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ORIGINAL PAPER

An anatomical study of vascular communications between anterior tibial and peroneal osseosomes and its clinical application in proximal hemiarthroplasty of radiocarpal joint following tumor excision

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Abstract

Background There are speculations that the proximal third fibular osseosomes, supplied by the anterior tibial vessels cannot be reliably recruited on the peroneal vessels supplying fibular diaphyseal osseosomes. Anatomical study by the authors eschewed this speculation and paved way for an evidence-based surgery. Cadaveric dissection, dye injection, and radiological studies revealed existence of a reliable anastomotic musculoperiosteal vessel between these two osseosomes that could effectively recruit the proximal fibular osseosomes on the peroneal vessels. Also, operative tips and tricks for safeguarding these anastomotic vessels were defined by the cadaveric study. Aesthetic and functional outcomes were assessed in five clinical cases, where the fibular heads were harvested reliably on the peroneal pedicle and stable wrist joints were reconstructed following oncological excisions.
Methods Based on the evidence from the anatomical study, five clinical cases (three males and two females) affected by stage III GCT (giant cell tumor) of distal radius underwent microvascular fibular head hemiarthroplasty following tumor excision. Average follow-up of the patients was 18 months.
Results At the end of follow-up period, all patients had an average MSTS (Musculoskeletal Tumor Society) score of 23. Scores ranged from 21 to 25. Patients had good functional outcomes with 69% average mobility in the reconstructed wrist when compared with the opposite normal wrist. Aesthesis of the reconstructed wrists were acceptable.
Conclusion The cadaveric study demonstrated concrete anatomical evidence of existence of an anastomotic musculoperiosteal vessel between anterior tibial and peroneal fibular osseosomes in all the specimens. Clinical study validated the safety of the vascularized proximal fibular hemiarthroplasty on peroneal pedicle. It may be a reliable method for reconstruction of the radiocarpal joint in the post-GCT distal radius excision with good aesthetic and functional outcomes.

Level of Evidence: Level V, therapeutic study

Keywords Microvascular proximal fibula hemiarthroplasty of radiocarpal joint · Anterior tibial fibular osseosomes · Peroneal fibular osseosomes · Anastomotic musculoperiosteal vessel · Distal end radius GCT

Introduction

Despite several clinical and anatomical studies [1–7], there exists speculation about the safe recruitment of proximal fibular osseosomes on the peroneal diaphyseal osseosomes. Osseosomes are block of osseous tissues extending from periosteum to endosteum supplied by a single perforator from the source vessel. Thus, each bone is made up of multiple osseosomes that in turn form the epiphysis and diaphysis of the long bone. Donald Serafin [3] described, for the safe harvest of the head of fibula on diaphyseal blood supply, the anterior tibial artery cuff with its branches to the head of fibula has to be piggy-backed on the peroneal artery. But, Innocenti et al. [1, 6, 7] in

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their studies have demonstrated the safe harvest of proximal fibular osseosomes, based only on the anterior tibial vessels. Taylor et al. [8] showed that in addition to supply to fibular head, anterior tibial vessels gave few tiny musculoperiosteal vessels to proximal fibular shaft as well. These studies [1–10] implied that the proximal fibular osseosomes could be reliably harvested only on the anterior tibial vessels. The above studies also [1–10] envisaged the need for bipedicled fibular harvest with cumbersome separate microvascular anastomosis of anterior tibial vessels. In addition, they imposed restriction on the dimension of fibular diaphysis when harvested only on anterior tibial pedicle. Until date, neither anatomical nor clinical study are available in the literature to substantiate the hypothesis of anastomosis existing between the fibular anterior tibial and peroneal osseosomes facilitating the simple single pedicled peroneal vessel-based proximal fibular reconstruction. The authors designed the cadaveric dissection, dye injection, and radiographic studies to throw light into this gray area.

An anatomical study was conducted to demonstrate the presence of anastomosis between fibular peroneal and anterior tibial osseosomes, and also to define the method of harvest of proximal fibula safeguarding this anastomotic vessel.

A clinical study was conducted to validate the safe recruitment of anterior tibial proximal fibular osseosomes to the peroneal osseosomes through this musculoperiosteal anastomotic vessel. Through this clinical study, the authors looked forward to assess the aesthetic and functional outcomes of peroneal vessel-based proximal fibular reconstruction of the radiocarpal joint following oncological excision of giant cell tumors.

