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The role of VFG in wrist arthrodesis: Long term results in a series of 11 patients and literature review

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ABSTRACT

Background: Total wrist fusion (TWF) is indicated for longstanding degenerative, posttraumatic and/or post-oncological conditions to provide pain relief and wrist stability at partial expense of wrist motion.
Patients and Methods: A total of 11 consecutive patients who had completed TWF with Vascularized Fibula Graft (VFG) for massive distal radius defects were identified retrospectively from our center using inpatient records. We evaluated bone fusion times and long term functional outcomes following the procedure. Post-operative grip strength (GS) and prono-supination were objectively measured. The new Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire was used to rate disability and symptoms; pre- and post- operative pain with the Visual Analog Scale (VAS) was assessed. A literature review of the present studies about TWF with VFG was performed, with the aim of comparing long-term functional results of the surgical techniques so far reported in the English literature.
Results: Our experience with TWF using VFG appeared slightly better than that found in the literature. The procedure was successful in all the cases, achieving bone union in 4,8 months on average. Complication rate was 27,2%, no flap loss was recorded. There were no wrist instability, deformation or dislocation; mean pronation/supination (P/S) was 57,5°/61,2° Average grip strength resulted 59% of the contralateral side. Mean recorded levels of visual analog scale (VAS) for pain postoperatively were 2,32 ± 0,792, which improved significantly from the pre-operatively value of 7,90 ± 0,79. Mean overall satisfaction was good and all the patients comfortably returned to normal activities.
Conclusions: Wrist arthrodesis by means of VFG resulted to be an effective and reliable option in dealing with massive defects of distal radius with involvement of radio-carpal joint. Although the cohort analyzed is relatively small and definitive conclusions cannot be drawn, the long term radiographs and the overall functional outcomes encourage to use the described surgical option over other techniques, such as prosthetic replacement and non-vascularized bone grafts.

Introduction

Wrist arthrodesis represents to date the standard of care in case of severe traumatic damage or oncological ablation of the distal radius in adults [1]. In case of extended defects affecting the radio-carpal joint, fusion is intended to provide pain relief and preserve as much function as possible in the wrist. As regards bone replacement, the surgical strategies so far reported in the literature include the use of a massive autograft from the tibia [2], ulnar translocation or centralization [3], the use of bone grafts [4], osteoarticular allograft [5] and prosthetic replacement [6]. Since its introduction in the clinical practice by Taylor in 1976 [7], the use of the fibula as vascularized flap has gained popularity over the decades, up to represent the most suitable donor site for extended bony defects reconstructions. The first case of distal radius defect reconstructed by means of a vascularized fibula graft (VFG) dates back to 1977 [8]. Six years later, the same authors reported their experience with the aforementioned after tumor ablation on 10 patients, ascertaining progressive bone graft hyperthrophy, less creeping substitution, fragile fractures and non-unions [9]. Moreover, the studies subsequently carried out, highlighted that fibular length, diameter, geometrical shape and mechanical strength appear ideal for the replacement of the forearm bone losses [10,11]. The use of VFG for total wrist arthrodesis has been rarely reported. On the ground of this, we present our experience with a self-developed wrist fusion technique with VFG practiced in 11 distal radius defects including the radiocarpal joint. The very long-term follow-up allowed us to better assess the functional outcomes of the procedure in terms of functional recovery, complications and

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Table 1
Demographic characteristics of the patients.

Patient	Age at surgery	Sex	Dominant Limb	Etiology	Surgical procedure	Bone Gap
1	51	F	Yes	GCT	TWF-VFG	8 cm
2	56	F	No	GCT	TWF-VFG	9 cm
3	23	F	Yes	EF	TWF-VFG	10 cm
4	44	M	Yes	GF	PWF OC-VFG	13 cm
5	36	M	Yes	EF	TWF OC-VFG	15 cm
6	49	M	No	GCT	TWF VFG	9 cm
7	32	M	Yes	GCT	TWF VFG	9 cm
8	36	M	No	GCT	PFW VFG	10 cm
9	27	M	Yes	GCT	TWF VFG	8 cm
10	26	M	Yes	GCT	TWF VFG	8 cm
11	28	M	Yes	GCT	TWF VFG	8 cm

Giant Cell Tumor (GCT); Exposed Fracture (EF); Gunshot Fracture (GF); Total Wrist Fusion (TWF); Vascularized Fibula Graft (VFG); Partial Wrist Fusion (PWF); Osteo-Cutaneous Vascularized Fibula Graft (OC-VFG).

Table 2
Details on secondary cases.

Patient	Defect cause	Previous surgeries	Reason for failure
2	GCT	Reconstruction with custom made Meuli prosthesis (implanted in 1982)	Aseptic loosening
7	GCT	Allograft	Graft fracture
11	GCT	Allograft	Pseudarthrosis and graft subluxation

re-intervention rate. A literature review was carried out, with the aim of comparing the results we achieved with those of the surgical techniques so far reported in the English literature.

Patients and methods

All patients provided written informed consent for the procedure, including that for taking photographs/videos for scientific purposes.

By searching the appropriate billing codes and text-based surgical database, we identified 11 patients with distal radius defects treated between 2003 and 2018. Indications for wrist fusion with VFG included 3 post-traumatic bone losses and 8 post-oncological defects after Giant Cell Tumor (GCT) Campanacci grade III resection of the distal radius ($n = 8$ patients). Three cases were secondary procedures after prosthetic replacement ($n = 1$) and osteoarticular allograft ($n = 2$). In one case, a single bone forearm was created by distal ulna translation onto the radius due to oncological issues. In all the cases bone fixation was obtained with a single bridging plate. All the reconstructive procedures were performed by the senior author, in a double-team setting. Mean age at surgery was 37 years (range 23–56 yr.). Female:Male (F:M) ratio was 0,22 (3F:8 M). The dominant limb was involved in 8 cases. Mean bone gap was 9,7 cm (range 8–15 cm). Fibula donor site was contralateral in 10 cases (Tables 1 and 2).

Objective evaluations: strength was measured with a hydraulic hand dynamometer (Sh 5001, Saehan Corporation, South Korea); prono-supination was assessed by means of a goniometer; bone fusion times assessed via post-operative radiographs collected every two months for a year.

Subjective evalauations: patients' daily activities and general postoperative quality of life were estimated with the new DASH-questionnaire; pain with the visual analog SCALE (VAS) scale; to rate patients' satisfaction a 4-points grading scale (1 = unsatisfied, 2 = slightly satisfied, 3 = satisfied, 4 = very satisfied) was used.

