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# CHIRURGIA della MANO

Chirurgia e riabilitazione della mano dell'arto superiore e microchirurgia

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Chirurgia e riabilitazione della mano dell'arto superiore e microchirurgia

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Italian Society for Surgery of the Hand (SICM), gave me the opportunity to collect some of papers referring to pediatric congenital or post-traumatic anomalies, studied and written by members of PHISOS (Pediatric Hand International Society of Surgeons).

PHISOS is an international group of surgeons that specialize in the treatment of upper limb disorders in children. Members treat brachial plexus birth and traumatic injuries, peripheral nerve injuries, congenital differences, trauma, post-traumatic deformity, spasticity and sports injuries. An international society of surgeons dedicated to the care of children's upper limb from the brachial plexus to the fingertips. Founded in 2018, PHISOS has attracted experts in the field from around the world. Membership is by invitation only, with members selected for their contributions to the field, collegiality and willingness to collaborate and dedication to the welfare of children. Here are some papers, written and collected for Italian society members. Thanks to SICM for a so great opportunity.

*La Società Italiana di Chirurgia della Mano (SICM), mi ha dato l'opportunità di raccogliere alcuni lavori scientifici riguardanti patologie pediatriche congenite o post-traumatiche, realizzati e scritti da membri della società scientifica PHISOS (Pediatric Hand International Society of Surgeons).*

*PHISOS è un gruppo internazionale di chirurghi specializzati nel trattamento di disturbi dell'arto superiore nei bambini. I membri trattano paralisi ostetriche o post-traumatiche, lesioni nervose periferiche, anomalie congenite, traumi, deformità post-traumatiche, spasticità e traumi sportivi. Una associazione internazionale di chirurghi dediti alla cura degli arti superiori dei bambini dal plesso brachiale alle dita della mano.*

*Fondata nel 2018, PHISOS ha attirato esperti da tutto il mondo.*

*L'adesione è su invito esclusivamente, con selezionati membri per il loro contributo in materia, spirito di aggregazione è volontà a collaborare e dedicarsi al benessere dei bambini.*

*Sono in questa monografia riportati alcuni lavori, scritti e collezionati per i membri della SICM.*

*Grazie a tutti voi per questa grande opportunità.*

Massimo Corain  
Phisos President (2022-2024)

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# Free nonvascularized toe phalangeal transfer (FNVTPT)

## *Trasferimento libero non vascolarizzato di falangi delle dita del piede*

**Lorenzo Garagnani**<sup>1,2</sup>

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### Summary

Free nonvascularized toe phalangeal transfer is one of the treatment options for congenital digital hypoplasia. Specific anatomical and surgical technique aspects must be taken into account in order to achieve a favourable outcome, and donor site morbidity must also be considered.

**Key words:** free phalanx transfer, symbrachydactyly, digital hypoplasia

### Riassunto

Il trasferimento libero non vascolarizzato di falangi delle dita del piede rappresenta una delle opzioni di trattamento per l'ipoplasia digitale congenita. Al fine di ottenere un risultato favorevole, devono essere presi in considerazione specifici aspetti anatomici e di tecnica chirurgica, e deve essere considerata anche la morbidità del sito donatore.

**Parole chiave:** trasferimento libero di falange, simbrachidattilia, ipoplasia digitale

## Introduction

Free nonvascularized toe phalangeal transfer (FNVTPT) is an established surgical technique for the treatment of digital hypoplasia. It was first described by Wolff <sup>1</sup> then also reported by other authors <sup>2,3,4</sup>. Goldberg and Watson <sup>5</sup> and Buck-Gramcko and Pereira <sup>6</sup> popularised the technique. Free phalangeal transfer still represents a viable alternative to microvascular toe-to-hand transfer in cases where the latter cannot be performed or is not indicated. Radocha et al in 1993 published a series of 73 transfers suggesting that the transfers are more likely to survive and subsequently the epiphyses to remain open if the nonvascularized phalangeal transfer procedure is performed at an early age <sup>7</sup>. This finding was further confirmed by a more recent study published in 2021 <sup>8</sup>.

## Indication

Hypoplastic hand digits where a functional improvement may be achieved with the insertion of a phalanx. The procedure should ideally be performed at an early age and the pre-operative assessment should ascertain the presence of a sufficiently

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broad skin and soft tissue envelope to accommodate a toe phalanx without tension, the presence of a functional flexor and extensor tendinous mechanism and of an adequately developed metacarpal, and the presence of a viable toe phalanx of appropriate size and shape for the transfer <sup>7</sup>.

## Advantages

The main advantages of FNVPT are the following:

- this procedure can be performed at an early age;
- it does not involve sacrificing whole toes;
- it is technically less demanding than a microvascular toe-to-hand transfer;
- it does not appear to affect the gait;
- it has been historically perceived as a low morbidity procedure by families and surgeons alike.

## Surgical technique

It has been demonstrated that the viability and growth of the transferred toe phalanx in the hand depend also on the preservation of an intact periosteum therefore the phalanx should be transferred intact <sup>5,9</sup>. Subsequently, the size of the skin and soft tissue envelope at the recipient site is the limiting factor for the phalangeal size as the hypoplastic digit must accommodate the intact transferred phalanx without an excessive tissue tension in order to reduce the risk of post-operative tissue necrosis, phalangeal loss and other complications <sup>10</sup>. The traditional technique for toe phalangeal harvest involves a dorsal incision on the recipient site where a bursa or a fibrous-cartilaginous remnant distal to the metacarpal head may be present. The aforementioned structures distal to the metacarpal head should be incised preserving their proximal attachment and exposing the metacarpal head in order to create a metacarpophalangeal joint with proximal soft tissue attachments for the base of the transferred phalanx. A space is then created in the hypoplastic digit preserving the neurovascular bundles. A dorsal, extensor tendon splitting approach is typically used in the donor toe. The chosen phalanx is harvested as a whole, preserving the flexor and extensor tendons in the donor toe. The proximal toe phalanx has been traditionally more commonly used for the transfer, however the middle phalanx can be chosen when a smaller bone transfer is required <sup>11</sup>. The toe phalanx is harvested extraperiosteally. A proximal cuff of capsule including collateral ligaments and plantar plate should be harvested with the phalanx in order to obtain a more stable attachment to the recipient site. A double ended Kirschner wire is inserted longitudinally into the phalanx, ensuring that it does not protrude from the phalangeal base. The free end of the Kirschner wire is then used to pierce

the fingertip skin and the phalangeal graft is guided into the recipient soft tissue pocket down the Kirschner wire. Once the donor phalanx is appropriately positioned in the soft tissue envelope, the Kirschner wire is driven into the metacarpal. The capsule and collateral ligamentous structures at the phalangeal base are then sutured to the previously prepared tissues around the metacarpal head, ensuring that the flexor and extensor tendons are also attached to the dorsal capsule and plantar plate respectively. The skin is sutured avoiding excessive tension and the tourniquet is released to verify that an adequate soft tissue perfusion is present. Traditionally, either pre-operative soft tissue expansion, intra-operative z-plasty or local flaps have been adopted to reduce the risk of excessive soft tissue tension and subsequent ischaemia. The author prefers a palmar V-Y approach to the recipient site that increases the palmar length of the soft tissue envelope allowing to accommodate an intact phalangeal graft with a reduced tissue tension whilst correcting any flexion contracture of the hypoplastic digit <sup>10</sup>, followed by skin suture with absorbable suture material. The donor site management will be discussed in a separate section.

## Post-operative care

A soft dressing, a cast and a bandage are applied, protecting the surgical wound and the K-wire. The cast and K-wire are usually removed at 4 weeks post-operatively.

