs showed an increased mobility, and thus increased strain, at the C3/4 as well as the C5/6 levels, with evidence of pseudarthrosis at the C3/4 vertebrae (Fig. 1). Facet block at the C3/4 level resulted in prolonged relief from neck pain. Thus, during the relapse of his neck pain we decided to limit ourselves to the operative treatment of the C3/4 level: the pseudarthrotic graft was removed and the vertebral space was debrided anew. During this procedure, we noticed that the bones here were poorly vascularized. An 8-mm-high iliac crest was interposed in this space and the graft was fixed to the vertebral bone with a plate and screws. The patient reported significant reduction in neck pain. The symptoms relapsed with time, and within 3 months the pain reached the initial intensity. Control lateral radiographs showed a reduction in the height of the bone graft (graft collapse), pseudarthrosis formation, as well as loosening of the screws [we noticed that the screws had attained a convergent pattern in contrast to the pattern shown on previous postoperative radiographs, where the screws were divergent to each other (Fig. 2)]. Moreover, facet block at the C3/4 level did not, now, reduce neck pain completely, and we observed increased mobility of the C5/6 segment too. Only a facet block at both levels (C3/4 and C5/6) brought forth reduction in pain.

Based on our knowledge about the poorly vascularized, porous bone tissue in this patient, gained through the previous operations, our aim now was to offer the patient, possibly, a final operative treatment, whereby we proposed to stabilize both the stress-loaded C3/4 and C5/6 levels with a vascularized compact bone, and at the same time preserve the well-fused, but poorly vascularized C4/5 level. We achieved this by transplanting a free vascularized fibula flap in the form of a double island, preserving the periosteal con-

Fig.2 X-ray films of the cervical spine 1 week (*left*) and 3 months (*right*) after stabilization with plate and screws. The screws were initially divergent (*left*; although the plate-screw-angle seen here is not optimal). With time they had achieved a convergent position (*right*). This, and the hypodensity of the area around the screws, denote screw loosening (*right*). The C3/4 graft has collapsed, and kyphosis is seen

Fig.3 Post-operative radiograph of the patient 7 months after the procedure. The kyphotic deformity seen on the pre-operative films is still persistent, since we refrained from posterior procedures for reasons explained in text. There is no anterior dislodgement of the bone flap and the bone fusion is adequate. The patient is free of symptoms (25 months follow-up)

nection between the islands, which was draped over the preserved C4/5 block segment in order to revascularize it. The technical considerations are described below. The patient has remained symptom free ever since (25 months follow-up). Control radiographs showed adequate bone fusion (Fig.3). The initial peroneal nerve weakness of the donor leg after the operation completely ameliorated within a few weeks under intensive physical therapy. The patency of the vascular anastomoses was confirmed at 4 months using Doppler ultrasonography.

Operative technique

A two-team approach was employed. The patient was positioned supine with his head extended and immobilized with a Mayfield three-point fixer, his donor lower extremity rotated internally, with

the knee flexed slightly. While one team operated on the cervical spine, the other raised the bone flap on the peroneal vascular pedicle. We harvested 17 cm of the fibular shaft including a cuff of soft tissue around it, leaving approximately 9–12 cm both proximally and distally, following the Gilbert technique (anterolateral approach) [14]. Using this approach facilitates a two-team procedure, since no repositioning of the patient is necessary. The vascular pedicle was 10 cm long (Fig.4).

At the cervical end, the previously utilized right medio-lateral approach was used and dissection was carried out well above and below the plate, thus exposing the levels C3 through C6. The screws and plate were removed. The scarred and compromised bone tissue were thoroughly debrided at the C3/4 and C5/6 levels till the borders of the bone showed vitality through bleeding. During the approach, the superior laryngeal artery and the external jugular vein with its tributaries were carefully dissected and held

Fig. 4 Bench surgery of the fibular flap: extreme care is taken not to injure the vascular pedicle and the periosteal sheath in performing the osteotomies to design the fibular segments into islands. The denuded central segment is taken out, leaving the periosteum behind. This sheath transmits the nourishing vessels to the distal segment and, by virtue of draping, revascularizes the preserved C4/5 block segment

with vessel loops to serve as donor vessels for the vascular anastomoses.

The fibular flap was modified on the bench as follows. The periosteum was transversely and longitudinally incised on the lateral side as shown in Fig. 4, and a piece of denuded bone a little more than the length of the C4/5 segment (left in situ) was removed. Care was taken to preserve and leave behind the periosteal cuff of this segment (Fig. 4). The height of the proximal and distal bone islands corresponded exactly with the debrided segments.

The double-islanded bone flap was then brought to the recipient area, and the two islands were introduced in a compact manner into the respective debrided vertebral levels (Fig. 3, Fig. 5). The vascular anastomoses were completed: the artery of the flap was sutured to the superior laryngeal artery in an end-to-end fashion, and the vein was anastomosed to the external jugular vein end-to-side. After completion of the arterial anastomosis and opening of clips, the vein filled with blood, denoting microcirculatory integrity of the transplanted bone islands.