DASH score was calculated with the following formula:

$$\text{Dash disabilty/sympton score} = \frac{[(\text{sum of n response}) - 1] \times 25}{\text{n}}$$

where n is equal to the number of n completed responses.

The patiens were followed up at 1–2 weeks, 1–3–6 and 12 months and/or until complete bone healing. The follow-up was on average 93,5 months (range 66–181 months). The self-developed operative techniques used for 9 total and 2 partial wrist fusions in this case series are described below.

Operative technique

Preparation of the recipient site

The management of the recipient site is as important as the reconstructive procedure itself and it should take into account some general principles which may be resumed as follows: eradication of infection, debridement of scarred soft tissue and resection of necrotic bone. In case of severely contaminated bone it may be advisable to implant an antibiotic spacer after aggressive resection of distal radius including the epiphysis and delay the reconstruction by at least 2 months. In every case the proximal resection of the radius must be radical and reach healthy and well vascularized bone: this is a prerequisite of paramount importance in order to obtain early bone fusion after the implant of the graft. The anterior (Henry) approach to the radius shaft was always used. It is suggested to perform a step cut osteotomy of the proximal bony stump in order to increase the contact with the transferred fibula and improve stability. Before releasing the tourniquet, the recipient vessels are selected for microvascular anastomosis. The cephalic vein is usually preferred due to similarities in size with the peroneal veins. When possible, the common interosseous artery is used for arterial anastomosis to preserve the major vessels.

Harvest of the fibula

The patient is placed in supine position with hip and knee flexed at 45° The fibula is exposed according to the classical lateral approach in the plane between peroneus brevis and gastrocnemius muscles. After section of the interosseous membrane, proximal and distal osteotomies are performed at desired location according to the length of the defect. We extend the harvest of periosteum beyond the osteotomy site in order to obtain a periosteal flap which should overlap the bone junction at the recipient site (Fig. 1). When needed, an osteocutaneous flap may be harvested including a skin paddle supplied by cutaneous perforators available in the distal half of the leg (Fig. 2). The skin flap may be measuring up to 10 × 20 cm^9 which is very useful and reliable in case of soft tissue defect. Small islands may be used with the aim to monitor the vascularity of the buried bone.

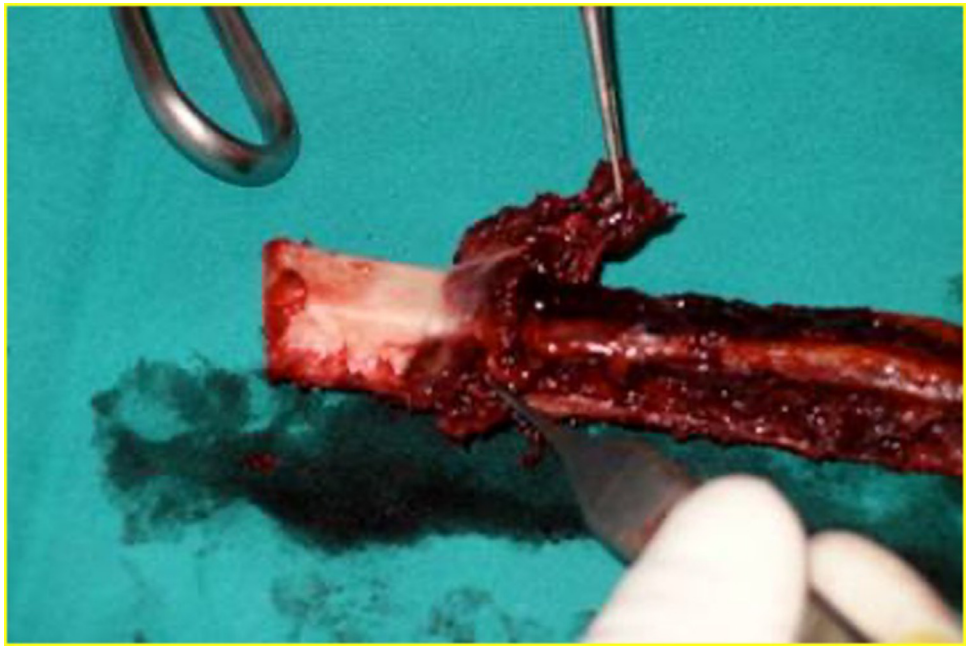


Fig. 1. A redundant periosteal flap is harvested.

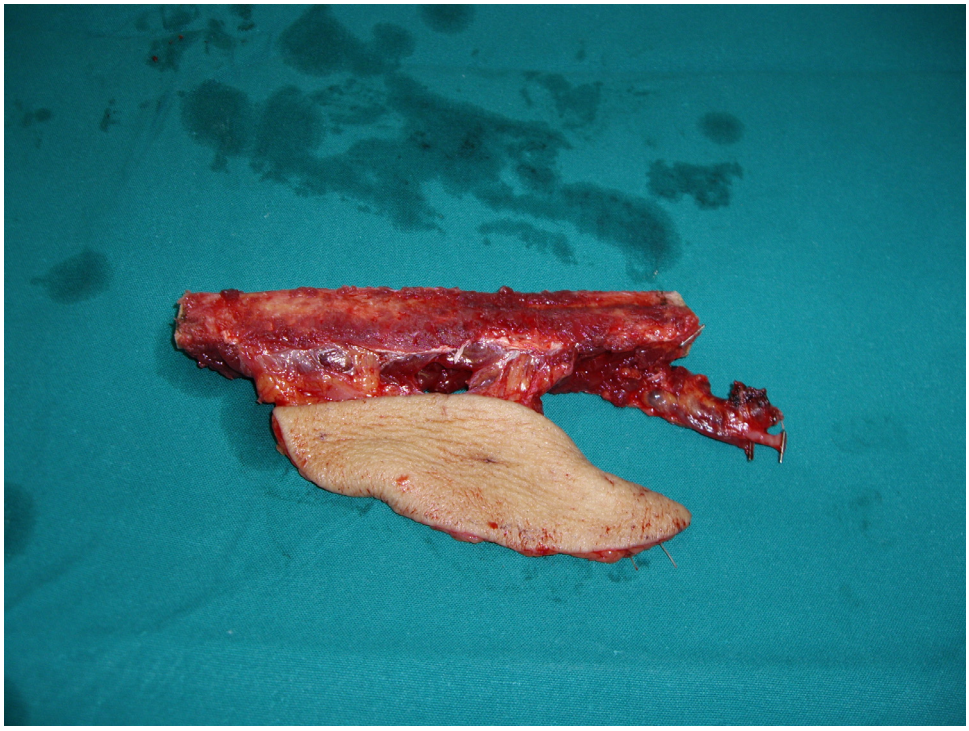


Fig. 2. The osteocutaneous fibula flap.