## Donor site management and morbidity

A number of techniques for toe phalanx harvest and donor site management have been described by various authors since the procedure's inception. Wolff <sup>1</sup> reconstructed the donor site using a rib cartilage graft, while Buck-Gramcko and Pereira <sup>6</sup> preferred to suture the flexor to the extensor tendons. Smith and Gault <sup>12</sup> did not suture the flexor to the extensor tendons. Radocha et al <sup>7</sup> maintained the toe length in the post-operative period with a Kirschner wire and a suture through the nail for toe distraction. Until recently, only a few studies acknowledged some long-term consequences on the donor site <sup>2, 6, 11, 13, 14, 15</sup>. Bourke and Kay in 2002 proposed iliac crest bone grafting to the donor toes <sup>15</sup>, however the long term outcomes of this technique are not currently available. In 2012, the first study exclusively focused on donor site morbidity with a long-term follow-up demonstrated universal deformities of the donor toes and commonly associated deformities of adjacent toes at the long-term follow-up <sup>16</sup>. The worsening of the donor site morbidity over time highlighted the fact that a short-term follow-up of the donor site in the foot is inadequate. It also remains unclear and a matter of debate whether any of the proposed donor

toe reconstructive options or post-operative protocols is superior to the others concerning the long-term donor site outcome.

## Pearls and pitfalls

- Risk of soft tissue necrosis and phalangeal exposure or extrusion in case of excessive skin and soft tissue envelope tightness/tension at the recipient site;
- Early physeal closure and lack of phalangeal growth in case of periosteal damage, physeal damage, partial phalangeal harvest or procedure performed too late in childhood<sup>8</sup>;
- Risk of phalangeal resorption especially when the periosteum is damaged, like following phalangeal trimming or harvest of partial phalanges<sup>16</sup>;
- Risk of metacarpophalangeal instability and subluxation if the recipient soft tissue envelope is too tight and/or in the absence of metacarpophalangeal capsuloligamentous reconstruction and tendon attachments to the transferred phalanx;
- No phalanges should be harvested from the second toe in case of potential requirement or consideration of a future microvascular toe transfer, making the third and fourth toes the preferential donor sites for FNVTPPT;
- It is paramount to discuss openly and thoroughly all aspects relating to this procedure, including those relating to the donor site morbidity, with the patient's family, ensuring that all other viable treatment alternatives are also explored and considered.

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# Congenital bifid thumb correction: causes of reoperation

## Correzione congenita del pollice bifido: cause di rioperazione

**Massimo Corain, Roberta Sartore**

Hand Surgery and Microsurgery Department, European Hand Trauma and Replantation Center, Verona University Hospital, Italy

### Summary

The aim of this study is to report results and complications occurred after surgery for congenital bifid thumb. From June 2015 to June 2020 a case series of 47 thumb duplications, Wessel type II, III and IV, was treated. All patients received removal and reconstruction of the thumb. They were evaluated using Tada score and plain X-ray with a mean follow-up of 6 years. Average Tada score was 3.8. Nine patients developed minor complications. A second surgery was necessary in 7 patients: 2 scar revisions, 3 corrective osteotomies, and 3 extensor pollicis longus tendon (EPL) retensionings. The percentage of reoperated patients is comparable with the data reported in the literature. Complications are minor and affect soft tissues. This is due to the difficult management of soft tissues and their possible evolution. EPL lag is difficult to treat and in our experience it has a tendency to recurrence after retensioning. Level of evidence: II.

**Key words:** congenital bifid thumb, reconstruction

### Riassunto

Lo scopo di questo studio è quello di riportare i risultati e le complicazioni si sono verificati dopo l'intervento chirurgico per il pollice bifido congenito. Da giugno 2015 a giugno 2020 è stata trattata una serie di casi di 47 duplicati del pollice, Wessel tipo II, III e IV. Tutti i pazienti hanno ricevuto la rimozione e la ricostruzione del pollice. Essi sono stati valutati utilizzando Tada score e pianura raggi X con un follow-up medio di 6 anni. Tada punteggio medio era 3.8. Nove pazienti hanno sviluppato complicazioni minori. Un secondo intervento chirurgico è stato necessario in 7 pazienti: 2 revisioni della cicatrice, 3 osteotomie correttive, e 3 sondaggi estensori lungo tendine (EPL) ritensioni. La percentuale di pazienti recidivati è paragonabile ai dati riportati in letteratura. Le complicanze sono minori e colpiscono i tessuti molli. Ciò è dovuto alla difficile gestione dei tessuti molli e alla loro possibile evoluzione. Il ritardo di EPL è difficile da trattare e nella nostra esperienza ha una tendenza alla ricorrenza dopo il retensioning. Livello di prova: II.

**Parole chiave:** pollice bifido congenito, ricostruzione

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## Introduction

Thumb duplication is a preaxial polydactyly with an incidence of 1:3,000 newborns, representing 6.6 % of hand deformities <sup>1,2</sup>. Typically, thumb polydactyly



occurs sporadically and unilaterally, but it may also be associated with Holt-Oram syndrome, Fanconi anemia, or Rubinstein-Taybi syndrome, thus requiring a thorough record of patient's medical history and physical examination with attention to other congenital abnormalities. Holt-Oram syndrome affects 1 in 100,000 births and is characterized by a variety of cardiac defects and hand anomalies, with thumb hypoplasia being the most common. Typically, patients with Holt-Oram syndrome have been diagnosed before examination by a hand surgeon. Fanconi anemia is a rare condition affecting 1 in 300,000 births and is characterized by bone marrow failure. In one series, 1 of 83 patients with preaxial polydactyly had Fanconi anemia. Rubinstein-Taybi syndrome affects 1 in 125,000 births and is characterized by growth delay, dysmorphic facies, intellectual disability, and duplication of the distal phalanges of the thumb. These conditions are rare, therefore they are not routinely screened unless the related medical signs can be observed<sup>3-6</sup>.

Thumb duplication is recognised among "duplications" in the International Federation of Societies for Surgery of the Hand (IFSSH)/Swanson classification<sup>7</sup>, among "abnormal formation/differentiation of the hand plate in the radio-ulnar axis" in the modified Oberg-Manske-Tonkin (OMT) classification<sup>8,9</sup>, and among "late limb patterning/differentiation in abnormal axis differentiation in hand plate" in the latest update of the OMT classification<sup>10</sup>. According to the recent literature, its pathogenesis seems to involve Sonic Hedgehog Homolog protein (SHH), a signaling molecule produced in the Zone of Polarizing Activity (ZPA), a mesenchymal area containing signals that lead the limb to grow along the anteroposterior axis in vertebrates<sup>8</sup>.

The Wassel morphological classification is the most commonly used to guide the surgeon in decision making<sup>11</sup>. It includes 7 types of deformity based on the level of the duplication. Wassel type IV thumb is the most common variant and occurs in 40% of patients, while type II thumb is the second most common variant and occurs in approximately 20% of patients. Although this classification is widely used for its ease of use, it shows a limited correlation with postoperative clinical results<sup>12</sup>. Typically, bifid thumbs are underdeveloped and have varying degrees of abnormal tendons, bones, ligaments, and vasculature. To integrate the Wassel classification, several subsequent modifications of the original Wassel classification have been proposed, including triphalangeal subtypes, type IV subtypes, and systems incorporating symphalangism, deviation and triplication<sup>13-15</sup>.

Radiographs should be obtained to correctly assign classification and guide the surgical planning. Fingernail involvement in Wassel type I or II deformity requires a different surgical planning compared to type III or IV deformity. Preoperatively, it is important to emphasize to parents that, although surgical reconstruction improves appearance and

function, the operated thumb will never be identical to the unaffected contralateral, with the preoperative joint angulation, stability, and motion providing a clue to the resulting thumb function<sup>16</sup>.

Although little evidence is available regarding the most suitable timing for surgery, most authors recommend reconstruction between 1 and 2 years of age. This facilitates skeletal growth, it allows a less technically challenging reconstruction and the development of fine motor skills, such as thumb-index tip (pincer) grasp. Despite this, surgery can be safely delayed until after 2 years of age for patients with multiple comorbidities or when a more complex reconstruction is required. Historically, simple excision of the less-developed digit was the treatment of choice until follow-up revealed unsatisfactory functional and cosmetic outcomes. Specifically, excisional management alone frequently resulted in joint instability and off-axis or absent pull of the tendons on the preserved MCP and IP joints. Excision without reconstruction frequently results in a Z deformity of the residual thumb, which does not provide proper collateral ligament support and in-line pull of the flexor and extensor tendons. Increasing emphasis has been placed on thorough reconstruction of all abnormal structures in the retained thumb because of these unsatisfactory outcomes<sup>1,4,17-20</sup>.

