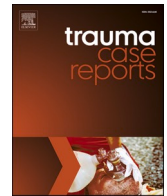




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# Trauma Case Reports

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## Case Report

# A case report of upper limb loss of substance: Use of functional gracilis free flap, brachioradialis transposition and bioglass for bone regeneration

Pasquale Gravina<sup>a,1</sup>, Francesco De Francesco<sup>b,\*</sup>, Pier Paolo Pangrazi<sup>b,1</sup>,  
 Andrea Marchesini<sup>b</sup>, Alexander D. Neuendorf<sup>b</sup>, Andrea Campodonico<sup>b</sup>,  
 Antonio Gigante<sup>a</sup>, Michele Riccio<sup>b</sup>

<sup>a</sup> *Clinical Orthopaedics, Department of Clinical and Molecular Science, polytechnic University of Marche, Ancona, Italy*

<sup>b</sup> *Department of Reconstructive and Hand Surgery, AOU "Ospedali Riuniti", 60126 Ancona, Italy*

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## ABSTRACT

Complex trauma of the upper limb is a common consequence of involvement in serious accidents. Loss of substance including nerve, bone, tendons and vascular defects are challenging surgical issues. A 27-year-old male presented with complex upper limb trauma and loss of a proximal third of the posterior forearm structure as well as loss of active finger extension, ulnar and radial nerve territory anesthesia and ulnar fracture. A composite nerve-tendon-muscle-skin gracilis free flap was retrieved from the contralateral leg, related to tendon transfer of BR to ELP, to supply active hand extension. The patient was required to adhere to intensive post-surgical rehabilitation and monitored for a 3-year follow-up period. Our assessment revealed adequate skin trophism and sufficient muscle strength recovery against resistance (M5). The functional flap associated with tendon transfer was considered an efficient procedure for the management of a complex trauma with loss of posterior interosseous nerve and bone exposition. The free re-innervated gracilis flap may be used to repair complex soft tissue defects with exposed bone and to restore finger extension following severe forearm injuries.

## Introduction

Upper limb injuries are common occurrences of complex trauma following road, industrial or ballistic accidents. A complex injury affects the bone and the associated soft tissues such as nerves, vessels, tendons and skin. Reconstruction of these defects is a challenging enterprise in regenerative and hand surgery owing to the peculiar anatomy and biomechanics of this region. In reconstruction, the availability of local and regional flaps, able to repair the relevant structures is scarce with the gracilis free flap remaining the sole

\* Corresponding author at: Department of Reconstructive Surgery and Hand Surgery, University Hospital (AOU Ospedali Riuniti di Ancona), via Conca 71, 60123 Ancona, Italy.

*E-mail addresses:* [pasquale.gravina@ospedaliriuniti.marche.it](mailto:pasquale.gravina@ospedaliriuniti.marche.it) (P. Gravina), [francesco.defrancesco@ospedaliriuniti.marche.it](mailto:francesco.defrancesco@ospedaliriuniti.marche.it) (F. De Francesco), [pierpaolo.pangrazi@ospedaliriuniti.marche.it](mailto:pierpaolo.pangrazi@ospedaliriuniti.marche.it) (P.P. Pangrazi), [andrea.marchesini@ospedaliriuniti.marche.it](mailto:andrea.marchesini@ospedaliriuniti.marche.it) (A. Marchesini), [alexanderdietrich.neuendorf@ospedaliriuniti.marche.it](mailto:alexanderdietrich.neuendorf@ospedaliriuniti.marche.it) (A.D. Neuendorf), [andrea.campodonico@ospedaliriuniti.marche.it](mailto:andrea.campodonico@ospedaliriuniti.marche.it) (A. Campodonico), [gigante@univpm.it](mailto:gigante@univpm.it) (A. Gigante), [michele.riccio@ospedaliriuniti.marche.it](mailto:michele.riccio@ospedaliriuniti.marche.it) (M. Riccio).

<sup>1</sup> Equally first authors.

