Surgical Feasibility Study on Cadaver for Vascularized Wrist Joint Transplantation

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Purpose Despite modern advancements in the treatment of late stages of wrist joint degeneration, few reliable options exist for patients requiring motion-preserving reconstruction of their radiocarpal and midcarpal joints. Vascularized composite allotransplantation (VCA) could be considered an option for wrist reconstruction in the future. The goal of this study was to describe the relevant anatomy and design a potential surgical technique for wrist VCA.

Methods Anatomic studies were performed on 17 human upper extremities. The arterial system of each cadaver was injected with latex dye or radiographic contrast. After injecting a contrast medium visible on a computerized tomography (CT) scan, the initial three specimens were examined using microCT. This confirmed joint vascular patency and allowed for the dissection of the other specimens that were injected with latex for the study of joint vascularization and the design of the wrist VCA. We then outlined a donor and recipient surgical technique for transplant based on recipient CT scans. Customized cutting guides were designed for the transplant procedure. After the procedure, we performed angiography of the VCA to determine the vascularity of the transplant.

Results Using a combined volar and dorsal approach, we were able to perform a complete wrist VCA procedure. After the completed transplant procedure, angiographic imaging of the specimens demonstrated that the flap dissection and transplantation preserved the nutrient endosteal supply to the distal end of the radius and ulna, as well as to the carpal bones and the metacarpal bases.

Conclusions The dissection of the donor, recipient, and the entire vascularized joint transplant procedure served to illustrate the anatomical feasibility of the cadaveric surgical technique. This establishes an anatomic basis for the possibility of future human clinical applications.

Clinical relevance This study helps investigate the anatomical feasibility of a wrist VCA. *(J Hand Surg Am. 2024;49(3):212−221. Copyright © 2024 by the American Society for Surgery of the Hand. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).)*

Key words Cadaver, joint transplant, surgical anatomy, vascularized composite allotransplantation, wrist transplantation.

Severe chronic cases of wrist pancarpal arthritis are challenging entities to be treated, particularly in young or high physical-demand patients.[1−4] Total wrist arthroplasty (TWA) currently is not a reliable therapeutic option for young patients.[1] Due to complications and high

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rates of failure, the implant's lifespan is often limited and may require revision within 10 years.[2,4,5] Despite recent advancements in the field of hand and wrist surgery, a reliable alternative is still lacking.[1,2,6]

Likewise, after distal radial resection for oncological indications, patients have been treated using nonvascularized osteoarticular cadaver distal radius allografts;[7] however, this has not been proven to be a reliable option in the long term. In addition, wrist allograft healing has been found to take a minimum of 6 to 8 months, and due to the fact that it is a nonvascularized graft, infection and nonunion are common.[8,9] Vascularized composite allotransplantation (VCA) has evolved over the past 25 years, and in select patients, it has been found to be an effective method of restoration for transradial and transhumeral amputees. Experimental work has even been performed to demonstrate the possibility of elbow joint VCA,[10–14] despite a clinical case not having been performed. Although descriptions exist in the literature that focus on vascular and neural anatomy as it pertains to hand and arm VCA, isolated human wrist vascularized allotransplantation has not been described.

The present study aimed to describe the vascular and neural anatomy of a wrist VCA model. We describe each step required to perform a vascularized wrist joint allotransplantation including the donor procurement, recipient design, and implantation of the wrist allograft. We also describe a surgical procedure using customized cutting guides, which is reliably reproducible on cadaver specimens.

MATERIALS AND METHODS

We used 17 previously frozen human upper extremities for this study. The number of specimens was based on a previous study of vascularized joint transplantation.[11] The study design was approved by our institutional review board biospecimen subcommittee. None of the specimens had any known history of previous surgery, infection, trauma, or peripheral vascular disease. Each specimen was thawed for 24 hours at room temperature before any injection procedure was performed for vascular and anatomical studies.

In the first three specimens, the radial, ulnar, and interosseous arteries were proximally cannulated at the forearm using 5 F, 4 F, and 2.6 F catheters (Glidecaths, Terumo), respectively, and the vascular tree was irrigated with normal saline until clear effluent was observed from the draining veins. Barium sulfate was prepared as a suspension of powder in water at a ratio of 1:2, and then mixed with red latex at a ratio of 1:2 of the suspension and latex, respectively, as reported by Morsy et al.[15] After injection of the specimens, they were left to cool at 4°C for 48 hours and then were scanned using a high-resolution computed tomography scanner (vivaCT 80 in vivo microCT scanner). Three-dimensional reformats were created using Dragonfly Software. The other cadaver specimens were cannulated using the same catheters, washed, and injected with red latex rubber under mechanical pressure using a peristaltic pump (Masterflex, L/S Economy Pump System) and then left to cool for 48 hours. Subsequently, they were thawed for 24 hours before performing cadaver dissections.