Total wrist fusion: personal technique

With the double purpose to maximize the stability of the assemblage and to minimize the dorsal bulging of the plate, the following refinements have been routinely adopted in the present cases series:

(1) A longitudinal groove (Fig. 3) is dug with high speed bur in the carpal bones along the axis of 3rd metacarpal bone in order to host the fibula which should reach the basis of the 3rd metacarpal bone to optimize the contact. The direction of the groove may be adapted to the desired angle of ulnar deviation. The furrow must be large and deep enough to contain the fibula which must be placed at the same level of the metacarpal bones (Fig. 4a,b), minimizing the bulking and optimizing the bone contact.
(2) We used of a Limited Bone Contact Dynamic compression plate (LC-DCP) with variable thickness and screws dimension. Namely, a plate thicker in the forearm with screws 3.5 and thinner at the capometacarpal level with screws 2.7 (Fig. 5).
(3) With a single bridging plate, the fibula is:
   (i) fixed to the residual radius with a step cut osteotomy (Fig. 6).
   (ii) secured to the volar cortex of lunate and capitate previously dug.

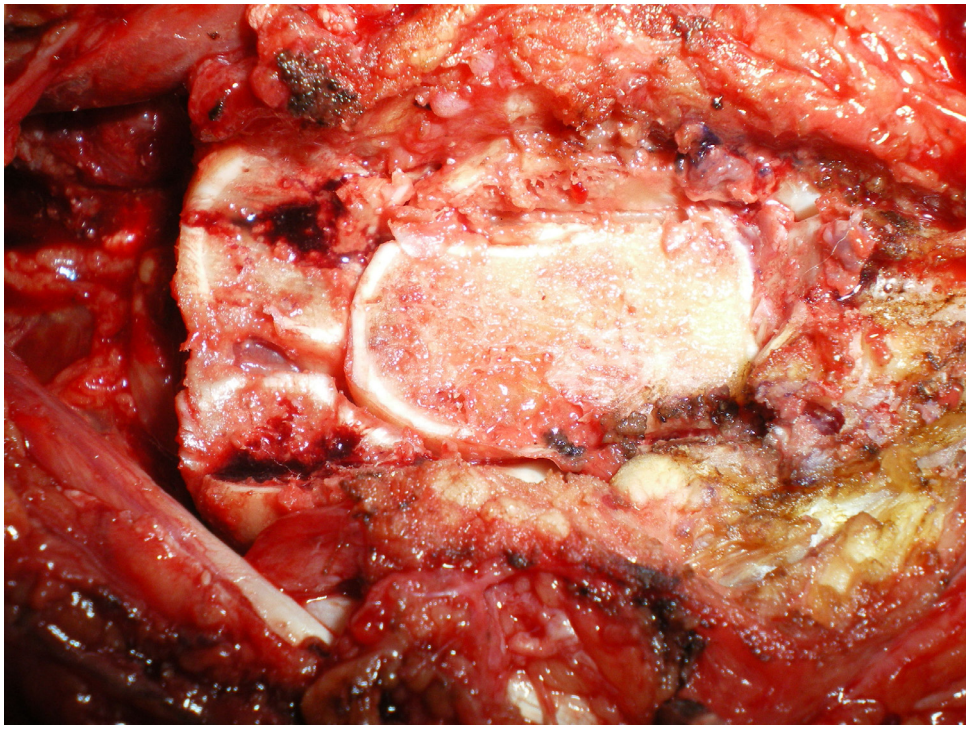


Fig. 3. A longitudinal groove is dug with high speed bur in the carpal bones along the axis of 3rd metacarpal bone in order to host the fibula.

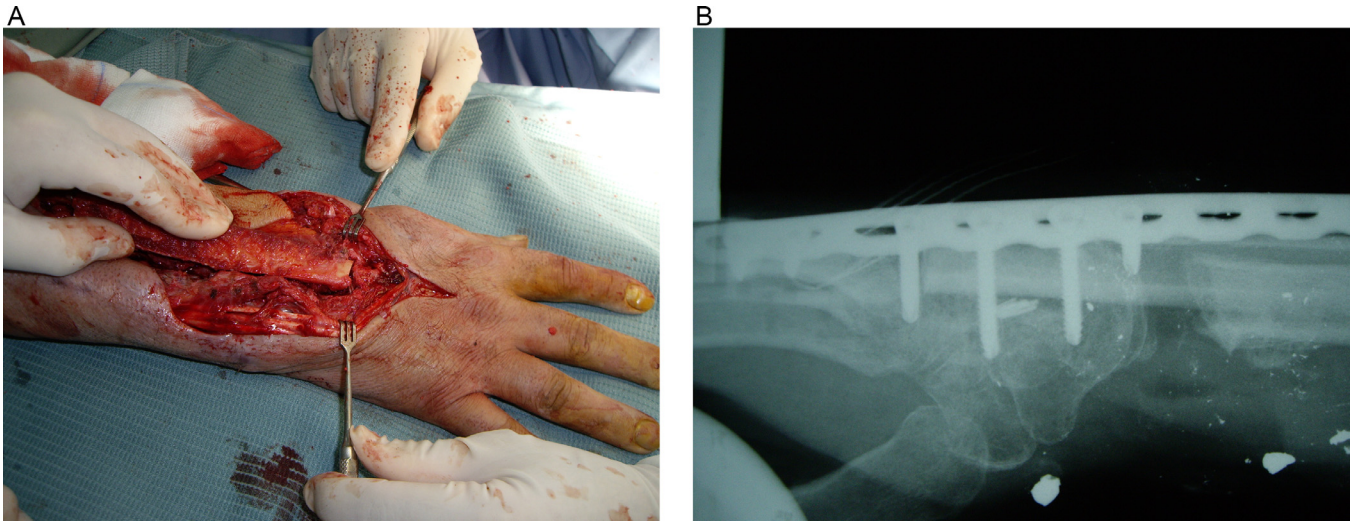


Fig. 4. VFG is correctly aligned with the III metacarpal. (a) intra-operative view (b) related radiological finding.

(iii) fixed to the 3rd metacarpal bone, ensuring making sure of correct alignment.