The main goal of the surgical correction is the creation of a stable, well aligned, functional and cosmetic thumb. Treatment of radial polydactyly is complex, as the clinical presentation is highly diverse, with each subtype requiring a specific surgical approach. Surgeons must take into account the unique anatomy of each case before deciding on the most suitable correction technique for the best overall result. The outcomes vary and depend largely on the preoperative diagnosis and procedure performed. Tonkin and Al-Qattan reviewed and described the most commonly used methods of surgical correction. In general, a correct surgical treatment of DT gives good well-maintained outcomes<sup>21,22</sup>.

The aim of the study is to report the authors' case series between 2008 and 2013, considering all the causes that led to resurgery in order to improve both functional and cosmetic impairments of the thumb.

## Materials and methods

Between June 2015 and June 2020, 47 thumb duplications in 41 patients (26 males and 15 females) were treated at the Authors' Institution. Mean age at first surgery was 16.4 months (range 11-26). 36 caucasian patients and 5 african patients were treated. According to the Wassel classification<sup>11</sup>, 28 patients had type IV duplication, 10 type III, 7 type II and 2 type I. All the patients were treated by two senior surgeons with removal of the radial supernumerary thumb

and reconstruction of soft tissues when required. 30 cases had retensioning of the radial collateral ligament (RCL) at the MCP joint, 8 cases had rebalancing of the extensor pollicis longus (EPL) tendon, 8 cases had subtraction osteotomy of the proximal phalanx or the first metacarpal bone and 2 cases had additive osteotomy with a bone graft from the donor finger in MP clinodactyly. Postoperative treatment included arthrorisis with Kirschner wire for 5 weeks with a thermoplastic static splint to maintain the thumb in abduction and opposition. The splint was worn night and day for the first 2 months and during the night for another 2 months. Patients were periodically evaluated at the Authors' Paediatric Hand Surgery Outpatients Clinic. Mean follow-up was 6 years (range 3-8 y). Thumb function was evaluated for each patient using the Tada score<sup>23</sup>, in association with plain X-rays (antero-posterior and lateral).

## Surgical technique

The procedure is usually performed using dorsal zig-zag incisions, followed by deep dissection and inspection of the joints. Slight traction is established to enable evaluation of the IP or MCP joint congruency. Mainly in types II and IV, chondroplasty of the radial facet of the proximal phalanx and the metacarpus is necessary to give congruency to the joints, then followed by their testing for stability. In all the cases involving radial resection, the radial collateral ligaments are reattached with preservation of the capsular-periosteal flaps. Soft tissue from the base of the proximal phalanx is sutured to the metacarpal neck to reconstruct the MCP joint. The thenar muscles and the radial collateral capsular-periosteal flap are reattached at the same site. At this point of the procedure, if some joint instability remains, part of the EPL or flexor pollicis longus (FPL) tendon is used as a circumferential pulley around the proximal phalanx, suturing the tendon to itself. If there are connections between the FPL and the extensor tendons, they may be cut out. In order to ensure joint axial alignment, it is important to avoid eccentric pull of the EPL tendon by its radial insertion on the base of the distal phalanx. The duplicated EPL tendon of the dissected thumb, if present, may be sutured to its corresponding remaining tendon of the ulnar thumb at the ulnar base of the distal phalanx. The eccentric position of the tendon is then modified, and its deforming forces are consequently neutralized. At this stage, the soft tissue procedures described above allow proper alignment in nearly all the cases. If good alignment is not achieved with these procedures, osteotomy becomes necessary. Ulnar-base head-neck junction osteotomy of the proximal phalanx or of the metacarpal bone may be necessary to achieve axial alignment in some cases, mainly in types II

and IV, respectively. Corrective osteotomy is controversial in the youngest patients. When osteotomy is indicated, a 0.7-mm K-wire is introduced from the tip to the base of the thumb and left in place for 4 to 6 weeks. Any delta phalanx needs to be removed and corrective osteotomy is indicated. Z-plasty of the first web space is performed mainly in type IV thumbs when the first-space contracture limits their functionality. An elasticizing silicone cream is recommended starting from week one after suture removal to reduce retracting scars.

## Results

All 41 operated patients (100%) were included; 7 of them were treated bilaterally. Clinical evaluation with Tada score<sup>23</sup> revealed a good or satisfactory functional result in 90.8% of patients, with a mean score of 3.8 points (range 1-5) and a mean follow-up of 6 years. In case of reoperated patients, the Tada score obtained before the second procedure was reported. Plain radiographs showed a good realignment of the thumb axis in 19 cases (86.3%), clinodactyly in 2 cases and Z deformity of the thumb in one case. Nine out of 47 thumbs (19%) developed minor isolated or associated complications: 4 hypertrophic surgical scars, 3 EPL deficits, 2 clinodactylies for MP and IP instability respectively, 1 nail dystrophy and 1 Z deformity. Seven patients (14%) were reoperated to treat complications on average 22 months after the first procedure (12-38 months): 2 scar revisions with Z-plasty, 2 wedge osteotomies in subtraction; 1 corrective double osteotomy of the metacarpal and the first phalanx for Z deformity; 3 EPL retensioning for active extensor lag of the distal phalanx.

## Discussion

Polydactyly is one of the most frequently observed congenital hand malformations. Being such a common upper limb malformation, investigation into its cause and the consequent therapeutic measures is highly relevant. Various studies suggest that a gene localized to chromosome 7q36 is responsible for preaxial polydactyly types II and III. The Wassel classification is the universal classification for thumb duplication. From the time it was first described to the present day, triphalangism has been progressively considered as a different condition to that of thumb duplication, since it requires a different approach<sup>24</sup>. According to many authors, the Wassel classification should only be used as a preliminary evaluation, since it does not consider the anatomical alterations of the soft tissues and skeletal dysmorphisms such as thumb triplication, triphalangism, thumb hypoplasia, deviation and symphalangism, as reported in the classification proposed by Zuidam and colleagues

in 2008<sup>15</sup>. These anatomical variations of the thumb, if incorrectly treated, can lead to postoperative complications along the whole first ray<sup>25</sup>. A careful intraoperative evaluation is therefore mandatory in order to plan the appropriate correction of the soft tissues in order to limit the incidence of complications.

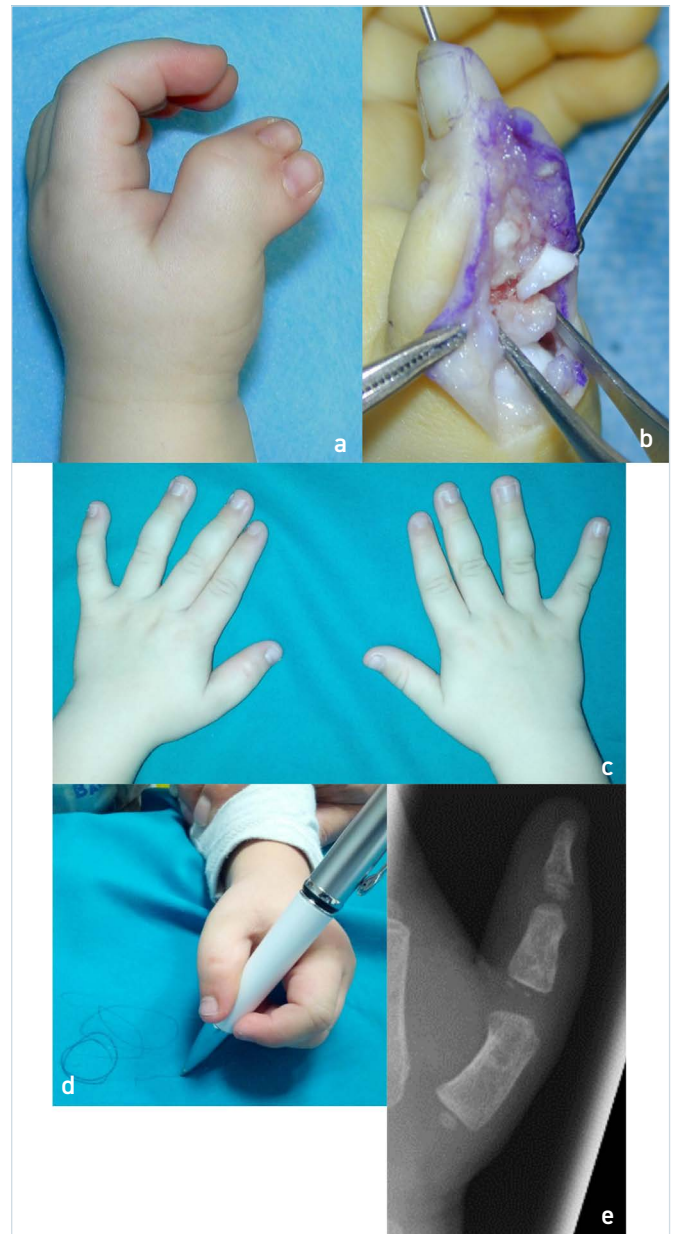
The surgical procedure has four well-defined aims for the dominant thumb: functional alignment, stability, overall good function and satisfactory cosmetic appearance. A decrease in motion range is acceptable to achieve IP and MCP joint stability. Historically, types II and III thumbs with symmetrical radial and longitudinal sizes have been treated with the Bilhaut-Cloquet procedure<sup>26</sup>, although this procedure is currently under discussion because of some concerns regarding split nail deformity, stiffness, and late deformity caused by epiphyseal damage and growth arrest. Recently, some authors also reported a modified Bilhaut-Cloquet technique that offers satisfactory results with radial resection and soft tissue reconstruction adopted in Wassel type IV thumbs with divergent MCP and convergent IP joints<sup>22,24,27</sup>.