A tapering Rheomacrodex scheme (500 ml – day 1 post-op; 250 ml – days 2, 3; 100 ml – days 4, 5) was administered for 5 days following surgery. The patient wore a stiff neck collar for 4 months and received rehabilitation therapy of the neck muscles and active physical therapy of the donor leg.

Fig. 5 The two fibular islands are introduced into the debrided cervical segments with the flat, vessel-bearing side facing ventrally. The cervical segments are retracted maximally for the placement of the strut graft. On releasing the retraction, the graft sits snugly in the given position. This maneuver eliminates the necessity to hammer the fibular strut. Then the vascular anastomoses are completed

Technical danger areas in using the above-described method

One should be aware of the soft tissue scars in the ventral path to the cervical vertebrae in repeatedly operated patients such as this case. The donor vessels for the vascular anastomoses should be located far from this scar tissue, and they should be superficial enough to facilitate easy vessel manipulation. Consequently the vascular pedicle of the bone flap should be long enough to 'surface' the anastomoses.

In harvesting the fibula it is important to dissect free and preserve the peroneal nerve that runs relatively close to the vascular pedicle. Failure to do this will result in peroneus paresis of the donor foot.

The compromised bone tissue of the vertebral bodies should be a major consideration, and the modification of the flap on the bench should follow only after completion of vertebral debridement. This will determine the length of the central denuded bone segment of the vascularized strut to be removed, as well as the exact length of the fibular islands used for the interposition.

In designing the flap, extreme care should be taken to preserve the vascular pedicle and periosteum. Injury to these structures might easily result and remain unnoticed, especially when high-velocity instruments like the oscillating bone saw are used for the modification. Thus, in removing the central bone segment, it is advisable to cut the bone only to three-quarters of its diameter with the bone saw, and remove the rest using a dissection spatula to sep-

arate the bone from the periosteum, and a punch to remove the bone, carefully preserving the periosteal bridge.

The bone flap is inserted into the debrided spaces in such a fashion that an anterior dislodgment does not result at a later stage. This is achieved by leaving behind a little ridge on the ventral border of the debrided vertebrae. The fibular flap is inserted into the debrided levels with the flat, vessel-bearing side facing ventrally. This makes clear visualization of the strut to be inserted difficult. Here it is advantageous to distract the vertebral segments maximally apart and then carefully insert the bone flap, without needing to hammer it in. With release of traction, the graft should sit snugly. The graft position can be controlled by intraoperative X-ray, and adjusted appropriately. Careful hammering on the sides of the bone segment will not cause fatal injury to the vascular pedicle, but this maneuver should be avoided.

Donor site morbidity is an important consideration, about which the patient should be instructed while getting informed consent. Pain, weakness and foot drop are some conditions expected in the aftermath of harvesting vascularized fibula, the symptoms being not completely based on the surgical soft tissue trauma [30].

A technical error in any of the above-mentioned surgical steps will jeopardize the final results of the procedure. In such a case, the patient would not benefit from the technique and at the same time would have complaints related to the flap harvest. For these reasons, the indications for this method should be strict (i.e., repeated failure – graft collapse – of conventional techniques, relatively well-fused intermediate segment, technical feasibility and infrastructure, realistically motivated patient), and the operating surgeons should be familiar with the requirements and demands of the situation at both the donor and recipient sites.

Discussion

The use of free or pedicled vascularized bones for intervertebral interposition and stabilization has been reported [10, 17, 22, 24, 27, 28]. Such flaps are found advantageous especially in secondary and/or complex reconstructions [10, 24], in combined reconstruction of defects of bone and the integument [22], and in progressive spinal deformities or tumors [27]. The value of vascularized bone strut grafts in the treatment of kyphoscoliotic conditions, where much mechanical stress tolerance is required, has been emphasized [29].

The free vascularized fibula is well known for its 'salvaging' properties, owing to its abundant vascularity, compact tri-cortical bone tissue, excellent fusion and functional hypertrophic adaptation it exhibits at the recipient site. Vascularized fibula has been used successfully in several occasions of failed reconstructions [2, 5, 10, 25]. Bone tumors [26] and congenital or acquired pseudarthro-

ses [12] are some other indications for free fibula transfer.

The free fibula has two major sources of blood supply: the proper nutrient artery and the vessels invading the bone from its periosteal layer. It is suggested that the nutrient artery of fibula is mainly responsible for the perfusion of the medullary structures, whereas the periosteal vessels nourish the cortical layers [5, 6]. From the surgical point of view, the transplanted fibula needs either the medullary or the periosteal blood supply for its survival and function. The survival rate is not influenced by the absence of the medullary circulation when the periosteal blood flow is preserved, the medullary circulation in such a case being re-established through a reversed periosteal blood flow pattern [6, 15]. This is the basis of the success of split fibular flaps, where only the periosteal blood supply is preserved [3, 4]. Thus, through a transverse osteotomy, preserving the periosteal connection, the fibular shaft is divided and doubled over, either to produce a larger bone diameter, for example, for reconstruction of weight-bearing long bones [4], or to attain a sufficient height in mandibular reconstruction [3].