We dissected each specimen dorsally and volarly. The radial, ulnar, and interosseous arteries were dissected proximal to distal to identify all the vascular branches terminating within the wrist joint. Once the donor technique was refined on five specimens, we focused on developing the recipient preparation technique. Dissection was performed using 4.5× loupe magnification. All measurements were recorded using a surgical caliper by two different surgeons. All surgical steps of the procedure were photographed using a digital camera. Using the remaining four specimens, we used computerized tomography (CT) to develop customized cutting guides (Fig. 1) and performed the full transplant procedure (Fig. 2). After the transplant, we injected the VCA with radioiodine solution and performed fluoroscopic scans to demonstrate the vascularity of the transplant. We also used angiographic assessment to demonstrate the integrity of the vessels vascularizing the joint at the conclusion of the procedure.

Using a standard protocol, CT images were used to segment the patient's anatomy using Materialize Mimics. Next, the segmented anatomy data were imported into Materialize SurgiCase Sharp. A virtual planning session then occurred between the surgeon and the clinical engineer, and the segmented anatomy was manipulated to determine where to perform the osteotomies and what fixation to use. Patient-specific predrilling and cutting guides were then designed based on the plan using the patient's unique anatomy. The guides and corresponding polyamide bone models were 3D printed using a 3D Systems Selective Laser Sintering (SLS) machine.

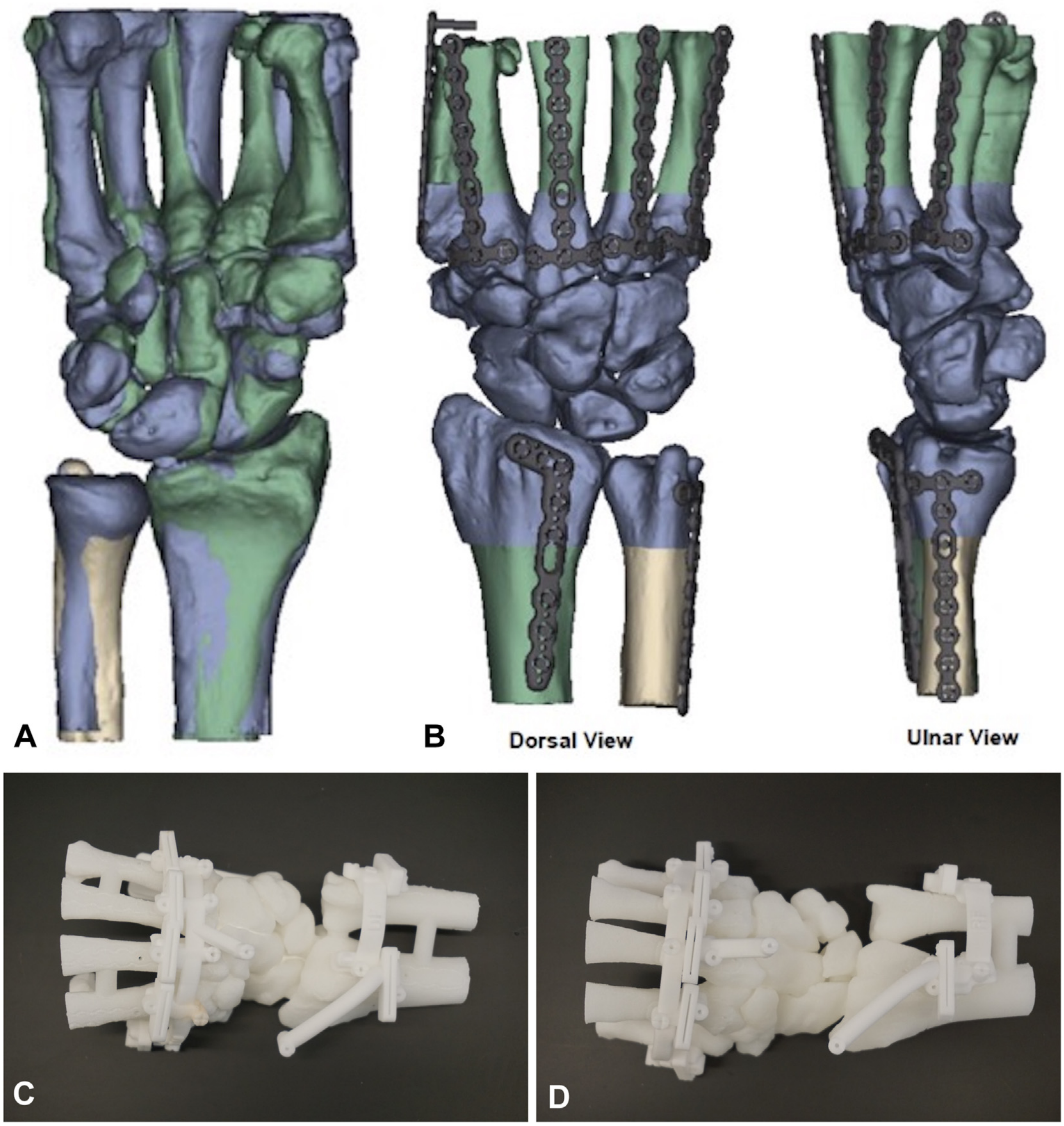

FIGURE 1: The cadaver model of wrist VCA preoperative CT scan reconstruction and surgical study. **A** Volar view of the preoperative 3D CT scan reconstruction of the donor (violet) and the recipient (gray and green), the engineering study demonstrated excellent congruence between donor and recipient. Superimposition of the 3D reconstruction and CT scans. **B** Preoperative 3D CT scan reconstruction and transplant procedure with osteosynthesis. The donor is in violet and the recipient is gray and green. **C** and **D** Customized cutting guides for donor and recipient harvesting seated on 3D CT scan printed model reconstruction.