Materials and methods

Institutional ethical committee approval was obtained for both cadaveric and clinical studies

Cadaveric study

The authors examined 28 specimens in the 14 adult preserved cadavers. Sixteen leg specimens were from male cadavers and rest from female cadavers. A lateral curvilinear incision posterior and across the head of fibula was made extending from popliteal fossa to lateral malleolus. On opening the popliteal fossa, the popliteal vessel branching pattern was examined for any anatomical variations, and the posterior tibial peroneal trunk was followed with ligation of all small genicular and muscular branches. Leaving the cuff of soleus on the proximal posterior fibula, the rest of soleus was reflected. Detachment of fibula with its head along with the distal popliteal vessels was done. All small-unwanted muscular branches were ligated along the course of peroneal vessels except for the osseous supply, and then the attention was directed towards the anastomotic musculoperiosteal vessels between the peroneal and anterior tibial systems within the cuff of soleus on the posterior surface of fibula. In specimens meant for dye injection study, the dilute formalin was injected to check for the rent in the vessel walls, which were sutured with fine silk. Then, the formalin was milked and mopped out with woven cotton gauze. The India ink was injected in retrograde manner from popliteal vein with little pressure, and red lead oxide solution was injected into popliteal artery. Then, the specimens were frozen for 24 h and photographs were taken. Remaining specimens were X-rayed after injection of an average 8.5 ml of low osmolar iodine dye in to the popliteal artery.

Clinical study

Based on the evidence gleaned from the anatomical study, five clinical cases (three males and two females) (age ranging from 35 to 49 years) that were affected by the Enneking stage III GCT involving the distal third radius had undergone microvascular fibular head hemiarthroplasty following tumor excision. Three had their dominant hand involved and two had involvement in nondominant hand. Clinical data of these patients are given in Table 1. This study was conducted from January 2011 to December 2016.

Selection criteria

1. All patients who had only Enneking stage III GCT involving the distal radius were included.
2. All patients who were fit enough to undergo excision and primary reconstruction were only selected.

Exclusion criteria

1. All patients who had nonsalvageable GCT tumor involvement
2. Patients with other malignant tumors involving both bones of distal forearm with overlying soft tissues (in spite of salvage surgery)
3. All patients with pulmonary metastasis

Preoperative preparation

Preoperatively, all these patients had their tissue diagnosis confirmed by histopathological examination. In all cases, preoperative X-rays, CT, and MRI scan of the involved parts including the radiological chest examinations were done. Written informed consent for surgery, anesthesia including consent for the photography and their display for research purposes were obtained.

Table 1 Clinical data of patients

Case no. and EnneKing stage of the distal radius GCT	En bloc excision description	Size of skeletal defect (cm)	Musculoskeletal Tumor Society (MSTS) score at the end of follow-up	Wrist flexion and extension at the end of follow-up in degrees (ROM of normal wrist for comparison)	Complication at donor site	Complication at recipient site including locoregional recurrence and average time for bony union (months)
1/st III	WLE + BR + PQ	11.5	25	59/55 (86/70)	Nil	Nil (9)
2/st III	WLE + EPL + ECRB+ BR + PQ	10	21	45/30 (60/45)	Nil	Venous anastomotic revision (8.5)
3/st III	WLE + BR + PQ	9	22	50/20 (70/30)	Nil	Mild hematoma (drained and healed uneventfully) (9)
4/st III	WLE + BR + PQ	10.5	23	58/35 (80/46)	Nil	Superficial infection. (treated and healed) (10)
5/st III	WLE + EPL + ECRB+ BR + PQ	11.5	24	55/25 (75/42)	Nil	Nil (8)

WLE wide local excision, *BR* brachioradialis, *PQ* pronator quadratus), *EPL* extensor pollicis longus, *ECRB* extensor carpi radialis brevis, *ROM* range of mobility

MSTS final score was computed after examining the five factors like pain, functions, emotions, hand positioning, and dexterity attained. Each factor was graded on 0 to 5 scale with nil on "0" score to best on "5" score. All flaps survived well