The removal of one of the two thumbs is indicated in type III and higher and in cases of a remarkable asymmetry of the two thumbs in type I and II. This technique includes the removal of the hypoplastic thumb, usually the radial one, in order to preserve the ulnar collateral ligament (UCL) at the IP or the MP joint, in association with the reconstruction of

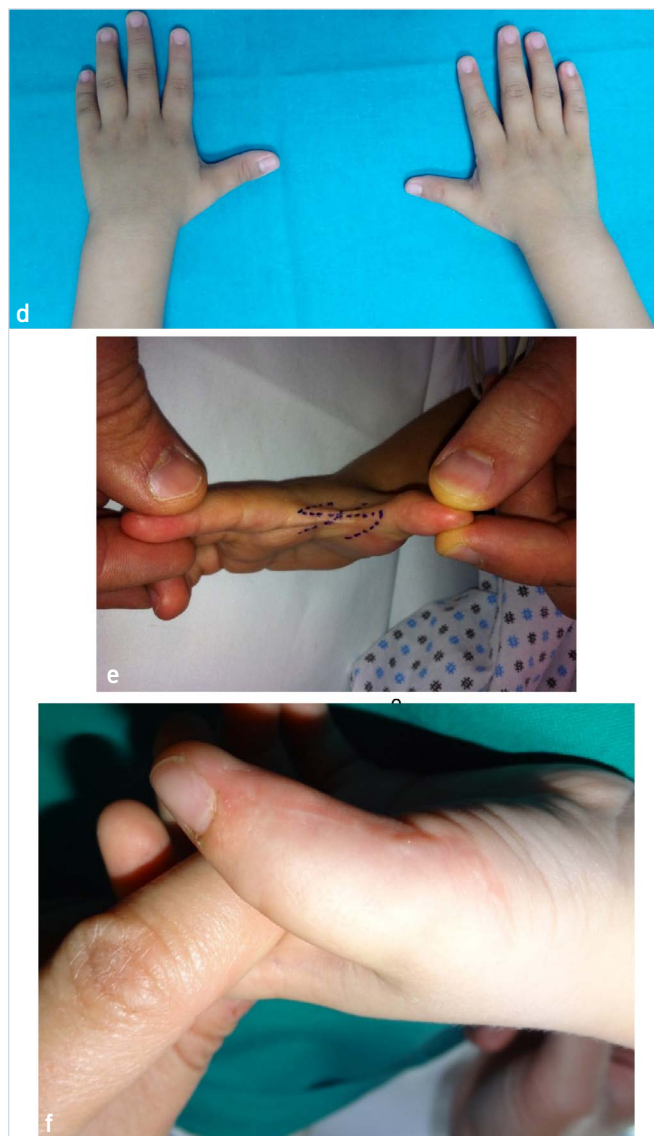
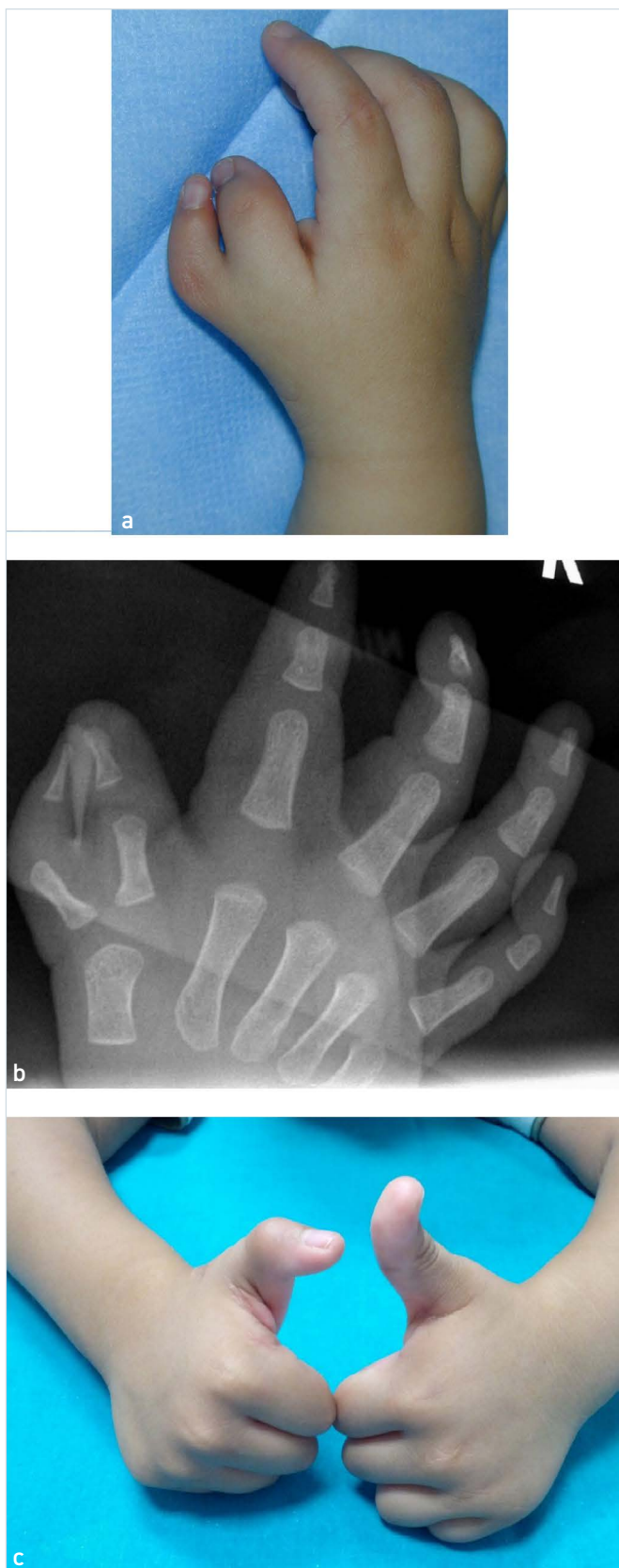
the ligamentous and tendinous complex or osteotomy<sup>22,28</sup>. The complications reported in the literature include excessive joint instability and Z deformity<sup>25</sup>.



**Figure 1.** Most frequent causes of reoperation: articular instability (Wassel type II-IV). a) Thumb Z deformity; b) scar hypertrophy; c) extensor deficiency (EPL); d) nail-dystrophy (Wassel type I-II).



**Figure 2.** Patient with type IV deformity (Wassel classification), (a-b) preoperative image, operated at 12 months with removal of the radial thumb, in association with additive osteotomy with graft of donor thumb, RCL reconstruction and EPL retensioning (c-d). Clinical and radiological evaluation at 30 months post-op, showing restoration of the anatomical axis with optimal clinical and functional results (Tada score 5) (e-f-g).