RESULTS

Vascular and neural anatomies of wrist allotransplantation: key points

We identified three main arches on the volar aspect of the wrist joint and three main arches on the dorsal aspect of the wrist joint. We also identified anatomic variants that are summarized in Table 1. From proximal to distal, the first arch found on the dorsal side of the wrist is the radiocarpal arch, followed by the dorsal intercarpal arch and the metacarpal base arch[16,17] (Fig. 3A). On the volar aspect, we identified the volar radiocarpal arch, the intercarpal arch, and the deep palmar arch (Fig. 3B, C). We documented the deep palmar arch distance to the third-digit carpometacarpal joint (Table 1). The anterior and posterior interosseous nerve distances from the radiocarpal joint and Lister's tubercle were measured. Each radial, ulnar, and interosseous collateral artery entering the wrist joint was identified, and the distance of their origin in relation to the radiocarpal joint or carpometacarpal joint was measured (Tables 1 and 2). The anterior interosseous nerve, artery, and vein were followed and recorded to design the preliminary transplantation prototype. On the dorsal side, preserving the wrist arterial anastomotic

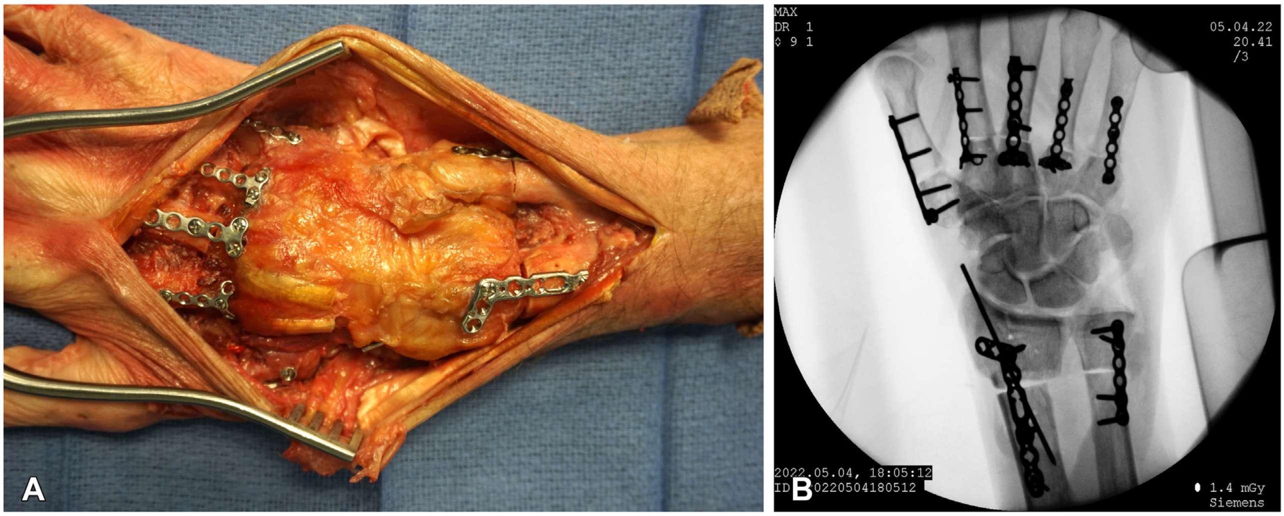

FIGURE 2: The cadaver model of wrist VCA transplant. **A** Wrist VCA transplant procedure and bone osteosynthesis is completed, and the type of plates used are only demonstrative. **B** Wrist VCA transplant procedure postoperative x-ray. The preoperative 3D CT scan study and the use of customized cutting guides resulted in excellent congruence between the osteotomy surfaces of the recipient and the donor transplant boney structures.

TABLE 1. Main Arteries of the Wrist Joint and Anatomical Variants—Endosteal and Periosteal Blood Supply of Our Specimens as per Gelberman Study[15,16]

Blood Supply	Location From RC/CMC Joint	The Most Frequent Origin	Structure Perfused	Percentage of Presence	Average Diameter*
DRCA	7.12 mm (4–11 mm) RC	Radial A.—Ulnar A.—Anterior Interosseous A./RA+UA/RA + AIA (dorsal branch)	Distal radial metaphysis, lunate, triquetrum	80%	1 mm
PRCA	8.25 mm (5–12 mm) RC	Radial A.—Ulnar A.—Interosseous A./RA+UA	NI	100 %	1 mm
DIA	8.38 mm (8–10 mm) RC	Radial A.—Ulnar A.—D. Interosseous A./RA+UA/RA + AIA/UA + AIA	Distal carpal row and proximal row (lunate and triquetrum)	100 %	1.6 mm
PIA	8.83 mm (7–11 mm) RC	Radial A.—Ulnar A.—A. Interosseous A	NI	40%	1.8 mm
DPA	8.62 mm (4–16 mm) CMC	Ulnar Artery	Perforating vessels to the BMA and palmar metacarpal arteries, distal carpal row	100%	3 mm
BMA	8.83 mm (3–15 mm) CMC	Radial A.—Ulnar A.	Distal carpal row and base metacarpal bones	30% complete	< 1 mm

BMA, base metacarpal arch; CMC, carpometacarpal joint line; DIA, dorsal intercarpal arch; DPA, deep palmar arch; DRCA, dorsal radiocarpal arch; PIA, palmar intercarpal arch; PRCA, palmar radiocarpal arch; RC, radiocarpal joint line.