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option for this kind of trauma. The extensor mechanism of the hand is sub-served by the radial nerve and the posterior interosseous nerve (PIN), the terminal branch of the radial nerve. In the case of injury distal to the PIN, wrist extension may be spared, due to the presence of lateral extensor muscles, the brachioradialis (BR), the extensor carpi radialis longus and brevis (ECRL and ECRB) in addition to the extensor carpi ulnaris (ECU). Extension of the long fingers and thumb is invalidated as the innervation of the relative muscles (extensor common digits and extensor pollicis longus) is pertaining to the PIN. Extension of the hand and wrist is fundamental to enable prehension which is described as “all the functions that are put into play when an object is grasped by the hands—intent, permanent sensory control, and a mechanism of grip.” [1]. The prehension phase involves approach, grip and release of grip [2]. If the patient is not able to stabilize the wrist, the grip strength is consequently attenuated from 25% to 50% [3]. To release the grasp, thumb and finger extensions are required with the engagement of the extensor digitorum communis (EDC) and the extensor pollicis longus (EPL) muscles intrinsic to proximal interphalangeal (IP) extension. We present a patient that reported complex trauma with loss of cutaneous proximal third of the dorsal forearm and extrinsic hand muscle tendons as well as interosseus posterior nerve and ulnar defects. We aimed to restore hand extension and to cover the cutaneous loss of substance with a gracilis re-innervated free flap [4]. The aforementioned flap is considered an optimal muscle to reconstruct the extensor digitorum communis muscle of the forearm (EDC) supplied with relevant pedicle and single motor nerve (obturator nerve) to regenerate motor skills and secure skin coverage regarding cutaneous loss of substance. In addition, we proposed the use of the Brachioradialis pro Extensor pollicis longus as a tendon transfer [5,6].

### Case report

A 27-year-old male from Italy presented as victim of car and motorcycle collision with injury to the distal third of the right forearm [Fig. 1A, D]. The intervention procedure was conducted according to the Declaration of Helsinki and the Guidelines for Good Clinical Practice. The patient submitted written informed consent for surgery and follow-up with related protocol confirmed by the local Ethics Committee. A physical examination revealed abundant loss of substance of the third distal of forearm in bone and soft tissues. The patient reported anesthesia in the ulnar nerve distribution (IV e V fingers) and paralysis to the intrinsic muscle determining inability to flex the metacarpal (MCP) joints and to extend the interphalangeal (IP) joint. Intrinsic impairment had caused a reduction in pinch and grip strength along with paralysis of the adductor pollicis, flexor pollicis brevis and the first dorsal interosseus muscles. Consequently, the patient was affected by diminution of pinch strength and finger abduction due to dysfunction of the palmar interosseus muscle. Moreover, the patient displayed deficit in extension of the long fingers and the opponens pollicis. The patient had received emergency orthopedic and plastic surgery treatment in our hospital before the procedures herein described. The initial assessment and intervention envisaged fixation of the ulnar bone by external fixator [Fig. 1B, C, E], tissue damage was estimated as a lesion of the posterior interosseus nerve (PIN), loss of the vascular and nervous pedicle at the distal third of forearm, the ulnar nerve was damaged and sutured with 8/0 Nylon, the ulnar artery was cauterized (the previous doppler revealed vascularization from radial artery), and a first debridement of the wound was performed. The injury site showed signs of contamination and was dressed as an open wound [Fig. 1B, C] with iodate bandage. After 6 days the patient was submitted to a new debridement, fasciotomy of dorsal hand was performed, and Negative Pressure Therapy was applied on the wound at the distal third of forearm. After 45 days from the initial surgery, no wound or bone infection was detected therefore reconstruction process was initiated [Fig. 1F]. A composite gracilis free flap was selected. The patient was prepped and draped as per standard procedure with exposure of the pubic symphysis and the medial condyle of the femur [Fig. 2A]. General anesthesia was administered to transpose the tendon of BR pro EPL [Fig. 3] using the Pulvertaft suture technique as in previous surgical interventions [5,6] and the flap was harvested [Fig. 2B]. The contralateral gracilis muscle is appropriate for harvesting due to its accessibility towards the site of the donor vessels. We performed a longitudinal incision of 20 cm in length at 3–4 cm beneath the pubic symphysis, precisely between the adductor tubercle and the medial condyle of the femur [Fig. 2B]. We continued the incision to the muscular fascia until identification of the gracilis muscle. The adductor longus was also identified and retracted superiorly. The neurovascular anatomy is discernible by posteriorly retracting the gracilis muscle from the underbelly of the adjacent portion of the adductor longus muscle. The obturator nerve is located at 1–2 cm above the vascular pedicle. The dissection along the neurovascular pedicle was then extended to the appropriate length. The dimension of the forearm gap was matched to the approximate muscle template length. The inferior edges of the muscle were transected to determine a neo-tendon [Fig. 2B]. The neurovascular bundle is not to be separated from the underbelly of the muscle during harvesting under any circumstances. The obturator nerve and vessels were dissected to reach the maximal length [Fig. 2D]. The vessels were lowered only after complete dissection of the forearm and identification of the vessels. The leg incision was subsequently sutured using the standard procedure and drainage tubes were inserted. The recurrent artery of the radial artery was identified and isolated on the lateral side of the forearm including two comitans veins and the interrupted PIN. The free flap was inset into the forearm, the obturator nerve was sutured to the PIN [Fig. 2G], the gracilis tendon was sutured to the EDC using Pulvertaft techniques, the vascular pedicle was sutured to the forearm vessels (recurrent radial artery and two comitans). Arterial and venous anastomoses were performed via 9-0 nylon sutures under the operating microscope [Fig. 2F]. Drain tubes were inserted and layered closure was adopted for the incision [Fig. 2I]. Following surgery, the patient was monitored for several months initiating a rehabilitation program with a specialized physiotherapist. The BR pro EDP extension was assessed using the Geldmacher evaluation scheme [7]; the function of the gracilis flap was evaluated in compliance with the Medical Research Council Muscle Strength Grading System (MRC) [8] and general hand function was verified via the Michigan Hand Score [9]. The results are displayed in Table 1. Six months after surgery the ulnar fracture was affected by pseudoarthrosis [Fig. 4A], therefore new surgery for bone defect was managed using Bioglass to avoid iliac crest draft considering the patient's medical history of surgical interventions. The area of ulnar pseudoarthrosis was meticulously debrided and irrigated. All non-viable bone tissues were removed [Fig. 5A, B]. After identification of 2 cm bone defect [Fig. 5C], we implanted an activated Bioglass spacer in the site of the bone defect