Limited wrist fusion: personal technique

In case of preservation of the carpal bones, a limited arthrodesis is preferred in order to maintain some motion at the midcarpal joint. Since the scaphoid bridges the two carpal rows, an osteotomy of the scaphoid is mandatory to maintain motion when a Radio-Schapo-Lunate (RSL) arthrodesis is performed. A single fibula is difficult to fix properly to the residual proximal pole of the scaphoid and the lunate because of the limited bone contact. In order to implement the bone stock and maximize stability, we perform a Sauve Kapandji (SK) procedure between the caput ulnae and the distal tip of the fibula (Fig. 7). This provides a larger bone contact with lunate and scaphoid and simultaneously prevents possible mismatching in length of the ulna and guarantees a good pronation and supination. Once removed the articular cartilage of lunate and scaphoid, a four bones arthrodesis (fibula, caput ulnae, scaphoid and lunate) can be safely performed using a distal radius plate.

Literature review

A search strategy was developed to look for published studies involving Total Wrist Fusion (TWF) with Vascularized Fibula Graft (VFG) after trauma or tumor ablation in the distal radius in two electronic databases: PubMed and Google Scholar. These electronic databases were considered from the earliest date available to the 30th of July 2021. A first advanced search was carried out using the following couple of 'quest phrases' "*total wrist fusion*" AND

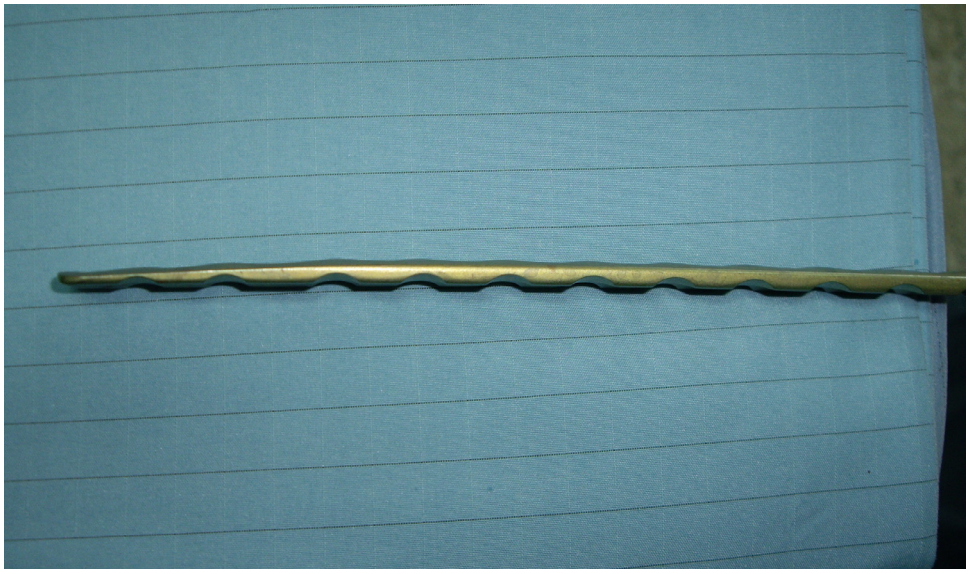


Fig. 5. Limited Bone Contact Dynamic compression plate (LC-DCP) thicker in the forearm with screws 3.5 and thinner at the capometacarpal level with screws 2.7 is used.

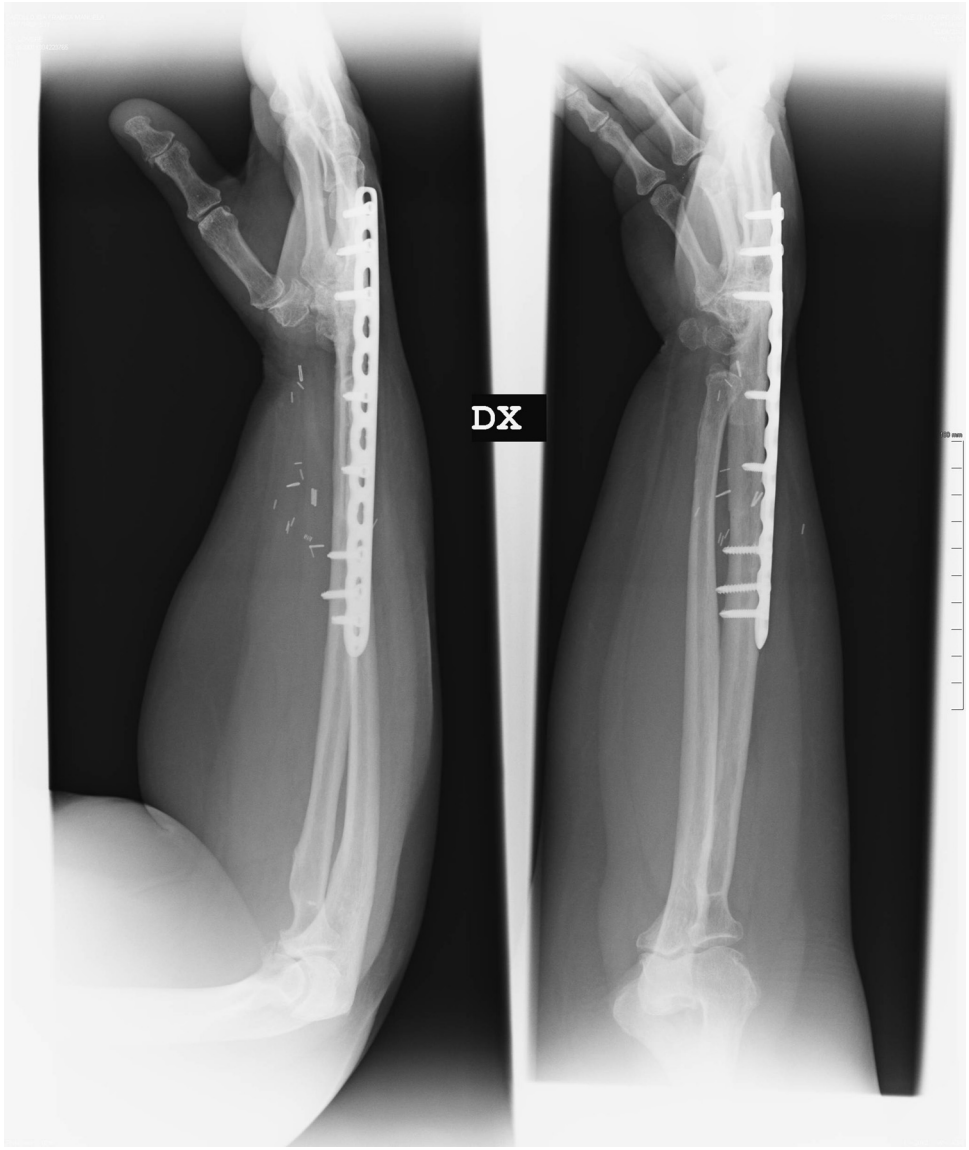


Fig. 6. A step cut osteotomy of the proximal bony stump is performed in order to increase the contact with the vascularized graft and improve stability.