**Figure 3.** Patient with type IV deformity (Wassel classification), (a-b) preoperative image, operated at 15 months with removal of the supernumerary radial thumb. Clinical and radiological evaluation at 20 months post-op, showing EPL lag, but good axis realignment (c-d). Clinical evaluation after EPL retensioning and Z plasty of the first web (e-f).

Functional results in radial polydactyly have been usually evaluated using the Tada score, which is a validated functional scale that takes into account the most common complications. Apart from the Koichi scale used by Abid et al., the Tada score is used in all the studies on thumb duplication<sup>29</sup>. Although its use is usually recommended to facilitate the comparison between studies, recently Dijkman et al. showed that the JSSH assessment system provides the most reliable eva-

luation of the final results for radial polydactyly<sup>30</sup>. This system includes 13 items overall: seven functional, four cosmetic and two subjective. This evaluation system will be increasingly used in future studies, possibly replacing the Tada score<sup>30</sup>.

The incidence of postoperative complications (Fig. 1) is reported to be as high as 27-49%. Although most complications are minor, a second procedure is necessary in 11.5-37% of cases. Naasan and Page reported an incidence of complications of 49% in 43 patients, with the need of reoperation in 16.3% of cases. Ogino et al. reported an incidence of complications of 34% in 113 hands, with reoperation in 11.5% of cases<sup>31</sup>. Ozalp et al. reported an incidence of reoperation of 37.3% in 67 patients (with ligamentous reconstruction, tendon retensioning, corrective osteotomy, and interphalangeal arthrodesis)<sup>32</sup>. Cabrera González et al. treated 99 patients with the removal of the supernumerary thumb, reporting an incidence of complications of 27% and reoperation in 12% of cases<sup>12</sup>. The results reported in this study (minor complications 19% and reintervention 14%) are similar to the literature. Patients treated for scar hypertrophy, clinodactyly and Z deformity obtained both functional and cosmetic improvement, suggesting that a corrective procedure is highly recommended for these cases.

Perez-Lopez et al. observed that the most common complications are late axial deformity, simultaneous clinodactyly and instability, with secondary procedures including collateral ligament reconstruction, tendon reattachment, and arthrodesis of the IP joint. They reported that the lowest rate of complications occurred in patients treated before 6 months of age (0% complications) or between 7 and 12 months of age (19% complications), suggesting surgery for patients aged between 7 and 12 months. Moreover, Wassel types III and IV resulted in a higher rate of complications.

Stutz et al. reported on the long-term outcomes of 41 patients with preaxial polydactyly and observed a 19% revision rate at 8 years postoperatively (mean value). The primary cause for the revision surgery was instability, which was frequently associated with pain. Revision surgeries included five IP joint arthrodesis, four tendon realignment procedures, one carpometacarpal collateral ligament reconstruction, and one opposition transfer. Larsen and Nicolai reexamined 19 patients at 22.5 years (mean value) from surgery. Seven patients were dissatisfied with the cosmesis of their thumb because of the residual angular deformity, and 14 thumbs showed > 20° of malalignment<sup>33</sup>. Goldfarb et al. found that the unsatisfactory cosmetic appearance of the thumb after preaxial polydactyly correction was associated with residual angulation as well as a reduced nail width<sup>34-36</sup>.

The treatment of the EPL tendon lag remains challenging. All the 3 cases treated with tendon retensioning, arthrorisis with Kirschner wire and static splint experienced a provisional improvement and a deficit relapse 6 months after the

procedure (Figs. 2, 3). This complication is rarely reported in the literature. Kawabata et al. described an extensor indicis tendon transfer to the EPL tendon, performed in 6 patients aged 4-12 years, and nail dystrophy only in Wassel type I and II<sup>37</sup>. The Authors consider the proper reconstruction of the lateral side of the nail mandatory and the Bilhaut-Clocquet modified technique should be preferred, in order to preserve a complete nail. The surgical treatment of congenital thumb duplications needs a solid knowledge of the anatomical variants of the skeletal segments and soft tissues, also considering the possible structural and functional changes of the thumb. The removal of the supernumerary thumb alone is rarely satisfactory. It is nearly always necessary to perform additional procedures both to correct thumb axis and stability and to obtain the best cosmetic outcome. Despite these surgical measures, the Authors' experience shows that reoperation is frequent after the removal of the supernumerary thumb (32%), as described in the literature. This proves the complexity of the malformation and the evolution of the results obtained during the developmental age. The Authors believe that the appropriate timing and the proper technique during the first procedure could lower, but not erase, the incidence of postoperative deformities and imperfections of the residual dominant thumb.

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## Incidence of neurovascular compromise and rates of recovery in open pediatric both bone forearm fractures

*Incidenza di compromissione neurovascolare e tassi di recupero nelle fratture esposte di avambraccio in età pediatrica*

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### Conflitto di interessi

Gli Autori dichiarano di non avere alcun conflitto di interesse con l'argomento trattato nell'articolo.

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### Summary

**Purpose.** The management of nerve injuries in open pediatric forearm fractures remains unclear. The purpose of our study was to describe the relative frequency of nerve injuries with open both bone forearm fractures, as well as rates of nerve recovery after injury and the impact of early surgical nerve exploration.

**Methods.** We retrospectively reviewed 71 patients with open both bone forearm fractures at a tertiary care children's facility between January 1, 2005 and October 31, 2019. We reviewed the medical record for the presence and type of motor nerve injury, injury characteristics, timing of intervention, return to the operating room and presence of limitations in function at follow up. Injury characteristics and outcomes were summarized using univariate statistics.

**Results.** Ten patients (14%) sustained a concomitant motor nerve injury. Postoperatively, 7 patients demonstrated no limitation in function and complete nerve recovery at a median time of 8 weeks (range: 1-28) after injury. Two patients had persistent nerve deficits at final follow up and one patient left the country before completing follow up. Of the patients with nerve injury, five patients underwent nerve exploration at the time of operative intervention; three patients had nerves that were intact, one patient's nerve was caught in the fracture site, and one patient's nerve was partially lacerated.

**Conclusions.** Most nerve injuries associated with open forearm fractures recover spontaneously. However, nerve exploration at the time of injury can be justified as nerves can be lacerated upon injury or found incarcerated in the fracture site. Level of Evidence: IV

**Key words:** nerve injuries, pediatric forearm fractures,

### Riassunto

**Scopo.** La gestione delle lesioni nervose nelle fratture esposte dell'avambraccio

pediatrico rimane poco chiara. Lo scopo del nostro studio era quello di descrivere la frequenza relativa delle lesioni nervose con entrambe le fratture dell'avambraccio osseo aperte, così come i tassi di recupero nervoso dopo la lesione e l'impatto della prima esplorazione chirurgica del nervo.

**Metodi.** Abbiamo esaminato in retrospettiva 71 pazienti con entrambe le fratture dell'avambraccio osseo aperte in una struttura di assistenza terziaria per bambini tra il 1 gennaio 2005 e il 31 ottobre 2019. Abbiamo esaminato la cartella clinica per la presenza e il tipo di lesione del nervo motorio, le caratteristiche delle lesioni, i tempi di intervento, il ritorno in sala operatoria e la presenza di limitazioni in funzione al follow-up. Le caratteristiche e i risultati degli infortuni sono stati riassunti utilizzando statistiche univariate.

**Risultati.** Dieci pazienti (14%) hanno subito una concomitante lesione del nervo motorio. Dopo l'intervento, 7 pazienti non hanno dimostrato alcuna limitazione nella funzione e il recupero completo del nervo in un tempo mediano di 8 settimane (intervallo: 1-28) dopo la lesione. Due pazienti avevano deficit nervosi persistenti al follow-up finale e un paziente ha lasciato il paese prima di completare il follow-up. Dei pazienti con lesioni nervose, cinque pazienti hanno subito l'esplorazione nervosa al momento dell'intervento chirurgico; tre pazienti avevano nervi intatti, un nervo del paziente è stato catturato nel sito della frattura, e il nervo di un paziente è stato parzialmente lacerato.