*The arterial supply was meticulously dissected after intra-arterial latex injection. The radial and ulnar arteries give off the branches that form main archades of the wrist as following. In the column "The most frequent origin" is reported in order of frequency from which each arch was arising from. NI is indicated when with gross anatomy dissection was not able to define the precise position and distribution of the arch (because it was entering the joint capsule). Scaphoid bone usually has direct vessels from the radial artery, those anastomized with intercarpal and anterior interosseous artery also Pisiform bone has direct vessels from the ulnar artery; therefore, it is mandatory during dissection being extremely careful when dissecting those areas.

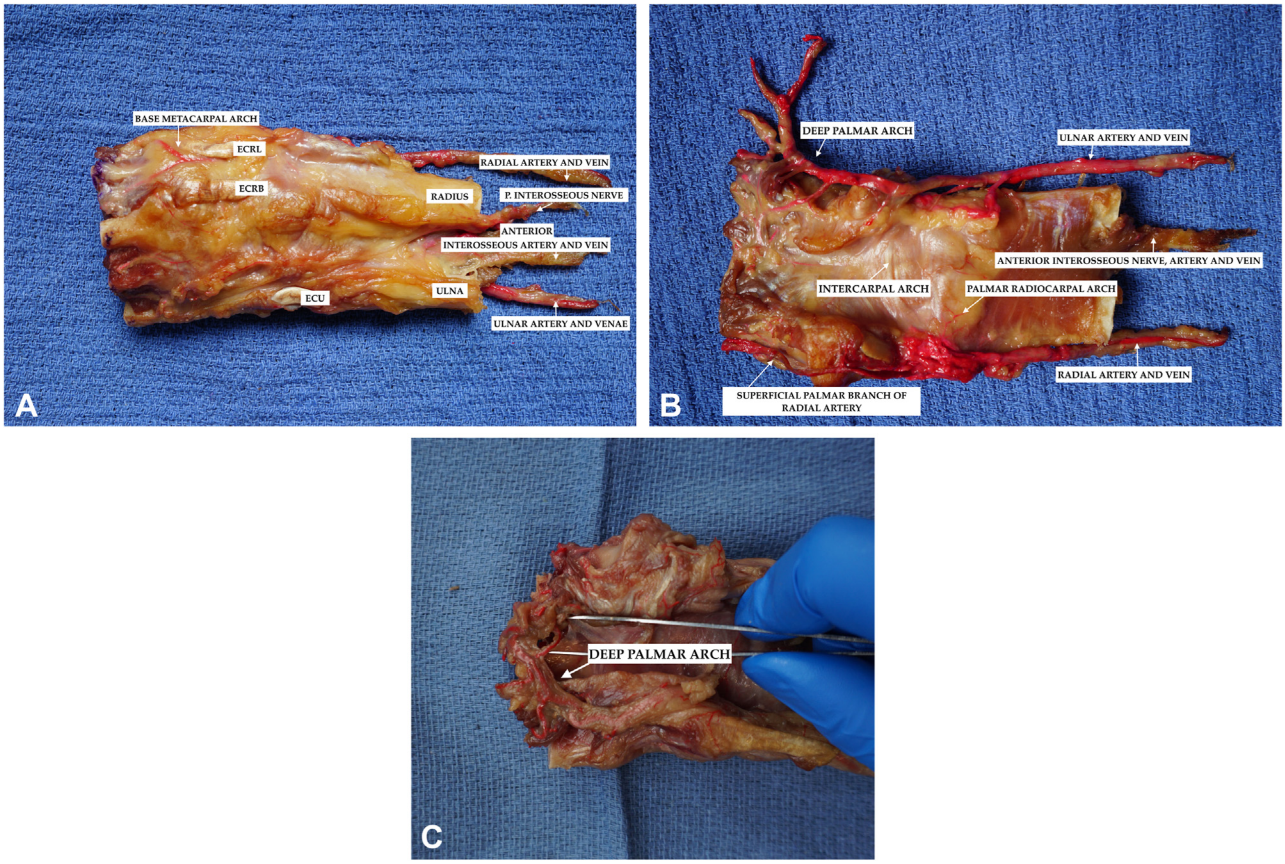

FIGURE 3: The cadaver model of wrist VCA donor design. **A** Dorsal aspect of the transplant and its components: on the left side, metacarpal bones cut, base metacarpal arch, extensor carpi radialis brevis, and extensor carpi radialis longus tendon stump (to be repaired later with the recipient tendons of the transplant). On the right side, dorsal radius and ulna, radial artery, venae comitans, ulnar artery and venae comitans, anterior interosseous artery and venae comitans, and posterior interosseous nerve. **B** and **C** Volar aspect of the transplant and its components. Image on the left demonstrates the cut metacarpal bones, and on the right, the volar aspect of the radius and the ulna. Latex injection is showing the vascularity of the transplant as described by Gelberman[15,16]: palmar radiocarpal arch, palmar intercarpal arch, deep palmar arch and direct branches arising from radial, and ulnar and anterior interosseous artery are forming a complex network that enters the joint capsule and supplies distal radius, ulna, carpal bones, and proximal side of the metacarpal bones. This complex vascular network ensures adequate perfusion to the VCA.