Fig. 7. Radiographic image of the Radio-Scapho-Lunate (RSL) self-developed arthrodesis technique; a Sauve Kapandji procedure is performed between the caput ulnae and the distal tip of the fibula in order to increase the proximal bone stock.

"*vascularized fibula*". A second search was made utilizing "*distal radius reconstruction*" AND "*fibula*". The third advanced search involved the use of "wrist arthodesis" OR "fusion" AND "fibula" AND "radius".

Inclusion criteria: studies describing total wrist fusion by means of vascularized fibula, with the full text available and written in English. If two or more articles from the same author or group of authors presented overlapping data, the article with the greatest amount of data was included in the literature review. Only the articles with available data regarding the functional outcomes (pronation/supination/grip strenght) analyzed in this paper were included.

Exclusion criteria: experimental studies, reviews, commentaries, letters to the editor, non-indexed articles and duplicates. We excluded all the articles discussing other surgical strategies (i.e. wrist arthroplasty, prostethic replacement, usage of non-vascularized grafts, usage of vascularized non-fibular grafts and others).

Manual searching of the reference lists of included studies and citation tracking were conducted to ensure that all relevant studies were found. The initial search resulted in 222 publications, of which 166 ones were screened and excluded by titles and abstracts. Two independent authors analyzed the full text of the articles obtained with the initial search to discriminate the studies that met the inclusion criteria.

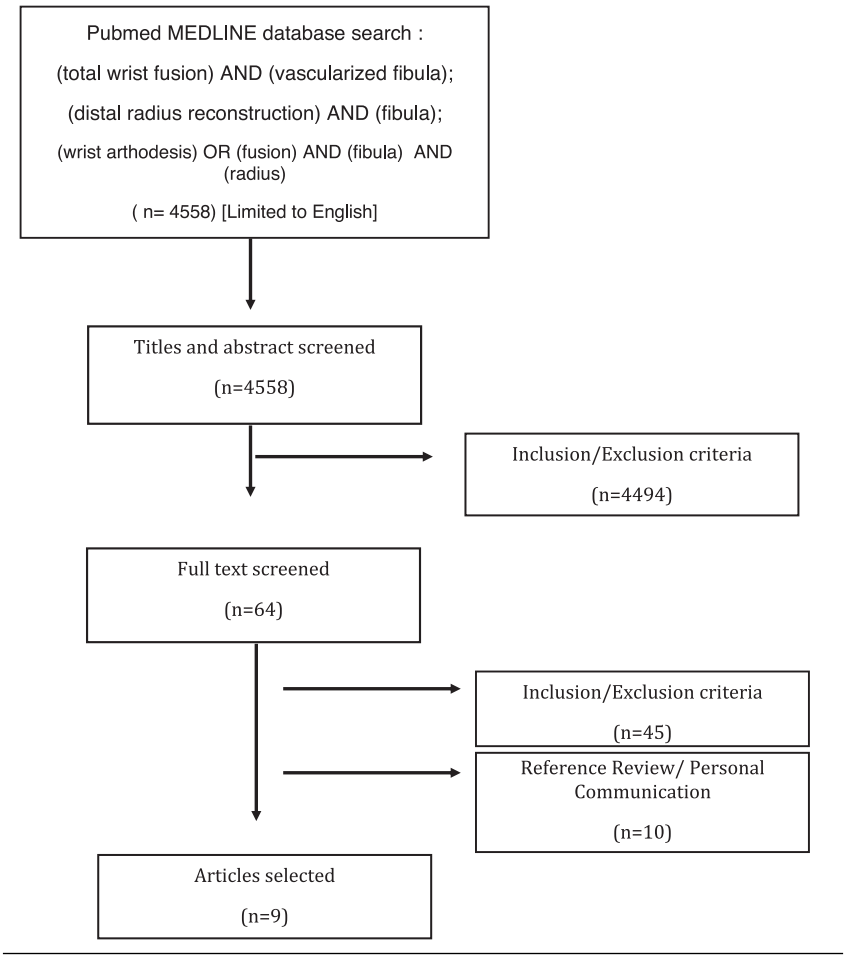
Subsequent exclusion criteria were as follows: papers with incomplete data, full-text not written in English and/or not available, papers discussing total wrist fusion with VFG utilized for multiple donor areas in which it was not possible to extrapolate the specific data related to wrist outcomes.

The selected 9 articles were examined and collected data were recorded in a spreadsheet for statistical analysis (Table 3). In order to compare the outcomes of our applied technique with those reported in the literature we applied the Mann-Whitney-U- test. Difference between the two groups were considered statistically significant with p value. $P \leq .0.05$. It is noteworthy to mention that in some works individual values for each patients were not available; in such cases reported values were used for comparison.

Case series results

The results of our case series are shown in Table 6. Fibula fusion was seen in all the patients, after a mean time of 4,7 months (range 3–7 months). Excluding the single patient with one bone forearm, mean pronation was 57,5° (range 90°–10°), supina-

Table 3
Study selection flowchart.



tion 61° (range 90°−0°). Average grip strength (GS) resulted 59% (range 20–100%) of the contralateral side. In particular, for oncological patients (8) mean prono-supination (P/S) was 84°−62° (range 90°/70°−90°/0°) and GS was 67% (range 20–100%). For post-traumatic patients (3) mean prono-supination was 60°−65° (range 35°/85°–70°/80°) and GS 12% (range 7–17%). Complications rate was 27,2% and specifically corresponding to: (i) 1 case of ulnar impingement with painful prono-supination, then treated with caput ulnae resection (Darrach procedure); (ii) 2 wounds dehiscence, with one of them resulting in exposure and partial necrosis of the previous fibula flap (thus requiring a second osteo-cutaneous fibula free flap); (iii) 1 stress fracture at the fibula-radius interface after plate removal for extensors tenosynovitis with the need of a new bone fixation. The donor sites had no major complications. DASH score was 12,8% (range 6–33%) for oncological cases (8) and 32,3% (range 7–77%) for non-oncological ones (3). None of the interviewed patients reported instability of the donor leg from which the fibula was harvested, nor pain or paresthesia. No one complained of pain in the reconstructed upper limb, neither at rest nor during activity. Mean recorded levels of VAS for pain post-operatively were 2.32 ± 0.792, which improved significantly from the pre-operation value of 7.90 ± 0.79. The overall satisfaction was good (mean 3,27 points) and everyone returned to their usual employment (Table 4) (Fig. 8a,b) .