Surgical technique

En bloc excision of the tumor including the biopsy site with margin was done. This had resulted, on an average, 10.5 cm skeletal defect at the distal third of radius exposing the wrist joint in all cases with loss of other musculotendinous units (Table 1). Appropriate tendon transfers and tendon grafting were carried out. After critical assessment of the resultant composite defect, flap harvest was started. Under tourniquet control proximal third fibula was harvested on contralateral side by lateral approach. On 130- to 140-degree axial rotation of the fibula, its articular surface would face the scapholunate articular surface. This rotation brought the nearly horizontal articular surface on the proximomedial aspect of fibula in congruence with the proximal articular surface of scaphoidlunate. In addition, the apex of the head of fibula formed the floor of anatomical snuffbox just distal to tip of ulnar styloid. This rotated fibular head position facilitated effective reconstruction of radial collateral ligament using part of tendon of biceps femoris with intermediate lamina of fibular collateral ligament which were harvested on the fibular tip. Proximal third fibula was always harvested with little extra length so that final adjustment can always be done at the time of final fixation. Soleus and lateral gastrocnemius were reflected from the posterior aspect of head of fibula leaving the 1-cm cuff of muscle on the bone to protect the musculoperiosteal anastomotic vessel within it. The lateral popliteal nerve was carefully mobilized. With retrograde dissection, the peroneal pedicle was traced to tibioperoneal trunk. The musculoperiosteal perforators to the fibular head from anterior tibial recurrent vessels were ligated close to the origin. A slight rotation of fibula disarticulation of superior tibiofibular joint was done. The anastomotic musculoperiosteal vessels were dissected carefully under magnification towards the head of fibula. Flap perfusion from the peroneal pedicle up to the styloid process of head of fibula was observed after releasing the tourniquet (Video 1). In all cases, the pulsation of this anastomotic musculoperiosteal vessel was noticed up to fibular head. Then, the fibular head osseous flap was fixed with hardware to the native radial bone with correct amount of axial rotation. A stout K wire was also passed through the reconstituted wrist in 15-degree extension. Only the radiocarpal ligament was reconstituted. The radial artery and cephalic vein were used as recipient vessels in the forearm. After the skin closure with Segmullar drain, the site of peroneal vessel was marked on the skin for postop Doppler monitoring. All the patients were followed up at monthly intervals after discharge with an average postoperative follow-up period of 18 months. For the initial 8 weeks in postoperative period, immobilization was done in the functional position with aluminum short-arm splint and K wire across the reconstructed joint. After removal of K wires, passive supervised stretching of the reconstructed wrist joint was done for 4 weeks, and night splinting was continued in functional position. At 12 weeks, they were given progressive active exercises. Thereafter, MSTS scoring was done with measurement of range of mobility in the reconstructed wrist at monthly intervals. Three monthly radiological screening was done in all cases for early detection of locoregional recurrences and bony union.

Results

Cadaveric study: (Figs. 1, 2, and 3) All these dissection-examination, dye injection, and radiological studies revealed on an average 2.75-cm length, 1.26-mm-sized musculoperiosteal (unvalved vein and artery) anastomotic vessel within the substance of soleus. In all cases, they connect the proximal most