previously prepared with a biologic camera. The ulna was then stabilized using an internal ORIF [Fig. 5D-G]. The Bioglass was activated according to the following procedure: 40 cc of venous blood was taken from the patient's contralateral arm and placed in two 20 ml vials and centrifuged for 9 min at 3200 rpm, the blood was then divided into three parts, the upper fraction containing monocytes, the central fraction containing platelet rich plasma and the bottom fraction containing the corpuscular elements. The first upper fraction was collected using two syringes of 5 cm<sup>3</sup> [Fig. 5E] to activate the Bioglass granules [Fig. 5F]. On termination, a radiography was performed [Fig. 4B]. Three months later [Fig. 4C] and five months later [Fig. 4D], the patient was monitored, and we observed satisfactory outcomes in the injury site. Currently, post-radiographic follow-up is limited by a short follow-up. Clinical results are displayed in Fig. 6 and Videos 1 and 2 on completion of follow-up.

## Discussion

Subsequent to free-tissue transfer, the gracilis muscle has been acknowledged as a favorable tissue source to reconstruct minor traumatic or iatrogenic impairments, due to its accessibility in leg adduction and adequacy owing to anatomical consistency and easy harvesting potential. The gracilis muscle is suitable for functional segmental harvest and transfer due to the architecture of parallel muscle fiber and longitudinal neurovascular organization. The gracilis flap is similar in width and length to the flexor and extensor muscles of the forearm. The tendinous distal third is adequate for flexor and extensor tendon attachment of the digits, allowing for remarkable finger function recovery. Pickrell and colleagues [10] used the muscle to reconstruct the rectal sphincter and were the first investigators to define the transplantation of the gracilis muscle in 1952. The gracilis muscle accommodates identification due to its palpability and predisposition of tendinous insertion. To date, studies have reported few cases of posterior interosseus nerve injury during hospitalization in relation to median, ulnar and radial nerve injuries. Besides, the functional outcome following primary repair or grafting is relatively poor when compared to events concerning other nerves. A limited number of studies have indicated traumatic PIN palsy as a complication in Monteggia fractures or in lacerated forearm injuries [11]. Management of impaired nerves in closed injuries has been the subject of controversy. Some authors recommend conservative treatment using braces and watchful waiting.