**Conclusioni.** La maggior parte delle lesioni nervose associate a fratture aperte all'avambraccio si riprendono spontaneamente. Tuttavia, l'esplorazione del nervo al momento della lesione può essere giustificata in quanto i nervi possono essere lacerati in caso di lesione o trovati in carcere nel sito di frattura.

Livello di evidenza: IV

**Parole chiave:** lesioni nervose, fratture esposte dell'avambraccio

## Introduction

Forearm fractures occur in approximately 1:200 children each year and are one of the most common upper extremity fractures in children<sup>1</sup>. Additionally, forearm fractures account for a large percentage of open fractures in the pediatric population. One large, multicenter study found that 32% of pediatric open fractures were in the radius or ulna, while a separate single-institution study reported 80% of pediatric open fractures to be in the forearm<sup>2,3</sup>. Rates of neurologic injury after open pediatric both bone forearm fractures have been described from 4-14%, with reports of nerves being partially lacerated, perforated, or trapped in the fracture site<sup>4-9</sup>.

Traditionally, open forearm fractures in children have been treated with formal operative debridement and fixation, at which time the surgeon could choose to explore the forearm and assess for nerve injury. Over the last decade, however, there has been an increasing trend towards nonoperative management of pediatric open fractures. A recent systematic review of 17 studies involving 1093 pediatric open fractures

found a lower rate of osteomyelitis, wound infection, and non-union in nonoperatively treated open fractures, but cautioned that the quality of available evidence is still quite low<sup>10</sup>. As many institutions move toward nonoperative management of these fractures, the question is raised whether the presence of a nerve injury should help inform the decision to operate, and whether there is a role for nerve exploration at the time of debridement, when a nerve injury is present.

In open pediatric both bone forearm fractures, little is known about predictors of nerve injury, relative rates of nerve injury, rates of nerve recovery, and the role of nerve exploration at the time of surgery. This study aimed to describe the relative frequency of nerve injuries associated with pediatric open both bone forearm fractures, to describe the rate of nerve recovery after injury, and to determine the role for early surgical nerve exploration in open both bone fractures.

## Methods

### **Study design and baseline characteristics**

After obtaining institutional review board approval, we performed a retrospective review of all patients between 0 and 19 years of age, treated for an open both bone forearm fracture at a tertiary children's hospital between January 1, 2005 and October 31, 2019.

We queried our electronic medical record for all patients treated for an open forearm fracture or an unspecified forearm fracture of the forearm using the appropriate codes



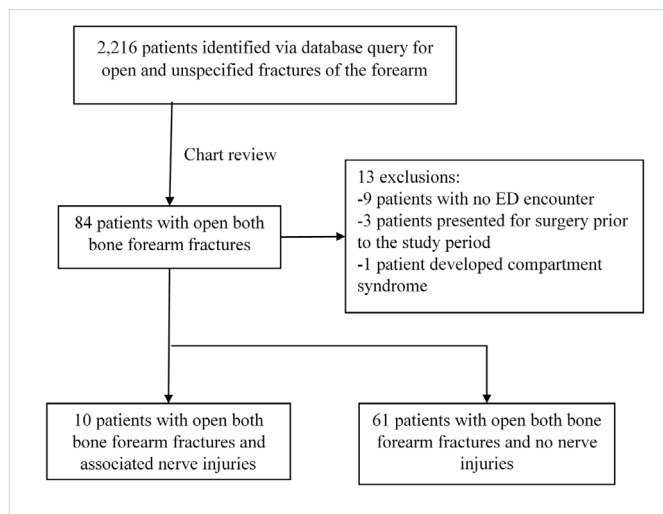


Figure 1. Consort study flow diagram illustrating case inclusion.

from the International Classification of Disease, Ninth and Tenth Revision, and identified 2,216 patients for further review. We excluded patients 19 years old or greater, patients without an emergency room encounter, patients with compartment syndrome, and patients without a documented neurovascular exam before and after treatment. Upon chart review we identified 71 patients with open both bone forearm fractures (Fig. 1).

The average age was 10.6 years (4.1-15.6) and 69 percent were male. Most patients suffered their injury when falling from less than five feet (61%). (Tab. I)

**Data collection**

The medical record of each patient in the cohort was reviewed. Demographic variables included age and sex. Injury characteristics included the presence and type of nerve injury, mechanism of injury, timing of operative intervention, presence of arterial injury, presence of perfused hand, fracture location of radius and ulna (proximal, middle, or distal third), fracture apex in the coronal and sagittal plane, type of operative fixation, presence of prophylactic fasciotomies, extent of soft tissue injury, return to the operating room and presence of limitations in function at follow up. A nerve was considered injured if motor function innervated by the median, ulnar or radial nerves was documented as absent. Patients with subjective paresthesias but intact motor function were not considered to have a nerve injury given the difficulty interviewing and examining pediatric patients. For patients with an injury to the ulnar, median or radial nerves, we recorded the presence of nerve exploration at the time of operative intervention, the extent of nerve recovery, and the timing of nerve recovery in weeks. Extent of nerve recovery

Table I. Injury and surgery characteristics (N = 71).

Characteristic	Freq.	(%)
Age (years; mean ± SD)	10.6	2.84
Sex (% male)	49	(69%)
Nerve injury	10	(14%)
Ulnar nerve injury	6	(9%)
Median nerve injury	2	(3%)
Radial nerve injury	2	(3%)
Vascular status	70	(99%)
Location of ulnar injury		
Proximal third	1	(1%)
Middle third	36	(51%)
Distal third	34	(48%)
Location of radial injury		
Proximal third	13	(18%)
Middle third	25	(35%)
Distal third	33	(47%)
Mechanism of injury		
Fall < 5 feet	43	(61%)
Fall > 5 feet	24	(34%)
Sports	3	(4%)
Penetrating trauma	1	(1%)
Surgical nerve exploration	6	(9%)
Extent of soft tissue injury		
I	60	(85%)
II	11	(16%)
Operative treatment	70	(99%)
Type of operative fixation used		
Mixed	25	(35%)
Pin	22	(31%)
Plate	19	(27%)
Cast	5	(7%)

SD, standard deviation.

was determined based on review of the clinical notes. Any motor deficit compared to the contralateral limb at the time of final follow up was considered incomplete nerve recovery. Recovery was considered complete if documented or if no deficit was noted at final follow up. Limitation in function was the presence of a complaint related to the injury at final

follow up. Mechanism of injury was categorized as sports, motor vehicle collision, fall from less than 5 feet, fall from greater than 5 feet, penetrating trauma or other. Falls from the monkey bars were considered falls from greater than 5 feet given monkey bars usually stand at least 5 feet off the ground. Extent of soft tissue injury was taken from the operative report and based on the Gustilo-Anderson classification <sup>11</sup>. Presence of arterial injury was considered present if a pulse was absent or an injured artery was discovered intra-operatively. All hands with normal capillary refill in each digit were considered perfused. Timing from injury to operative intervention was estimated based on the history of present illness and timing of operative intervention and then categorized as 0-12 hours, 12-24 hours, and greater than 24 hours. These time periods were chosen because they could be accurately estimated based on the history and timing of surgical intervention. Site and apex of the fractures were collected from review of the radiographs. The data presented here meets the Strengthening the Reporting of Observational Studies in Epidemiology.

**Statistical Analysis**

Injury characteristics and outcomes were summarized for the cohort. Continuous variables were summarized by mean and standard deviation (SD) or median and interquartile range (IQR), as appropriate. Categorical variables were summarized by frequency and percent. Multivariable logistic regression analysis of predictors of nerve injury was deferred because of our small study cohort.

**Results**

We examined a total of 71 open forearm fractures; 60 fractures (85%) were grade 1 and 11 were grade 2. Ten patients (14%) suffered a motor nerve injury associated with their open both bone forearm fracture. Ulnar nerve injuries were the most common, occurring in 6 patients (9%). In addition, there were 2 (3%) subjects with a median nerve injury, and 2 (3%) subjects with a radial nerve injury. Fracture location was near evenly split between medial and distal thirds, with only 1 open fracture in the proximal ulna. Most children (61%) sustained their open injuries after a fall from less than 5 feet (Tab. I).