TABLE 2. Main Nerve Involved Into the Transplant to Obtain an Innervated Joint

Nerve Supply	Location	Distribution
Anterior interosseous nerve	69.62 mm from RC joint	Volar aspect of the wrist joint entering the capsule
Posterior interosseous nerve	7.22 mm lateral to the Lister's Tubercle	Dorsal aspect of the wrist joint entering the capsule

network required sectioning of the extensor retinaculum and retracting each extensor tendon to isolate a VCA consisting of bone, vessels, nerves, and limited connective tissue. All muscles were dissected from the cadaveric model of the wrist VCA. The pronator quadratus was carefully dissected sharply to avoid damaging the anterior branch of the artery, anterior interosseous nerve, and interosseous vein. This was performed to maintain that neurovascular bundle as part of the transplantation.

Procedure for harvesting the donor, recipient, and full transplantation technique on a cadaver model

To develop a technique for procuring the donor (Figs. 3 and 4), the recipient (Fig. 5), and performing the full transplant procedure (Fig. 2), several dissections on cadaver specimens were performed. Each dissection allowed the identification of technical improvements and creation of a standardized procedure. The first three specimens, injected with barium sulfate and red latex, were examined using microCT analysis, which showed

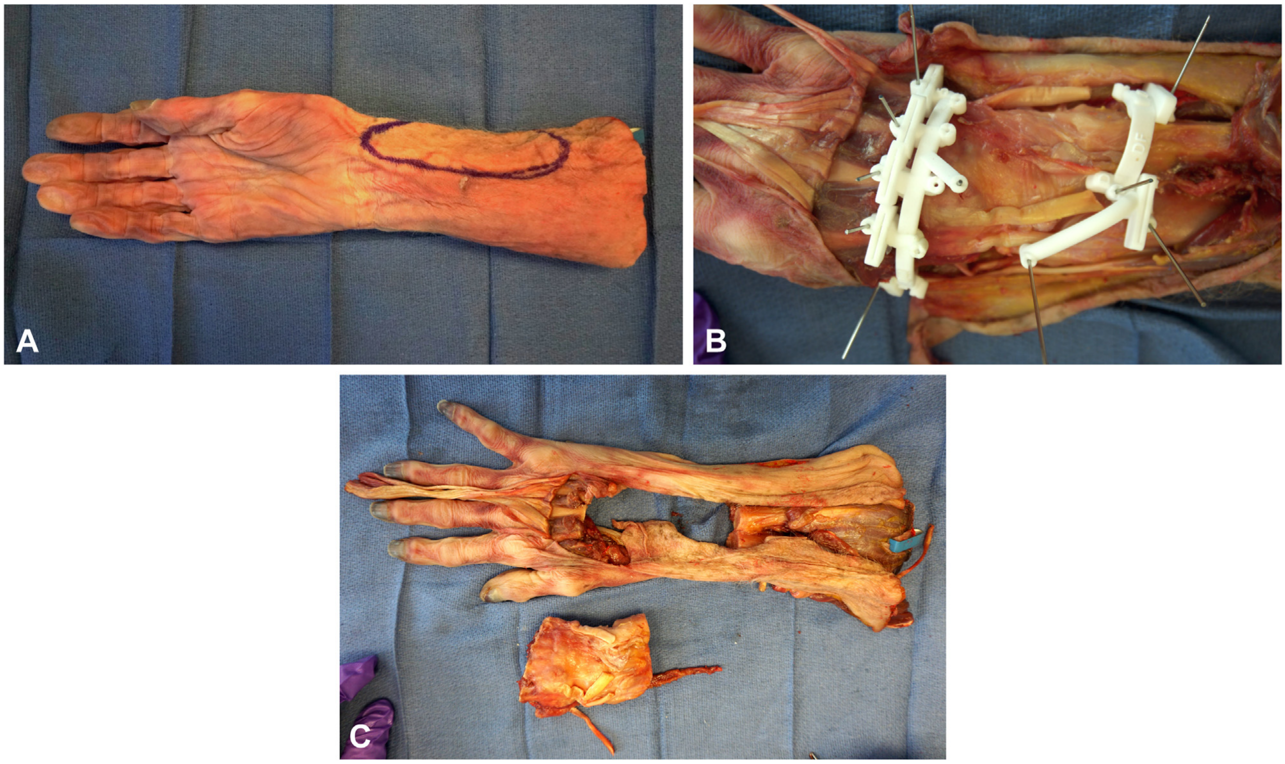

FIGURE 4: The cadaver model of wrist VCA donor procurement. **A** In donor transplant harvest, a radial forearm flap was included in the transplant to monitor the transplant and provide additional skin to aid in closure. **B** Dorsal aspect of the wrist: fingers on the left side, and radius and ulna on the right side. Donor-customized cutting guides seated on the specimen for wrist transplant procurement. Cutting guides are designed to cut the first to fifth metacarpal bones at their base and radius and ulna proximal to the distal radioulnar joint. **C** Dorsal aspect of the wrist. On the left side, extensors tendons are reflected. At the bottom of the image, the transplant is seen with its vascular pedicles, and some of the tendons that need to be repaired to the recipient tendons.