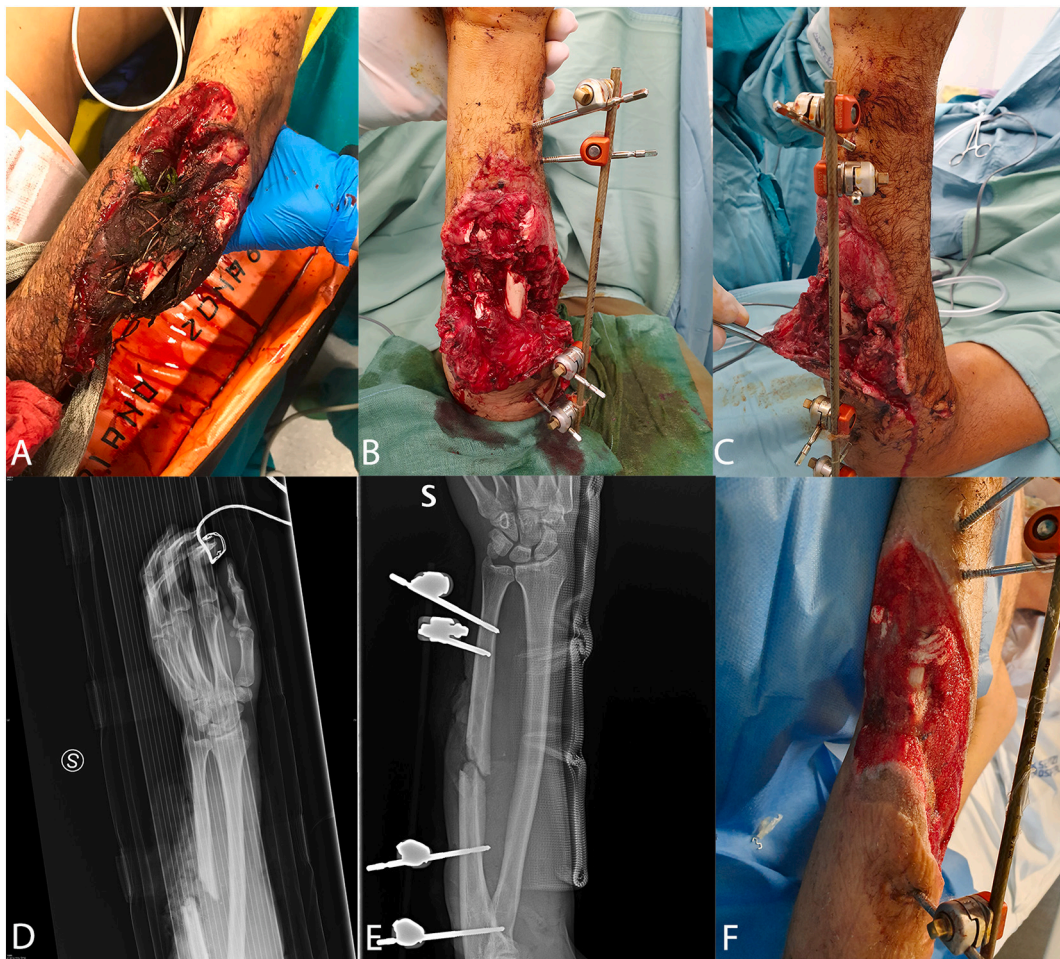


Fig. 1. Clinical presentation of 27-year-old trauma of forearm and emergency room treatment of the ulnar bone and tissue damage.







← Fig. 2. Gracilis Flap for reconstruction of tissue defect and finger extension.