All 71 subjects were treated with irrigation and debridement in the operating room. The fracture edges were irrigated and debrided until deemed clean through extension of the traumatic wound or the approach for fixation depending on fracture location. The vast majority (93%) also underwent operative fixation, consisting of plates and screws, intramedullary rods, or a combination. All patients received antibiotics upon presentation to the emergency room that were continued

until 24 hours post-operatively; cefazolin or clindamycin were used in all patients except one who received Unasyn for coverage of flora from a dog bite.

The 10 patients who sustained a nerve injury had their index surgery performed by 10 separate surgeons in our practice. Five patients had their injured nerve explored at the time of operative treatment; while 5 did not. Exploration was performed based on surgeon discretion. Three of the 5 patients who underwent exploration had a nerve that was bruised but intact, one patient’s ulnar nerve was found entrapped within the fracture site and a second patient’s ulnar nerve was partially lacerated and underwent repair. Postoperatively, 7 of the 10 subjects with nerve injuries (4 ulnar, 2 radial, and 1 median nerve injuries) demonstrated no limitation in function and complete recovery of the nerve at a median time of 8 weeks (range, 1 to 28 weeks) after injury. Three of the 71 subjects (4%) had persistent nerve deficits and limitation in function at the time of final follow up. One patient with a partial ulnar nerve laceration requiring repair at initial surgery had persistent dorsal interossei dysfunction at 20 weeks post-operatively. One patient who suffered a dog bite and was found to have a median nerve deficit but a nerve in continuity at the time of surgery complained of chronic pain, numbness in the median nerve distribution and weakness in forearm at final follow up 67 weeks after intervention. Another patient with an ulnar nerve injury that did not undergo exploration left the country after his three-week post-operative visit, at which time ulnar nerve function had not returned.

Of the 71 open fractures, 45% required a return to the operating room, the majority of which were for removal of hardware. Of the ten patients with nerve injury, 6 (9%) required return to the operating room for removal of hardware. (Tab. II) One patient with nerve injury (1%) required return to the operating room for repeat irrigation and debridement and scar revision in addition to their removal of hardware.

**Table II. Outcomes (N = 71).**

Characteristic	Freq.	(%)
Returned to operating room	32	(45%)
Limitation in function	3	(4%)
Nerve recovery	9	(13%)
Partial	2	(3%)
Complete	7	(10%)
Timing of nerve recovery (weeks; median (IQR); n = 9)	8	(5-19%)

*IQR, interquartile range.*

No surgical interventions were required to address nerve deficits. No patients had nerve deficits identified post-operatively.

## Discussion

This study of 71 pediatric open forearm fractures found a 14% rate of motor nerve injury. Although the ulnar nerve was the most commonly injured, it is interesting to note that both median and radial nerve injuries were also identified in this cohort. There were no associated vascular injuries in this cohort of type 1 and 2 open fractures. We could not identify predictors of nerve injury amongst patient factors such as age, sex, mechanism of injury, fracture location, or extent of soft tissue injury given our small numbers. Intra-operative procedures varied in our practice, as 5 of the patients underwent nerve exploration at the time of their index procedure, while 5 of the patients did not. Despite this, most subjects did well, with 7 of 10 subjects demonstrating complete nerve recovery at a median of 8 weeks after injury. These findings are similar to the more common scenario of nerve injuries associated with extension-type supracondylar humerus fractures in children. Nerve injuries are seen in approximately 11% of extension-type supracondylar humerus fractures, most of which are not explored, with a similar median time to recovery and high rate of recovery<sup>12</sup>.

Our study has limitations. First, we used a retrospective methodology and data reported here was obtained via chart review. Subtle nerve dysfunction at the time of last follow up may be missing, and timing of nerve recovery had to be estimated based on the first post-operative exam with normal nerve function. Second, we were underpowered to detect predictors of nerve injury associated with open both bone forearm fractures given our small numbers, and the literature would benefit from a meta-analysis or multi-center study.

In our series, most patients made a full recovery with only a small number of patients demonstrating residual limitations because of their nerve injuries. This is consistent with other series in the literature. Greenbaum described 62 open pediatric forearm fractures and found that 7 patients had nerve dysfunction identified preoperatively or postoperatively and all nerves recovered with appropriate fracture care. The injured nerves did not require intervention<sup>4</sup>. Haasbeek et al reported their experience with 46 open both bone forearm fractures, identifying three subjects with median nerve injuries and two with combined ulnar and median nerve injuries. All nerve injuries in their cohort recovered, including one child with a degloving injury who underwent acute median and ulnar nerve repairs<sup>5</sup>. Luhmann et al reported on 65 open pediatric forearm fractures and found that 9 patients had at least one nerve injured. There were six median nerve, three ulnar

nerve and two radial nerve injuries that all improved by two months post-operatively. Injured nerves were only explored if they were encountered during irrigation and debridement<sup>6</sup>. It is difficult to recommend a change in practice based on this series. Our findings support those surgeons who do not routinely explore the nerves in this scenario, given the rarity of these nerve injuries and the high rate of recovery despite only half of patients underwent nerve exploration. However, in the patients who did undergo nerve exploration, one patient was found to have a nerve trapped within the fracture site and a second patient underwent acute repair of an ulnar nerve laceration and these patients went on to full recovery. Given this possibility, those surgeons who routinely explore the nerves in this scenario may continue to feel that exploration is warranted, particularly when the injured nerve is directly in the operative field. Whether acute exploration is performed, it is important to recognize motor nerve injury as a major cause of prolonged recovery after pediatric open both bone forearm fracture. Patients with these injuries require longer postoperative follow-up, and families should be counseled on the risk of incomplete recovery.

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# Hand trauma under six years of age

## Trauma alla mano sotto i sei anni

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### Summary

**Introduction.** The use of the hand in daily activities undergoes an increase in the first years of age in relation to their increased interaction with their surroundings. For this reason, hand injuries are among the leading causes of access to pediatric emergency rooms.

Although the majority are minor trauma, there is a percentage of cases with risk of long-term outcomes such as retracting scars, sensitivity disturbances, and reduced residual growth.

The literature is poor with studies focused on pediatric hand trauma, especially in preschool age. The purpose of the study was to analyze the incidence of these injuries in a pediatric population under 6 years of age.

**Materials and methods.** The authors performed a review of patients presented at the pediatric emergency department of the Gaslini Institute in Genoa during the period from 2015 to 2021.

Inclusion criteria in the study were:

- trauma distal to the wrist (distal radius and carpus excluded);
- age less than 6 years;
- no previous treatment.

**Results.** Out of 1356 patients evaluated for trauma involving the hand, 390 of these met the inclusions criteria.

The male was involved more than the female; the main trauma was finger-cutting injuries, followed by crushing and palmar wounds.

The main traumatic mechanisms found were accidental closing of the fingers in a door or car door or chairs, wounds following accidental knives use and animal bites. The index finger was found to be the mainly injured, followed by the thumb and ring finger.

The age group between 1 and 4 years was prone to have the majority of patients. 362 children were treated in the emergency room while only 28 required hospitalization and surgery.

**Conclusions.** Analysis of the study data allows the authors to conclude that, although these are frequent injuries, they are often minor and do not require hospitalization. However, there is a need for the implementation of educational prevention programs that make both adults and children aware of the potential risks present in both home and non-domestic and school environments.

**Key words:** hand trauma, fingertip injuries, pediatric trauma

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#### Conflitto di interessi

Gli Autori dichiarano di non avere alcun conflitto di interesse con l'argomento trattato nell'articolo.

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**Riassunto**

**Introduzione.** L'uso della mano nelle attività quotidiane subisce un netto incremento nei primi anni di vita dei bambini in relazione alla loro maggiore interazione con l'ambiente circostante; per tale motivo le lesioni della mano sono tra le principali cause di accesso presso il pronto soccorso pediatrico.

Nonostante la maggioranza degli accessi sia per traumi di lieve entità, esiste una percentuale di casi con rischio di esiti a lungo termine quali cicatrici retraenti, disturbi di sensibilità, ridotta crescita residua.

La letteratura è povera di studi focalizzati sui traumi della mano pediatrica, soprattutto in età prescolare; scopo del presente lavoro è stato analizzare l'incidenza di queste lesioni in una popolazione pediatrica al di sotto dei 6 anni di età.