adequate vascularization of the distal radius, ulna, carpal, and metacarpal bones. We developed a specific procedure for donor wrist allograft procurement (Table 3), recipient preparation (Table 4), and the full VCA allotransplantation procedure (Table 5). At the end of the transplantation procedure and vascular anastomoses, we injected the transplant with iodine and under fluoroscopic control and demonstrated that the VCA was fully vascularized.

DISCUSSION

When considering surgical options for young patients with advanced pancarpal degeneration, two primary options exist, total wrist arthrodesis and TWA. Wrist arthrodesis is not an option for patients who want to maintain wrist mobility, whereas TWA has a high rate of failure within 10 years after the primary surgery.[6]

A solid union between any bone graft and the recipient site is crucial for stability. Nonvascularized (conventional) graft and vascularized autologous graft are two sources of bone graft. The first offers immediate support but weakens in the first 6 weeks due to resorption and revascularization; the other heals rapidly and offers superior initial strength. Vascularized autologous grafts are histocompatible, have low disease transmission risk, and low postoperative infection rate, but their disadvantages include limited quantity and donor site morbidity. Vascularized grafts demonstrate better outcomes in healing speed and reduction of postoperative complications and reoperation.[18–20]

Articular innervation is also very important. Joint innervation protects against potential trauma that could damage the joint, leading to neuropathic osteoarthropathy.[21] The only clinical trial conducted so far on knee vascularized joint transplantation has shown severe joint degeneration, likely related to the lack of innervation in the transplanted knee.[22,23] Wrist capsule innervation has been extensively investigated over the past three decades.[24,25] The posterior and anterior interosseous nerves are the primary innervation of the wrist's palmar and dorsal sides, respectively.[26] Therefore, we designed our wrist cadaver model of VCA to include those nerves as primary branches that innervate the wrist joint;