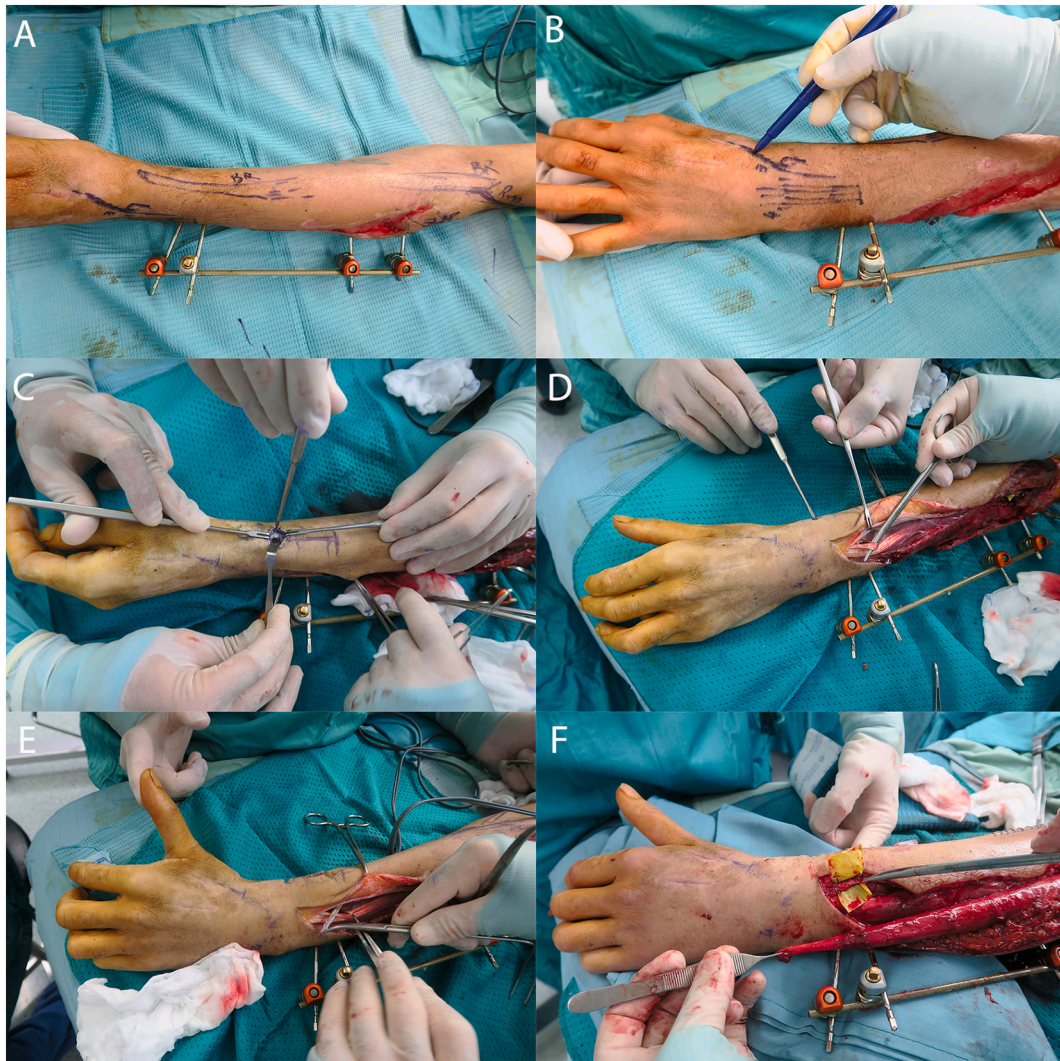


Fig. 3. Brachioradialis to Extensor Pollicis Longus for reconstruction of Thumb extension.

Surgical exploration is recommended in absence of motor re-innervation after 8 months. In open traumas, on the other hand, surgical exploration is mandatory and strongly recommended whereby direct neurotomy is performed. A nerve graft is recommended in the case of nerve laceration presenting a gap greater than 3 cm. Peripheral nerve regenerative potential following severe trauma is specifically unsatisfactory in extremely complex cases [12]. In our patient, the strategy to restore extension of the finger and thumb considers the use of the posterior interosseous nerve stump as a donor. A fundamental condition is the presence of full active wrist extension, which indicates the importance of radial nerve intactness. When we had to face the problem of one stage reconstruction for bone coverage and hand extensor mechanism reconstruction, we searched on literature about gracilis free flap, and we found no article talking about gracilis free flap for upper limb functional reconstruction, we found instead many different cases of gracilis free flap used for facial reanimation [13–15], lower limb reconstruction [16,17], breast reconstruction [18].

We stress the importance of free gracilis flap for these cases because of the good result it brings. We took the patient in operating room for gracilis free flap functional transfer, and we followed him up for 18 months. Wound healing occurred following 18 months of surgery and hand movement was partially retrieved with ability to undergo normal daily activities. After that we got a good functional result for the patient, who come back in daily activity without heavy limitation, we had to manage the ulnar fracture, which underwent to pseudoarthrosis. To avoid ulnar donor site damage for the patient who already undergone to multiple operations, we choose the Bioglass reconstruction [18–21]. The Bioglass technique follows the Masquelet procedure which enables and enhances formation and consolidation of the bone attributable to the regenerative process (without bone allograft). The removal of non-vital bone tissue and





Fig. 4. Pseudoarthrosis of ulnar fracture after six months and radiographic follow -up after bioglass treatment.