Literature review results

This study was designed to evaluate bone union times after TWF with VFG and achieved long-term functional outcomes in terms of forearm arc of rotation and GS. The presented literature search identified 9 papers [10–18] which met the inclusion criteria. According to this review, after ablative procedures at the distal radius, mean bone gap was 11,5 cm (range 7,2–18 cm). In most of the cases fibula graft fixation was examined utilizing compression plates and screws. Additional cancellous bone grafting at the junction sites is reported as well [11]. The reported bone union time was 5,2 months (range 3–8,6 months). It required a mean immobilization time of 8,7 weeks (a period of 6 weeks is the most reported [13–17]), over a follow up of 36,7 months (range 11,6–75,6 months) in average. Overall complication rate was 13, 5%, with a 18, 9% of cases for which an additional surgery was needed. More specifically, proximal non-union is the most reported complication following this procedure, with an incidence of 8,1%. It was treated either with a secondary iliac crest bone graft [10] or by means of a new bone fixation [18]. Only one case of skin flap loss is reported [11], managed with removal of the cutaneous paddle. Functional outcomes resulted as follows: pronation (P) was 51.2° (range 10–80°), supination (S) was 36,2° (range 10–65°) and GS was 50.8% (range 42–60%) of the contra-lateral side (Tables 5 and 6).

Discussion

Different pathological disorders may need Total Wrist Fusion (TWF) by means of Vascularized Fibula Graft (VFG) [19,20]. The most frequent oncological condition which leads to distal radius resection is the Giant Cell Tumour (GCT) but also ablation of sarcomas and severe traumas may require this major surgery [21,22]. There is a plethora of techniques which have the potential for

Table 4
Case series results.

Patient	FU (months)	BFT (months)	Immobilization time (months)	Rehabilitation	P/S	Grip Strenght (%)	DASH score (%)	Complications	*Re*-intervention
1	78	5	3	3	10°/50°	21/48	6	Donor site WD	None
2	66	6	6	2	70°/90°	6/20	8	None	None
3	106	4	6	12	35°/70°	7/41	7	Ulnar impingement	Caput ulnae resection
4	92	3	6	12	85°/60°	17/48	77	None	Donor site STSG - EIP pro EPL
5	98	5	5	12	n.a.	n.a.	13	Recipient site WD with plate exposure	2 local flaps failure - OC-VFG - Donor site STSG
6	66	4	2	9	90°/80°	40/100	7	None	None
7	88	6	2	5	n.a.	n.a.	33	None	None
8	78	4	1	2	90°/90°	28/50	6	None	None
9	92	4	2	2	0°/0°	28/50	17	none	none
10	181	7	3	4	80°/50°	34/65	9	Traumatic fracture	Plate removal - new IBF
11	68	4	2	10	n.a.	n.a.	11	None	None

Follow-Up (FU) ; Bone Fusion Time (BFT); Prono/Supination (P/S); Wound Dehiscence (WD); Internal Bone Fixation (IBF); Split-thickness Skin Graft (STSG); Extensor Indicis Propius (EIP); Extensor Pollicis Longus (EPL); Osteo-Cutaneous Vascularized Fibula Graft (OC-VFG); Internal Bone Fixation (IBF).

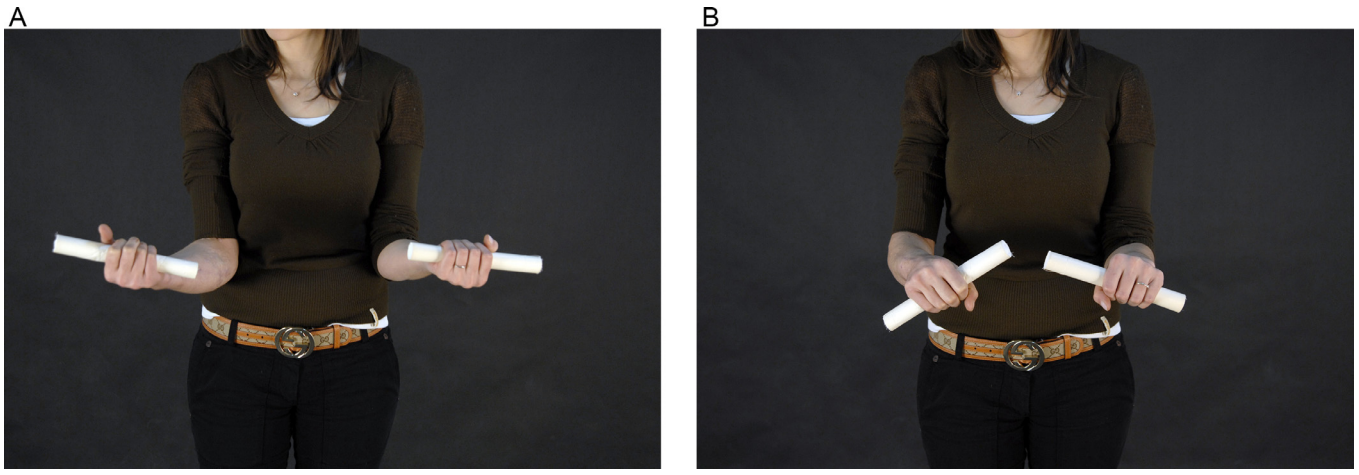


Fig. 8. a,b Functional outcomes after total wrist fusion with vascularized fibula graft according to the described technique : supination was fully recovered (a), pronation was 80° (b).