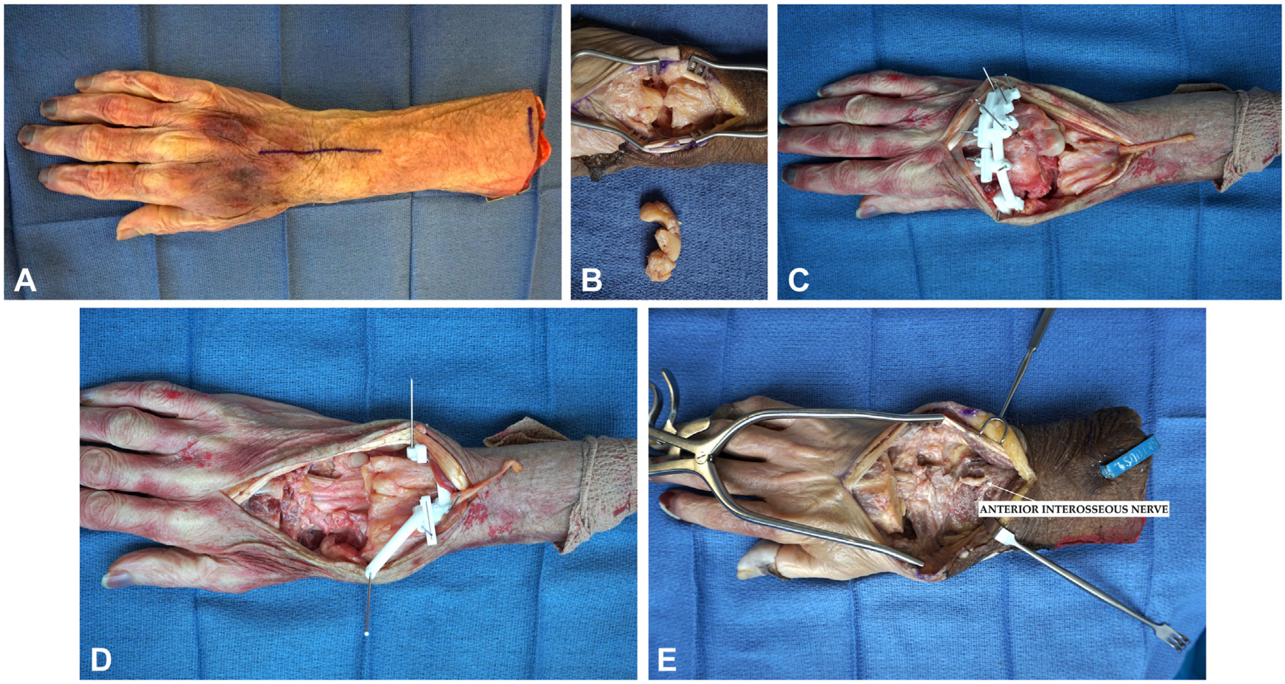

FIGURE 5: The cadaver model of wrist VCA recipient procurement: main steps. **A** Dorsal aspect of the recipient transplant, incision between third and fourth extensor compartments. **B** Dissection and proximal row carpectomy of the recipient. At the bottom of the image scaphoid bone, lunate bone, and triquetrum bone removed as per step number 8 as the "recipient technique for recipient wrist preparation" (Table 4). **C** Customized metacarpal bones cutting guides seated on the recipient to perform step number 10 of the "recipient technique for recipient wrist preparation" (Table 4), with PIN on the right side. **D** Customized radial and ulnar cutting guides seated on the recipient to perform step number 12 of the "recipient technique for recipient wrist preparation" (Table 4). **E** The recipient is ready to receive the transplant; anterior interosseous nerve is dissected to be reattached to the donor nerve from the transplant.

however, this could be a limitation because more than two articular branches innervating the wrist joint exist.[27] Even in cases of incomplete nerve regeneration, partial denervation of the wrist joint may not have a negative effect on wrist kinesthesia.[28]

We also include a radial forearm flap as a monitor (Fig. 4) to monitor rejection and assess the patency of the anastomosis, which can be a practical and effective option considering the cutaneous signs of rejection seen in human VCA.[11,22,23] The flap could also facilitate skin closure after a long surgical procedure that may prevent direct skin closure.

While designing the vascular supply of our cadaver model of wrist VCA, we studied anatomical variants to ensure adequate blood supply to the transplant (Table 1). We selected the ulnar artery, radial artery, all branches entering into the carpal joint (dorsal radiocarpal arch, volar radiocarpal arch, dorsal and volar intercarpal arch, and base metacarpal arch), deep and superficial palmar arch, and their comitans veins. We chose comitans veins because they are primarily responsible for the deep venous drainage of the joint. Because of the relatively small sample size, all potentially important anatomical variations of vessels and nerves may not have been identified.

We suggest dissecting the main arteries, such as radial artery, ulnar artery, and anterior interosseous artery, from proximal to distal to identify collateral branches before clipping, due to anastomotic variants reported among deep and superficial palmar arches.[29] Also, while dissecting the radial artery, it is important to avoid damage to the articular branches, such as the radiocarpal arch, intercarpal arch, and the superficial branch of the radial artery. When harvesting the donor, we suggest carefully dissecting the superficial branch of the radial artery into the thenar musculature. Other small branches can be identified entering the joint capsule radial to the flexor carpi radialis. Among the most complicated aspects of dissection is the separation of the palmar aponeurosis from the superficial palmar arch and dissection of the flexor tendons while preserving intact the deep palmar arch resting on the metacarpal bones. The deep palmar arch was a more consistent distance from the radiocarpal joint than the superficial palmar arch (Table 1). Most studies of the palmar arches have focused on

TABLE 3. Proposed Technique for Donor Wrist Preparation and Allograft Harvest

1. The donor hand, wrist, and mid-forearm lie on the operating table with their volar surface up.
2. A radial forearm flap of 10 × 6 cm is elevated and used as a monitor for the joint transplant.
3. The forearm is pronated, and the dorsal integument above the wrist, together with the subcutaneous tissue, sensitive nerves, and the superficial vessels, is completely removed. The dorsal extensor compartments are now exposed.
4. A step-cut incision is made over the fourth compartment, and two long retinacula flaps, radial and ulnar, are raised, exposing all the underlying extensor tendons.
5. Three cm of the ECRL and ECRB's distal insertions are kept intact, whereas all the remaining extensor tendons are excised.
6. The posterior interosseous nerve is identified, isolated for about 10 cm proximal to the wrist joint, and cut proximally.
7. On the volar surface, through a median incision from the midpalm to the distal forth of the forearm, two large skin flaps, radial and ulnar, are raised together with the superficial sensory nerves, and excised.
8. Three cm of the FCR and ECU distal insertions are kept with the transplant, whereas the PL is removed.
9. The transverse carpal ligament is incised longitudinally and removed. All flexor tendons and the median nerve are excised. The ulnar nerve is now identified and excised as well.
10. The palmar branch of the radial artery is entirely isolated from its origin throughout its course in the thenar musculature. Now, all thenar muscles can be safely removed from the carpus.
11. The radial and ulnar arteries and their venae comitantes are isolated for about 12 cm proximal to the radiocarpal joint.
12. The pronator quadratus muscle, the anterior interosseous artery, and nerve are isolated and kept with the transplant.
13. Perforating vessels from the radial and ulnar artery such as the dorsal radiocarpal arch, dorsal intercarpal arch, base metacarpal arch, and deep and superficial palmar arches must be preserved. Arteries to the metacarpal bones can be ligated or cauterized.
14. The deep and superficial palmar arches are preserved with the transplant; all collateral vessels that are not directed to the carpal bones can be ligated or cauterized.
15. All metacarpals are osteotomized from the dorsal side at their base keeping enough proximal length for at least three screws of a T-shape 2.0 mini plate. In our cadaver simulation, we used customized cutting guides.
16. Dorsally, just proximal to the DRUJ, both the radius and the ulna bones are osteotomized with an oscillating saw. In our simulation, we used customized cutting guides.
17. Now, the transplant is free, hanging only on the vascular pedicles, and the anterior and posterior interosseous nerves. The tourniquet is released, and the vascularity of the transplant assessed for 20 minutes.
18. Once good vascularity is confirmed, the vascular pedicles are clamped and cut proximally. The transplant is taken out from the dorsal approach.
19. Remove any extra soft tissue and irrigate the vascular tree with proper preserving solution as for any other transplant.