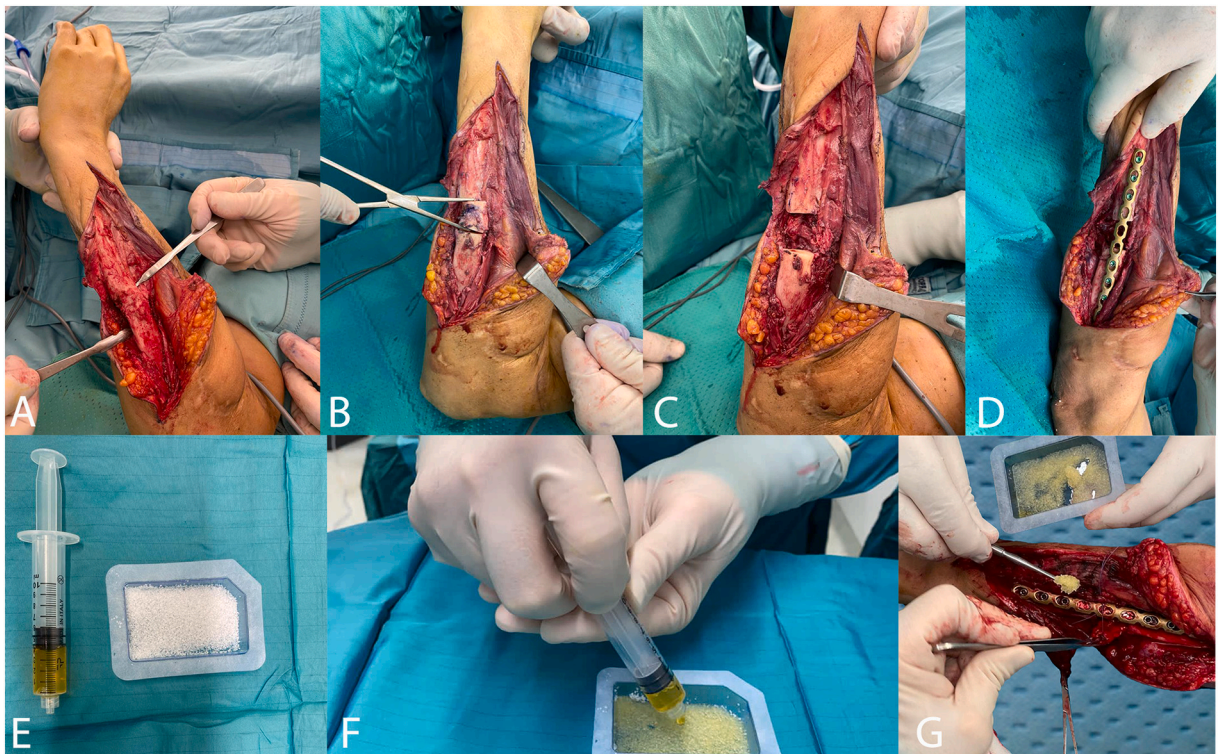
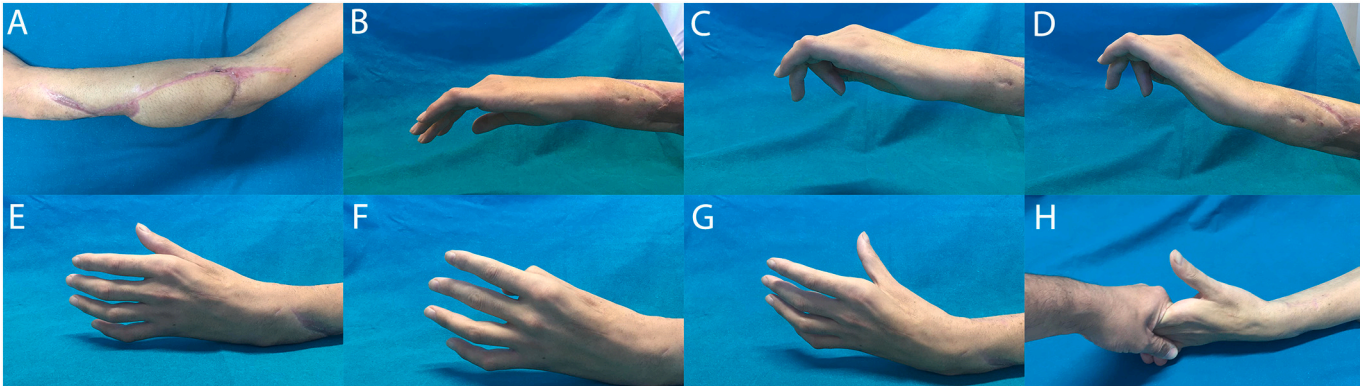


Fig. 5. Bioglass procedure for treatment of ulnar pseudoarthrosis.