success including prosthesis, allografts and autografts, both non-vascularized and vascularized [23]. Surprisingly, few case series studies are available in the English literature regarding TWF by means of VFG. Most of them are single case reports and, in addition, very few refer on technical details over a long-term follow-up. Our belief is that a good result after TWF should provide function, i.e. a stable and painless wrist and cosmesis, i.e. a flat and uniform dorsum of the hand. Accordingly, the type of osteosynthesis and the way to use the residual bones after the ablation are relevant variables in order to achieve a stable bone fixation. The self-developed described technique, due to the longitudinal groove dug in the carpus, where the fibula must fit, has the double advantage of offering three surfaces of contact to the fibula and at the same time allows for placing the fibula deep in the carpus, thus reducing bulging on the surface of the dorsum (Fig. 4a). The technique can be applied also in case of osteocutaneous fibula. As far as the proximal bony junction is concerned, the reviewed studies refer to the usage of plates and screws but none mention the type of the osteotomy is required. In all our cases, a step cut osteotomy was used, which guaranteed a very stable contact which is a crucial prerequisite for fast healing [24]. The latter, in our case series, was measured as Bone Fusion Time (BTF), and achieved on average in 4,7 months (range 3–7 months), a shorter time in comparison with the literature reported cases (5,2 months mean value; range 3–8,6 months) (Fig. 9). Our study, though, claims the longest follow-up of 93,5 months on average (range 66–181 months) compared with that of 36,7 months (range 11.6–75.6 months) found in the literature examined (Table 5) (Fig. 9). Consequently, the functional results we achieved may be considered reliable and durable. All the patients retained a good function of the salvaged limb; on average pronation, supination and Grip Strenght (GS) values were higher than those reported in the literature (Fig. 9). In our case series mean pronation/supination (P/S) was 57,5°/61,2°, while by the literature review mean P/S resulted 36,2°/51,2° On average GS was 59% of the contralateral side, against 51,2°(range 10–80°) by the literature review. Complications rate was 27,2%, slightly higher than what reported from other studies in this review. However, the need of re-intervention was almost equal (18,5% in our series, 18,9% from the cases analyzed in this review). Interesting is to highlight that the functional results we achieved in the oncological group of patients were more satisfactory than those obtained in post-traumatic patients. This is probably due to the fact that in case of post-traumatic extensive limb losses, both general and local conditions of the patients may be compromised and often require a more complex planning and multistage approach. Regarding partial wrist fusion, when the entire carpus is spared and the patient has high functional expectations, limited wrist arthrodesis may be a better option. Radio-Schapo-Lunate fusion is a well-known and established procedure with the aim to maintain some motions thanks to the midcarpal joint. The reported results are however not satisfactory from the Range Of Motion (ROM) point of view, unless an osteotomy of the scaphoid is carried out in order

Table 5
Characteristics of the selected studies.

Study (Author/Year)	Study Design	Nr. Patients eligible	Mean Bone Gap	Bone Fixation	Immobilization time	Complications	Average follow-up (months)	Average Bone Fusion Time (months)	Average P/S and GS	*Re*-intervention
CY Choo, 2018 [10]	CS	5	11.6cm	Na	Na	1 pathological fracture 2 radio-fibular non-union	75,6	4,3	GS : 60% P/S : NR	1 Bone fixation 2 Iliac crest graft
PW Clarkson, 2013 [11]	CS	1	7.2 ± 2.1 cm	- **distally** 1 or 2 plates fixation extended to the III Metacarpal bone - cancellous bone graft at the junction	6 weeks	skin flap loss	NR	6.9	GS : NR P/S : NR	**Early:** skin flap removal **Delayed:** 2 extensor tendon releases to improve motion, 1 hardware removal
K Kawamura, 2009 [12]	CS	6	11.5 cm (7–14 cm)	fibula interposed between the capitate/III metacarpus and the shaft of the radius and fixed using plates and screws	- Long arm cast for 4 weeks; - Short arm splint were applied up to bone union.	None	64	4	P/S: 123° GS: 59%	None
K Muramatsu, 2005 [13]	CS	1	16 cm	- **proximally** fixed to the ulna with a reconstruction plate - **distally** stump fixed to the proximal carpal row and the third metacarpal bone - wrist joint reconstruction plate.	6 weeks	None	16	3	P/S : −10°/10° GS ; 42%	None
KR Chin, 1999 [14]	CR	1	NR	- Fibula graft positioned in a trough at the base of the III metacarpal and the end of the radius. - 2 6-hole compression plate fixation	NR	None	41	NR	Gs P: 80° S: 65°	None
H Ono, 1997 [15]	CS	5	13 cm (12–14 cm)	**Proximally** 2–3 screws **Distally** compression plate between fibula and II-III metacarpus	NR	None	11,6	Proximal: 4 Distal: 4.2 @@Mean : 4,1	P/S :115 ° GS: 42,4%	None
T Okada, 1981 [16]	CR	1	10 cm	- **Proximally** compression plate - **Distally** k-Wires to fix the graft doweled into the navicular and lunate bones	- 4 weeks long arm cast - 2 weeks short metal arm splint.	None	12	NR	P/S : 55°/45° GS : NR	None
RW Pho, 1979 [17]	CR	1	NR	- **Proximally** Five-hole plate and four screws - **Distally** wrist transfixed with a K wire schapoid-fibula	6 weeks	NR	NR	6	P/S : 60°/25°	None
AJ Weiland, 1979 [18]	CS	3	9,5 cm (6,5–12 cm)	NR	NR	Proximal non-union	NR	8,6	NR	Bone fixation

Case Series (CS); Case Report (CR); Pronation/Supination (P/S); Grip Strenght (GS); Not Reported (NR).

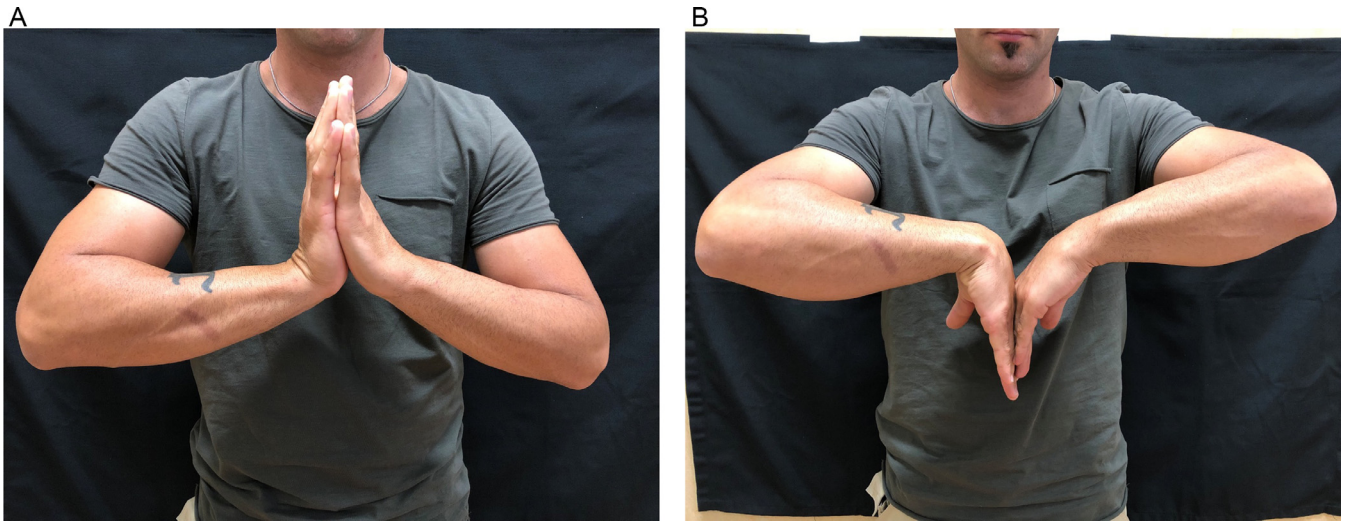


Fig. 9. Results comparison between our cases series (our) and the studies reported in the review (review). Boxes contains all the available data. Thick black line represent median values. P values obtained from Mann-Whitney-*U* test is reported as insets for each panel.