ECRL, extensor carpi radialis longus; ECRB, extensor carpi radialis brevis; FCR, flexor carpi radialis; PL, palmaris longus muscle; ECU, extensor carpi ulnaris; DRUJ, distal radial ulnar joint.

TABLE 4. Proposed Technique for Recipient Wrist Preparation

1. Dorsal approach: 10 cm median skin incision. The extensor retinaculum is exposed, and the IV compartment opened with a step-cut incision.
2. The PIN is identified and cut as close as possible to the carpal joint.
3. Through subperiosteal dissection, all extensor tendons within their compartments are lifted off the radius and ulna bones. The brachioradialis is detached from its distal insertion.
4. The distal radius, ulna, and the carpus are exposed.
5. A gentle S-shape 5 cm incision starts over the dorsal aspect of the I metacarpal to the first dorsal compartment; it turns then volarly toward the radial artery for 3 cm. The base of the I mtc is exposed.
6. Divide the distal part of ulna and radius (DRUJ) making pass underneath the PIN, artery, and vein.
7. Continue dissection in ulnar direction, open extensor digiti quinti sheath, and detach the ECU from the base of the fifth mtc for reattaching later.
8. Perform a proximal row carpectomy.
9. Expose the dorsal surface of the metacarpal bones from the second to the fifth.
10. Seat the customized cutting guides on the dorsal aspect of the mtc, from the first to the fifth and perform osteotomies being careful on keeping intact the surrounding periosteum as much as possible.
11. Remove the base of the mtc and the distal carpal row opening the transverse carpal ligament, while doing it, be careful of the content of the carpal tunnel.
12. Seat the cutting guides on the radius and ulna and perform osteotomies, removing the bones afterward. Peel-off the pronator quadratus keeping as much as possible long the AIN to be reattached with the donor stump of the nerve.
13. Place k-wire into the medullary aspect of the mtc bones longitudinally to guide osteosynthesis later.

AIN, anterior interosseous nerve; ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; EPL, extensor pollicis longus; MTC, metacarpal bones; PIN, posterior interosseous nerve.

TABLE 5. Proposed Technique for Wrist Vascularized Composite Allograft Transplantation

1. Place the donor wrist just aside the recipient site, then reverse it and start with AIN neurorrhaphy with 8.0 nylon suture.
2. Short the k-wires of the recipient to place the donor into the recipient to start osteosynthesis.
3. Advance the k-wires into the donor medullary base of the mtc bones to fix it as temporary fixation before starting with dorsal plate osteosynthesis.
4. Tunnel the RA and UA under the subcutaneous tissue to their volar anastomosis location.
5. Perform osteosynthesis of the radius and ulna with dorsal 3.5 mm nonlocking plates, respectively. The recipient forearm bones should be placed in full supination before plating.
6. Perform end-to-side micro-anastomosis of radial artery and the ulnar artery into the recipient vessels.
7. Perform neurorrhaphy of the dorsal interosseous nerve with 8.0 nylon suture.
8. Place each metacarpal in anatomical reduction between donor and recipient and start to fix with dedicate T-shape 2.0 mini plate, then remove K-wires of the temporary fixation.
9. Perform tenorrhaphy between tendons of the recipient and donor ERCB, ERCL, ECU, and FCR, then close the retinacula over the transplant and put the RFF on the dorsal side to provide soft tissue and help skin closure.
10. Final x-ray check, range of motion, and passive stability check tests.

AIN, anterior interosseous nerve; CMC, carpometacarpal joint; MTC, metacarpal bones; RA, radial artery; RFF, radial forearm flap; UA ulnar artery.

the anatomical variation of the arches.[30] In this wrist cadaver model of VCA procurement, it is critical to know the relationship in reference to bony and superficial landmarks. Although our sample size is limited, our results are consistent with others reported in the literature.[30] Another limitation of the study is that the specimens had not sustained trauma and, therefore, may not be representative of a potential donor with a history of trauma.

Many consider that the field of VCA is an experimental procedure, with very narrow surgical indications. Although that perspective is valid, VCA could evolve as a strategy with a broader scope in the future if the risks of immunological therapy are reduced or eliminated. Although hand transplantation has been performed in both adults and children with upper extremity amputations,[31] no reports of isolated vascularized wrist joint transplantation exist. We have demonstrated that this technique is feasible in cadavers. However, the present study is a preliminary investigation and still far from human application. This strategy would likely be reserved for the most extreme cases of wrist pathology and where a limited duration of immunosuppression would be required, considering animal studies that suggest it may be possible to interrupt immunosuppressive therapy once bone healing is complete.[32]

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