**Fig. 6.** Clinical outcomes after one-year followup, with optimal outcomes in finger, thumb and wrist flexion.

**Table 1**  
Evaluation score.

	T30	T180	T360	T720
<b>Geldmacher score</b>				
Radial abduction range	2	2	2	2
Elevation deficit	2	4	4	4
Opposition distance	2	2	2	2
Flexion extension deficit	2	4	4	4
Total score	8	12	12	12
<b>Michigan hand outcome</b>				
Overall hand function	6	6	6	6
Activities of day living	10	8	4	2
Work	2	2	2	2
Pain	2	6	8	8
Aesthetics	6	6	6	6
Satisfaction	8	6	2	2
<b>MRC</b>				
	M0	M3	M3	M5

the use of osteoprogenitor cells or osteoinductive growth factors are imperative for the Bioglass technique to enable defect filling and the closure of chamber with a collagen membrane. Furthermore, sufficient mechanical stability is to be ensured with plate fixation to avoid minimal movement of the graft. The aim of our study is not talking about bone pseudoarthrosis treatment, which has widely been discussed in literature, both with bone graft [22], or regenerative solution such as bioglass [18–21], bone marrow aspirate concentrate [23], platelet rich plasma [24]. Our objective is to let surgeon consider that the gracilis free flap may be considered as an ideal therapeutic option for reconstruction of upper limb lesions involving multiple tissue damage with loss of hand extension in view of its composite characteristics aforementioned as well as its ability to be innervated by a single motor nerve and tendon. Furthermore, bone grafts may be avoided by using Bioglass, a valuable material for small extra-articular bone gaps.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.tcr.2022.100609>.

### Statement of informed consent

Informed consent was obtained from the patient included in the study.

### Ethics statement

The study respects all ethical requirements in its objectives and methodologies. We strictly comply with widely recognized international codes of practice such as the Nuremberg code, the Helsinki agreement, the conventions of the Council of Europe on human rights and biomedicine, with particularly attention to EU legislation: 2001/83/EC, 86/609/EEC and FP7 Decision nr 1982/2006EC. Human biological samples are necessary because we need to test human cells, which have unique biological characteristics, distinct from those of animals. The overall intention in the project is to reduce the number of animal experiments. Only adult patients who are able to give consent will be included. All the patients, that are the subjects of our study, donated their consensus to scientific treatment and publication of their clinic situation and images. We have obtained written informed consent from all patients. This study was approved by our Internal Ethical Committee without any registration in public registry because this study is not a clinical trial.

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### Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### References

- [1] R. Tubiana, J. Thomine, E. Mackin, Movements of the hand and wrist, in: *Examination of the Hand And Wrist*, 2nd edition, Martin Dunitz, London, 1996, pp. 40–127.
- [2] P. Rabischong, Basic problems in the restoration of prehension, *Ann. Chir.* 25 (1971) 927–933.
- [3] W.E. Burkhalter, Early tendon transfer in upper extremity peripheral nerve injury, *Clin. Orthop. Relat. Res.* 104 (1974) 68–79.
- [4] R. Dibbs, L. Grome, W.C. Pederson, Free tissue transfer for upper extremity reconstruction, *Semin. Plast. Surg.* 33 (2019) 17–23.
- [5] P.P. Pangrazi, F. De Francesco, M. Riccio, Brachioradialis to extensor pollicis longus transfer to restore thumb extension in seven patients, *J. Hand Surg. Eur.* 43 (2018) 997–999.
- [6] F. De Francesco, P. Pugliese, M. De Francesco, P.P. Pangrazi, M. Riccio, Brachioradialis muscle tendon transposition in extensor pollicis longus reconstruction: anatomical study and a new surgical approach, *Hand (NY)* (2020) 1–9, 1558944720930295, <https://doi.org/10.1177/1558944720930295>.