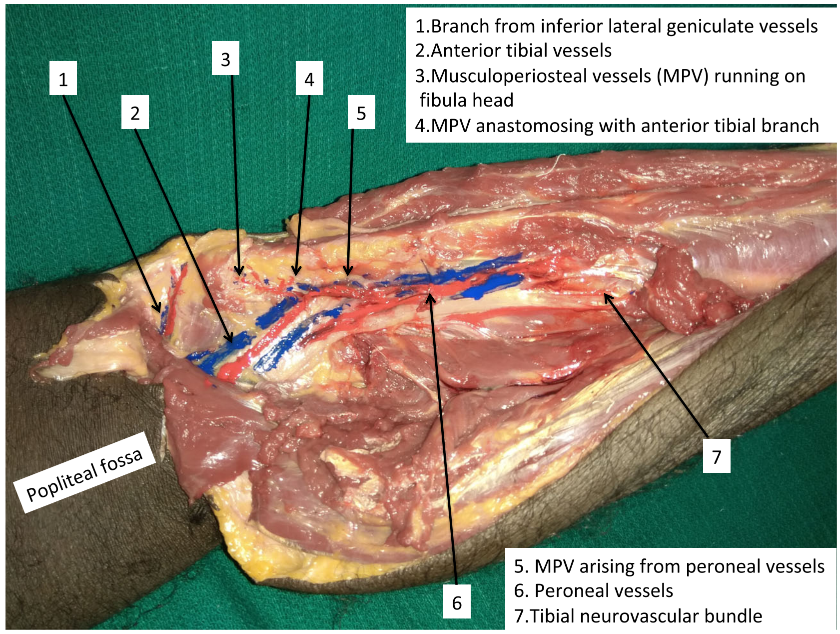

Fig. 1 Cadaveric dissection after the soleal arch reflection shows the anastomotic musculoperiosteal vessel (all three segments-3,4,5) arising from the peroneal vessel running towards neck of fibula. 1. branch from inferior lateral geniculate vessels 2. anterior tibial vessels 3. musculoperiosteal vessels (MPV) running on fibula head 4.MPV anastomosing with two anterior tibial vessels 5.MPV arising from peroneal vessels 6. peroneal vessels 7.tibial neurovascular bundle

musculoperiosteal branch of the peroneal vessel, to the musculoperiosteal branches of anterior tibial recurrent vessels close to the posterior aspect of neck of fibula. Leaving behind the 1.5-cm cuff of soleus on the posterior aspect of proximal third fibula and ligating the musculoperiosteal branches close to its origin from anterior tibial recurrent vessels safeguards these anastomotic vessels between the two osseosomes.

Clinical study: (tabular column 1) (Figs. 4, 5, 6, 7, 8, 9) (Videos 2, 3, and 4) At the end of the average follow-up period of 18 months, the average MSTS score was 23, and it was ranging from 21 to 25. Average wrist flexion and extension were 53.4 and 33° respectively. Average supination and pronation were 13.5 and 35.5° respectively. Patients had good functional outcome with 69% average mobility in the reconstructed wrist when compared with opposite normal wrist. None of them had any recurrence in the follow-up period. One patient had postoperative venous thrombosis for which revision of vein anastomosis was done. One patient had mild hematoma collection, which was evacuated, and the wound healed well. Yet, another case had infection along the suture line, which was treated with directive antibiotic therapy and it settled well. All patients had uneventful bone union with stable reconstructed wrist joints in an average period of 8.9 months. There were no donor site morbidities like lateral popliteal nerve palsies, instability of the knee joint, and late

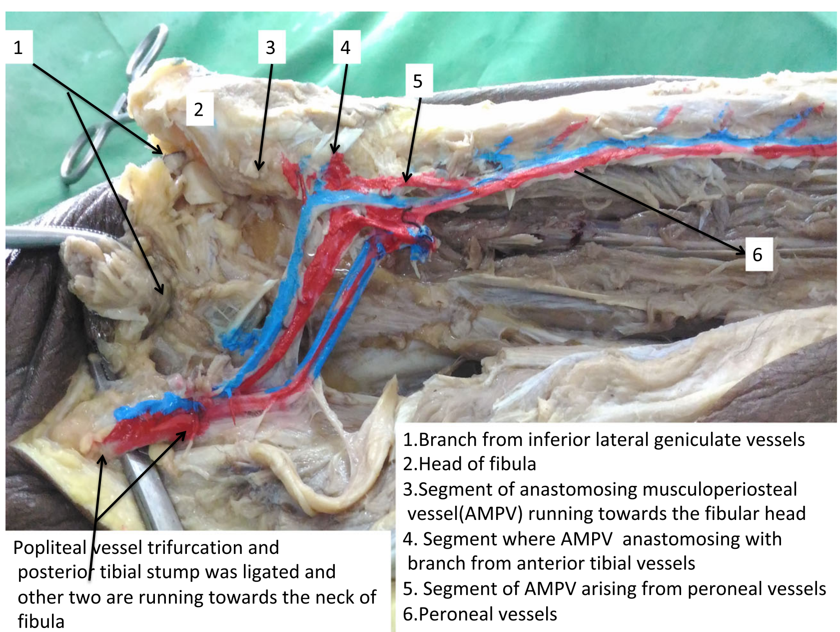

Fig. 2 Anomalous origin of peroneal vessel directly from the popliteal vessels. Here, the anastomotic musculoperiosteal vessel (all three segments—3, 4, 5)—popliteal vessel trifurcation and posterior tibial stump was ligated and other two are running towards the neck of fibula. 1. Branch from inferior lateral geniculate vessels; 2. head of fibula; 3. segment of anastomosing musculoperiosteal vessel (AMPV) running towards the fibular head; 4. segment where AMPV anastomosing with branch from anterior tibial vessels; 5. segment of AMPV arising from peroneal vessels; 6. peroneal vessels