Periosteum is an osteogenic tissue [9, 20]. Besides the osteogenic property, the periosteal flaps have 'shape-giving' and 'space-limiting' functions, where no loss of bone into the surrounding soft tissue results when the bone with disturbed integrity is draped with a vascularized periosteal sheath [23]. Vascularized periosteum formed as a tube with hydroxyapatite filling has been successfully used for reconstruction of tubular bones [11, 23]. Draping of a vascularized periosteum over avascular bone leads to subsequent vitalization of the sequestered bone tissue.

In the presented case, the 'islanding' of the vascularized fibular shaft to interpose two cervical levels, by virtue of the flap design, gave the additional advantage of draping vascularized periosteum over the scarred C4/5 level. This well-fused, but avascular block serves as the floor for the fibular segment inserted into the C3/4 and as the roof of the C5/6 interposition graft. The described flap design also offers the function of changing cell components of the damaged C4/5 level and, eventually, also of renewed osteogenicity, thus decreasing the probability of pseudarthrosis. For these reasons, a conventional en bloc resection of C3–C6 and contiguous replacement with the vascularized strut graft was not opted. Moreover, the 'aggressive' nature of the procedure is confined to the 'bench-modification' of the bone flap, and does not involve *in vivo* manipulation, as in the case of a contiguous C3–C6 corpectomy and replacement.

Apart from fibula, free or pedicled rib graft, iliac crest and split radial bone are some other vascularizable flaps used in vertebral reconstructions [16, 19, 28]. For reconstruction of a single vertebral level, vascularized iliac crest could be a suitable option, since the spongy tissue that takes part in the initial periods of bone fusion is abundant in the iliac crest. For stabilization of multiple vertebral

levels, fibula is a better option, since it is a flap that tolerates aggressive manipulation (multiple osteotomies) extremely well.

The decision to transplant a vascularized bone flap in the described patient was made as a result of several factors:

1. Previous conventional treatment modalities, such as iliac crest grafting, and plate and screw fixation had failed
2. We observed that at each previous operative procedure the bones were poorly perfused and highly porous – the reason why they had neither fused properly nor held the screws snugly
3. Conservative therapeutic strategies had been exhaustively employed before we decided to operate the patient again, and
4. At the time of this presentation and diagnosis, facet block at the C3/4 level alone did not lead to pain relief, but the combination facet block at both C3/4 and C5/6 levels did.

Based on these findings, we decided to make a trough through the well-fused C4/5 segment and set a single- or double-barreled vascularized fibula to stabilize the C3 through C6 segments.

The observations on debriding the recipient site made us change our strategy: the C4/5 block was solidly fused, but was avascular in spite of provocation. So we decided to respect the integrity of this block, and opt instead to manipulate the fibula graft to fit into the respective levels to be stabilized, leaving a vascularizing periosteal bridge.

We opted to transplant the fibula for two main reasons: firstly, because fibula offers excellent bone quality and it tolerates multiple osteotomies extremely well, still remaining richly vascularized through the periosteal sheath, and secondly, because the iliac crest region was extremely scarred on both sides from previous surgeries, making the harvest of a vascularized iliac crest impossible.

Alternative methods of cervical vertebral fusions have been described in the literature, especially after failed anterior fusion [1, 18]. Posterior procedures include pedicle screw fixation [1], inter-spinous process wiring, and pillar plating [18]. Posterior fixation would also allow the reduction or elimination of the kyphotic deformity seen pre-operatively. A carefully performed pedicle screw fusion should not cause neurovascular complications, but the possibility of one could not be completely excluded and depends on the technique employed [1]. Posterior articular pillar plating as part of a circumferential procedure provides an added fixation required to salvage failed anterior fusion [18]. Both the cerclage wire technique and pillar plating depend on intact, osseous posterior element [25]. We opted for a straightforward approach of free vascularized bone transfer, owing to the many reasons already mentioned. We refrained from posterior approaches, which could have corrected the kyphosis as well, for several reasons. Firstly, the dorsal approach mandates extensive soft and bone tissue dissection. Secondly, it was already clear to us (from previous operations) that the bones were too porous to hold the screws and vice versa. In such a case it is questionable whether pedicle screws (or wires) to correct the kyphosis would serve any better. Thirdly, using the dorsal approach would weaken the supporting muscles not only of the involved segments, but also of the neighboring motion units. These paraspinal muscles play a major role in post-operative physical therapeutic muscle strength build-up.

It is to be emphasized that the method described here has many technical hurdles that were mentioned. Apart from general prerequisites, such as technical feasibility and a cooperative patient, who has already undergone several surgeries and who would accept fibular donor site morbidity to relieve her/his cervical symptoms, the sine qua non for such a procedure may be considered as: (1) repeated failure of conventional techniques, (2) established poor bone healing and bone non-union with (avascular) punch grafts, and (3) a relatively well-fused intermediate block.

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