- [7] J. Geldmacher, M. Plank, K.D. Treuheit, Die Bedeutung der praoperativen Ausgangssituation bei der Beurteilung der Rekonstruktionsergebnisse an Strecksehnen, in: *Handchirurgie Mikrochirurgie Plastische chirurgie* 18, 1986, pp. 23–29.
- [8] M.A. James, Use of the Medical Research Council muscle strength grading system in the upper extremity, *J. Hand Surg.* 32 (2007) 154–156.
- [9] M.J. Shauver, K.C. Chung, The Michigan hand outcomes questionnaire after 15 years of field trial, *Plast. Reconstr. Surg.* 131 (2013) 779e–787e.
- [10] K.L. Pickrell, T.R. Broadbent, F.W. Masters, J.T. Metzger, Construction of a rectal sphincter and restoration of anal continence by transplanting the gracilis muscle; a report of four cases in children, *Ann. Surg.* 135 (1952) 853–862.
- [11] K. Hirachi, H. Kato, A. Minami, Kaneda K. Kasashima T, Clinical features and management of traumatic posterior interosseous nerve palsy, *J. Hand Surg. Br.* 23 (1998) 413–417.
- [12] M. Riccio, A. Marchesini, P. Pugliese, F. De Francesco, Nerve repair and regeneration: biological tubulization limits and future perspectives, *J. Cell. Physiol.* 234 (2019) 3362–3375.
- [13] K.O. Boahene, J. Owusu, L. Ishii, M. Ishii, S. Desai, I. Kim, L. Kim, P. Byrne, The multivector gracilis free functional muscle flap for facial reanimation, *JAMA Facial Plast. Surg.* 20 (2018) 300–306.
- [14] M. Roy, J.P. Corkum, P.S. Shah, G.H. Borschel, E.S. Ho, R.M. Zuker, K.M. Davidge, Effectiveness and safety of the use of gracilis muscle for dynamic smile restoration in facial paralysis: a systematic review and meta-analysis, *J. Plast. Reconstr. Aesthet. Surg.* 72 (2019) 1254–1264.
- [15] A.H. Lee, R.H. Liu, L.E. Eshii, P.J. Byrne, S.C. Desai, M. Ishii, K. Boahene, Free functional gracilis flaps for facial reanimation in elderly patients, *Facial Plast. Surg. Aesthet. Med.* 23 (2021) 180–186.
- [16] R. Pedreira, N.A. Calotta, E.G. Deune, Gracilis musculotendinous free flap for lower extremity reconstruction after surgical removal of malignant tumors: a report of five cases, *Microsurgery* 39 (2019) 515–520.
- [17] S. Shyamsundar, A.A. Mahmud, V. Khalasi, The gracilis muscle flap: a “Work horse” free flap in diabetic foot reconstruction, *World J. Plast. Surg.* 10 (2021) 33–39.
- [18] F. Bodin, C. Bruant-Rodier, L. Ruffenach, C. Dissaux, Breast reconstruction with free flap of gracilis, *Ann. Chir. Plast. Esthet.* 63 (2018) 486–497.
- [19] H.R. Fernandes, A. Gaddam, A. Rebelo, D. Brazete, G.E. Stan, J.M.F. Ferreira, Bioactive glasses and glass-ceramics for healthcare applications in bone regeneration and tissue engineering, *Materials (Basel)* 11 (2018) 2530.
- [20] A.C. Masquelet, F. Fitoussi, T. Beguè, G.P. Muller, Reconstruction of long bones induced membrane and spongy autograft, *Ann. Chir. Plast. Esthet.* 45 (2000) 346–353.
- [21] P.V. Giannoudis, O. Faour, T. Goff, N. Kanakaris, R. Dimitriou, Masquelet technique for the treatment of bone defects: tips-tricks and future directions, *Injury* 42 (2011) 591–598.
- [22] M. Jager, D. Wassenaar, A. Busch, M. Haversath, Pseudoarthroses, *Orthopade* 49 (2020) 547–560.
- [23] A. Memeo, F. Verdoni, C.F. Minoli, A. Voto, R.D. D’Amato, F. Formiconi, D. Priano, L. Montanari, E. Panuccio, Effectiveness of bone marrow aspirate concentrate (BMAC) as adjuvant therapy in the surgical treatment of congenital pseudoarthrosis of the tibia: a retrospective comparative study, *J. Biol. Regul. Homeost. Agents* 34 (2020) 431–440.
- [24] K. Basdelioglu, G. Meric, S. Sargin, A. Atik, A.E. Ulusal, D. Akseki, The effect of platelet-rich plasma on fracture healing in long-bone pseudoarthrosis, *Eur. J. Orthop. Surg. Traumatol.* 30 (2020) 1481–1486.