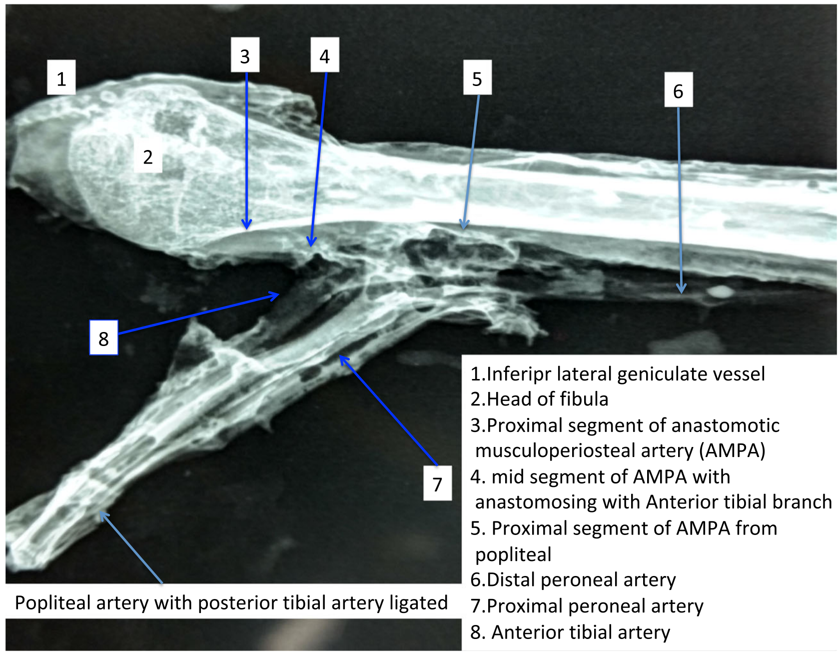

Fig. 3 X-ray after injection of low osmolar iodine dye. Shows musculoperiosteal anastomotic vessel (all three segments—3, 4, 5) between the popliteal artery with posterior tibial artery ligated. 1. Inferior lateral geniculate vessel; 2. head of fibula; 3. proximal segment of anastomotic musculoperiosteal artery (AMPA); 4. mid-segment of AMPA with anastomosing with anterior tibial branch; 5. proximal segment of AMPA from popliteal; 6. distal peroneal artery; 7. proximal peroneal artery; 8. anterior tibial artery

gait disturbances in any of these cases. Aesthesis of the reconstructed wrists were acceptable.

Discussion

Pho et al. [11] performed three reconstructions with proximal fibular physis based only on the peroneal vessels. Pho et al. [11] reconstruction was based on the hypothesis that there must be some anastomotic vessel between the fibular epiphysis and diaphysis. But, subsequent studies by Innocenti et al. [12, 13] demonstrated poor results with this approach in children. But, the authors had established both the anatomical and clinical studies in the matured skeleton that there existed a constant musculoperiosteal anastomotic vessel (connecting the perforators from anterior tibial recurrent vessels and peroneal vessels) facilitating the safe harvest of proximal anterior tibial osseosomes, on the single peroneal pedicle which simplified the reconstruction. This vessel probably not well-developed in the periphysis fibrocartilaginous mass later develops into a large communicating vessel in the matured skeleton. So, the authors' simplified anatomical approach had led to harvest of proximal fibula with well-homogenized blood supply up to adnexa of the fibular styloid. In turn, this paved way for sound union with residual bone

Fig. 4 35-year-old female with Enneking group III giant cell tumor involving the left distal radius