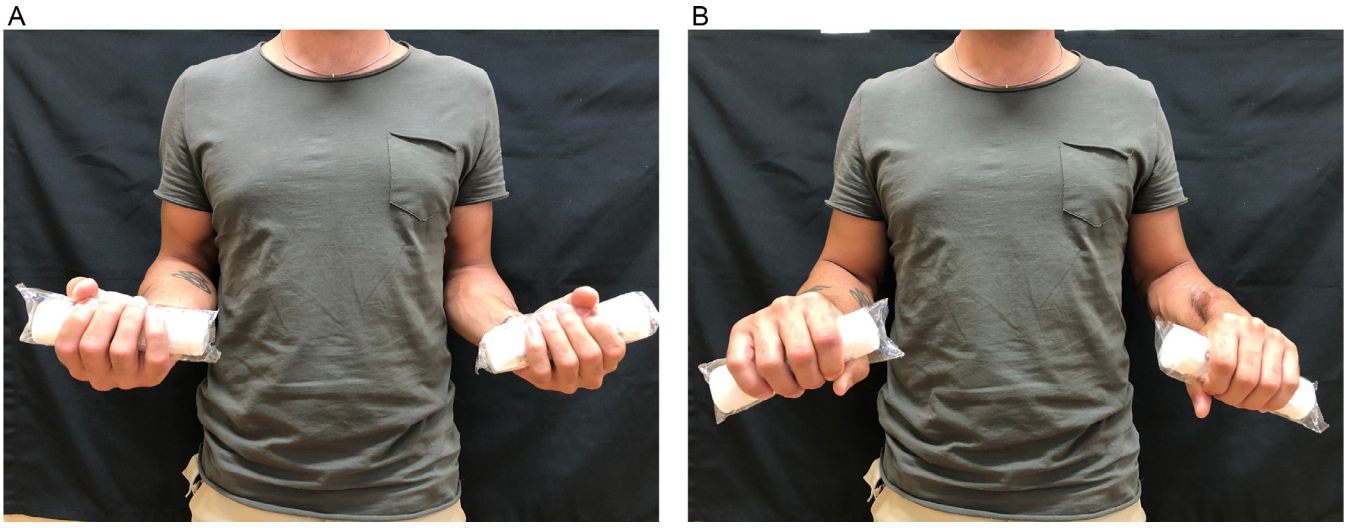


Fig. 10. a,b Functional outcomes after partial wrist fusion with vascularized fibula graft according to the described technique : wrist extension was 70° (a), flexion was 50° (b).

Table 6
Summary of complications according to the literature review.

Complication	Number of patients (tot. 24)
Flap Loss	1
Nonunion	3
Fracture of graft	1
Infection	0
Wound dehiscence	0
Hypertrophic scar	0
Fibular hardware failure	0
Peroneal n. palsy	0
Median n. palsy	0
Wrist subluxation	0
Wrist arthritis	0
	0

to free the mid-carpal joint [25]. After that, the range of motion in flexion and extension is supposed to be equal to 50% of a normal wrist, as found in our group of patients ($n = 2$) (Fig. 10a,b). In case of conventional arthrodesis with vascularized fibula, the stability of the bone fixation may be an issue because of the small surface of contact between the distal tip of the fibula and the carpal bones [26]. Therefore, in order to increase the bony stock involved, we suggest to add the caput ulnae according to the Sauve-Kapandji procedure [27], thus increasing the proximal bony contact and facilitating the use of a distal radius plate. The resulting assemblage is quite stable and allows for early rehabilitation which is crucial for a good functional outcome. Although it has been stated that the maximal grasp strength can be expected at 35° of dorsiflexion [28], this is not the only variable to be taken into account. Actually a fixed position of the wrist at 35° would interfere with many activities and for that reason most of the textbooks suggest to fix the wrist at 10–15° of dorsiflexion and slightly ulnarly deviated [29]. With the described technique it is possible to have full control on ulnar deviation but not on dorsiflexion, which will be limited to few degrees. In our experience, however, this has not been addressed by the patients as a limit for routine movements.

Lastly, studies have been carried out comparing wrist functional outcomes after non-vascularized and vascularized bony grafts for the reconstruction of distal radius defects [30,31]. As already stated by other authors [32], the vascularized fibula guarantees an early bone consolidation of the osteotomies and retain the ability to increase the mechanical resistance over time through a progressive

hypertrophy of the fibula itself. It can be transferred as a free composite flap to allow for soft-tissue coverage, it can be osteotomized in a double-barrel configuration [33], and can be combined with allograft in extended defects to provide vascularity and structural support at the same time [34]. Limitations of this study are as follows :

- Relatively small cohort (still consistent for the rarity of this reconstructive challenge).
- Many articles in the literature lacked functional data; this prevented us from their inclusion in our study and limited the consequent evaluations.

The association between vascularized fibula transplant and wrist fusion with the described techniques made it possible to achieve very satisfactory long-term functional results, comparable with those reported in the literature. More specifically, the patients rated their satisfaction very good in terms of acquired movement of hand and forearm, optimal mechanical resistance, absence of pain and relative fast recovery times.

Conclusion

In our experience wrist fusion with vascularized fibula resulted to be reliable and effective for wrist stability and pain relief. It appeared to be saddled with minimal, if any, recipient site morbidity and low complication rate, evaluated over a very long-term follow-up. The suggested technical refinements allowed to overcome some weak points of the standard procedure, such as dorsal bulging and stability of the osteosynthesis, providing encouraging results from both functional and esthetic standpoint.

Declaration of Competing Interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2021.11.004.

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