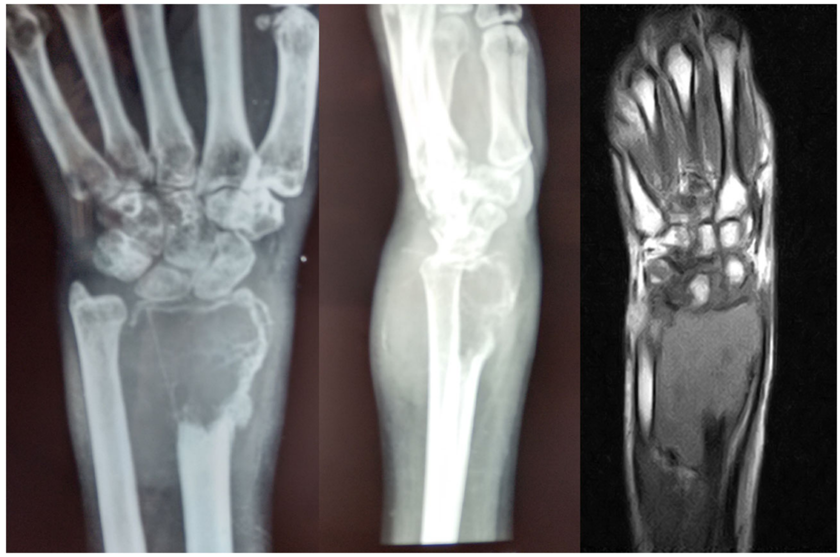

Fig. 5 X-ray of the tumor. MRI of the left wrist and hand showing breach of cortex of radius near the articular disc of distal radiocarpal joint by the tumor

and also led to a stable wrist-joint reconstruction with excellent functional and aesthetic results.

Giant cell tumor of bone is a locally aggressive benign tumor. This tumor has propensity to involve long bones near the epiphysis. The third most common site of involvement is distal end of radius. Tumor commonly occurs in the third and fourth decade. It involves both males and females equally [14, 15]. Enneking group III GCT is tumor expansion of the bone with breach of reactive bone and cortex with or without soft tissue invasion. It has been well-established by various studies [14–16] that the tumor excision with margin is the treatment of choice followed by reconstruction. Conservative treatment for Enneking stage III GCT is discouraged because of high recurrence rates [17, 18]. In our series, none of the patients had any recurrence; this could be attributed to the en bloc-wide local excision.

Use of osteoarticular allograft for the reconstruction was associated with complications like non-union, absorption of bone, dislocations, subluxations, painful wrist joint, and complex regional pain syndrome [19]. Custom prosthetic replacement of the distal radial tumors was associated with less functional results and more complications like extrusion and infection [20]. The authors had good functional results with aesthetically acceptable stable wrist attributed to the homogenously vascularized proximal autologous fibula based on the peroneal pedicle effectively recruiting the anterior tibial osseosomes. Also, in every case, our anatomical reconstitution of collateral ligament of radio carpal joint contributed to the stable-joint reconstruction. Stability of the reconstructed joint was also contributed by the congruent articular surface replacement.

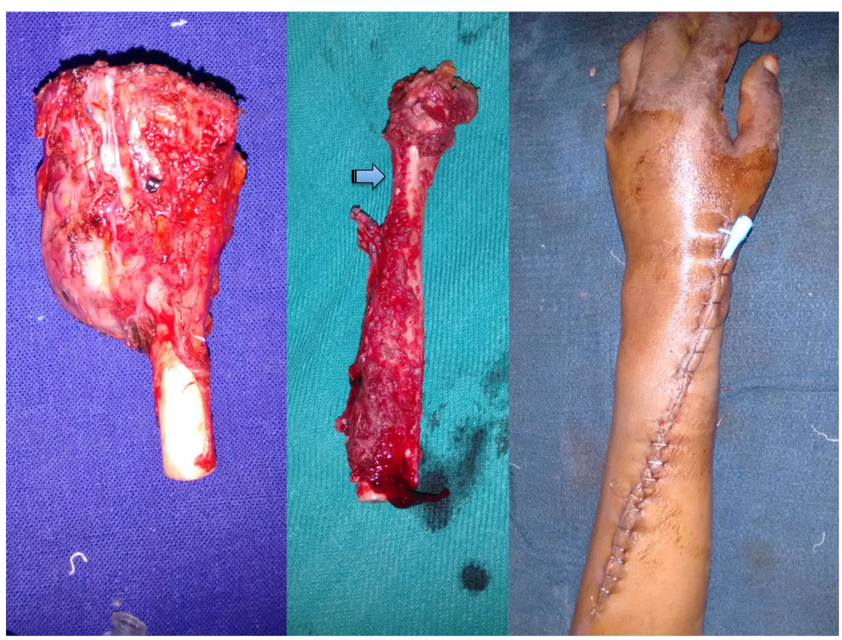

Fig. 6 Left: en bloc-excised tumor. Middle: free proximal third fibula harvested on the peroneal vessels (arrow showing skeletonized anastomotic)

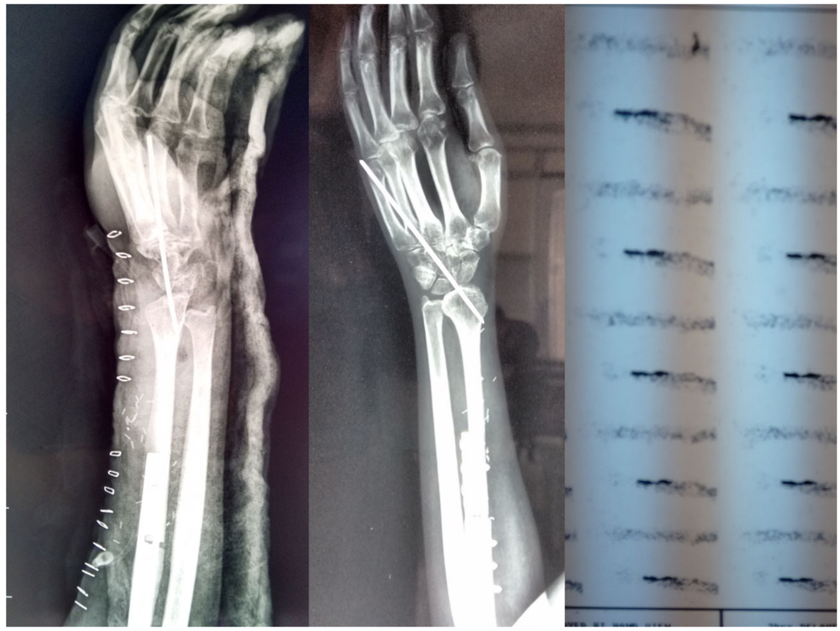

Fig. 7 Left: immediate postop X-ray. Middle: early postop X-ray. Right: technetium 99-m bone scan showing hyperemic proximal fibula in the three

Innocenti et al. [1] have reported three cases of common peroneal nerve palsy in their series of six patients. Probably, this could be related to harvest of proximal fibular osseosomes on the anterior tibial vascular pedicle (with retrograde venous drainage). During the dissection of anterior tibial vessels, there is also increased risk of injuring the nerve supply to the extensor compartment muscles contributing to the 50% complication rate in study by Innocenti et al. We have defined in our cadaveric dissection studies the safe initial release of common peroneal nerve by recognizing the fascia that extends from the biceps femoris tendon enclosing the nerve. This safe step was followed in every clinical case that paved way for no donor site morbidities. In our series, we never encountered any lateral popliteal nerve palsy attributed to this technique, which delivers the head of the fibula safely beneath the neurotendon sling. The authors' established technique is unipedicled on peroneal vessels and have forward flow pattern. The strength of this study is anatomical establishment of omnipresent

Fig. 8 Flexion and grip of the reconstructed wrist. Lower left: radial deviation and grip of reconstructed wrist. Lower middle: late 12-month postop X-ray

Fig. 9 Donor area with no morbidities

musculoperiosteal anastomotic vessel between peroneal and anterior tibial osseosomes of fibula. The limitation of the study is the small size. Nevertheless, the authors' study is the first clinical series establishing the safety of recruitment of anterior tibial osseosomes on the peroneal fibular osseosomes and simplified the fibular hemiarthroplasty reconstructions. The structured postoperative supervised regimen was needed to get good postoperative functional results.

Conclusion

The cadaveric study had elicited concrete anatomical evidence of existence of anastomotic musculoperiosteal vessel between anterior tibial and peroneal fibular osseosomes in all specimens. The cadaveric study enriched our anatomical knowledge and added a tool in the armamentarium of bony reconstruction of wrist joint and other needed areas. Our small clinical study validated the safe harvest of vascularized proximal fibula on peroneal pedicle with preserved anastomotic musculoperiosteal vessel in matured skeleton. Safe tips for harvesting also were defined by the study. With learned expertise, one could even dissect this musculoperiosteal anastomotic vessel and skeletonize it. This may be a reliable tool for reconstruction of the radiocarpal joint with good aesthetic and functional outcomes. Nevertheless, to establish the safety and longevity of this technique, large-scale clinical studies need to be encouraged.

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Compliance with ethical standards

Conflict of interest Balakrishnan Thalaivirithan Margabandu, J. C. Charan and J. Jaganmohan declare that they have no conflicts of interest.

Informed consent The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal.

The patients understand that their names and initials will not be published, and due efforts will be made to conceal their identity.

Ethical approval Institutional ethical committee has approved the study.

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