**Pazienti e metodi.** Gli autori hanno eseguito una revisione degli accessi presso il Pronto Soccorso pediatrico dell'Istituto Gaslini di Genova nel periodo compreso tra il 2015 ed il 2021.

I criteri di inclusione nello studio sono stati:

- traumi distali al polso (radio distale e carpo esclusi);
- età inferiore a 6 anni;
- nessun precedente trattamento.

**Risultati.** Nel periodo in esame, 1356 pazienti sono stati accettati per traumi riguardanti la mano; 390 di questi sono stati inclusi nello studio.

Il sesso maschile è stato coinvolto maggiormente del femminile; il principale trauma è stato rappresentato dalle lesioni da taglio delle dita, seguite da schiacciamento e ferite del palmo della mano.

I meccanismi traumatici principalmente riscontrati sono stati la chiusura accidentale delle dita in una porta o portiera di auto o sedie, le ferite da taglio con coltelli ed i morsi di animali.

L'indice è risultato il dito principalmente leso, seguito da pollice ed anulare.

La fascia di età tra 1 e 4 anni è stata quella in cui si localizzavano la maggioranza dei pazienti.

La maggioranza dei pazienti (362) sono stati trattati in pronto soccorso mentre solo 28 hanno necessitato di ricovero ed intervento chirurgico.

**Conclusioni.** L'analisi dei dati dello studio permette di concludere che, seppur trattandosi di traumi frequenti, sono spesso di lieve entità e non richiedono ospedalizzazione.

È tuttavia necessaria la realizzazione di programmi educativi di prevenzione che rendano sia gli adulti che i bambini consapevoli dei potenziali rischi presenti sia in ambiente domestico che extradomestico e scolastico.

**Parole chiave:** traumi della mano, mano pediatrica, lesioni apicali

**introduction**

The hand involvement in daily activities increases during the first ages of life, achieving the children to learn new skills in order to react to new challenges; it is by using the hand, kids can improve their brain functions allowing motor and sensitive areas to organize themselves<sup>1</sup>. Hand injuries continues to be among the most common trauma in childhood; when fingers are injured many daily activities, such as eating, playing or making schoolwork, are restricted or unexecutable with a negative impact on the entire family life. Boys are usually more at risk of injury as a result of their more reckless characters and home seems to be the place where the majority of injuries happens; however, different mechanisms of trauma in places other than homes may result from different social and cultural contexts.

In spite of the majority of patients suffer from minor traumatic injuries, there is the potential risk of permanent morbidities such as scar contracture, loose of sensation, growth disturbance with functional and aesthetic long term impacts<sup>2</sup>.

Although the high frequency of these traumas, the literature is relatively poor in reports on the subject and even less so for those involving children in pre school-age. The aim of the paper is to analyze the trauma of the hand in a population of children under 6 year of age, reporting on trauma mechanism and common option of treatment.

**Materials and Methods**

A retrospective analysis of hospital institutional database (tertiary pediatric care center) was carried out searching for the patients with hand trauma admitted at emergency room; the registers between 2015 and 2021 were analyzed using the ICD9 code for the research.

The inclusion criteria was:

- trauma distal to the wrist (distal radius and carpus excluded);
- age under 6 years;
- any previous treatment.

Patients with trauma at levels or proximal to the wrist, age over 6 years and children admitted for second opinions after a treatment carried out in a spoke center were excluded. Considering the nature of the study, the approval of ethical committee or IRB was not mandatory.

### Results

Out of 1356 hand trauma managed during the period of the study, only 390 met the inclusion criteria.

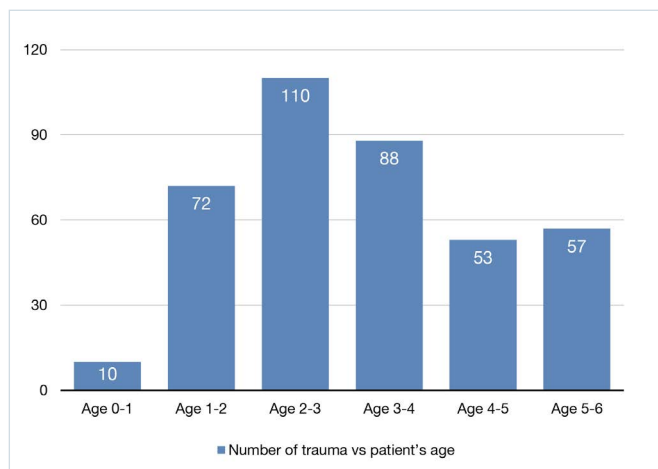
Male was affected in 59% (231 cases) of cases and female in the remnant 41 % (159 cases).

Fingers cutting injuries represented the main trauma (183 cases) followed by fingers crushes (88 case) and hand cutting injuries (60 cases) (Fig. 1).

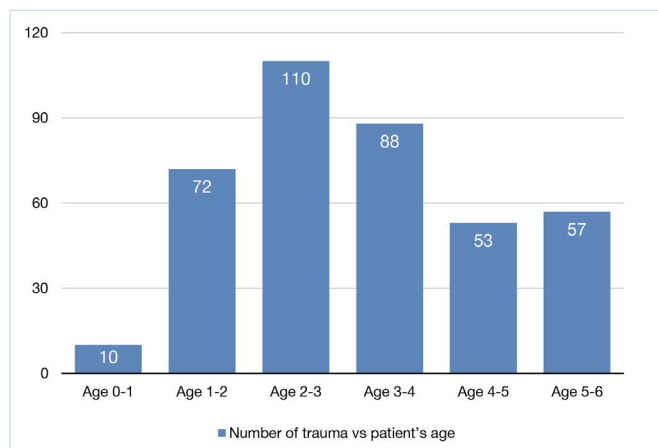
Fingertip was injured in 31 children while 25 suffered from isolated fractures of metacarpals or phalanges; finally 3 patients were affected by amputation, PIP dislocation and sprain. The most common mechanisms of injury were getting a finger stuck in a door, cutting the hand with glass, knives or scissors and crushing a finger inside a chair; another paramount causes were animal bites such as dogs, rabbits, cats, squirrels. Index was the most injured finger (33 %) followed by thumb (23 %) and long finger (22 %) whereas ring and little fingers were the least affected (15 % and 8 %). Figure 2 shows the rate between number of trauma vs patients



**Figure 1.** Shows four type of common hand injuries in pre school age.



**Figure 2.** The rate between number of trauma vs patients ages.



**Figure 3.** Number of surgeries vs patient's age.

**Table I.** Types and numbers of treatment carried out in emergency room with or without local anesthesia.

Treatment in emergency room	
Dressing	107
Skin suture	90
Steristrip placement	77
Skin suture & nail repair	49
Dressing and cast	33
Others	6

ages. All the children were treated; out of 390 children, 362 were treated in emergency room: Figure 3 reports on the per-

**Table II.** Types and numbers of surgical procedures performed under general anesthesia.

Surgical procedures	
Flexor tendon suture	6
Skin suture	5
Osteosynthesis	3
Advancement flap	4
Extensor tendon suture	2
Extensor tendon suture + osteosynthesis	2
Tendon graft + local flap	2
Flexor tendon suture + local flap	2
Flexor tendon suture + digital nerve suture	2

formed procedures. The remaining 28 patients underwent surgeries which are listed in Table I; furthermore, Table II shows the number of surgical procedures related with patient's age.

## Discussion

Despite not being the first reason of admission in emergency room, pediatric hand trauma still represents a paramount because of their potential interference with the daily life of the children and their family.

A child who experienced pain and immobilization reduces his daily activities such as eating, playing, making school activities; moreover, it could create a potential anxiety about recovery of function and long term sequelae.

Although the real incidence of hand trauma in children is still unknown, several authors reported on these injuries, highlighting how family, home, social and cultural environment could influence the risk of injuring the hands <sup>3,4</sup>.

To our knowledge, this analysis is the second one exclusively focused on a population under six years of age; it may be considered the period with higher risk of accidental hand trauma, especially at home, due to the fact children can easily escape the parental control guided by their poor judgment and high curiosity.

In the analyzed cohort, the ages between one and four seems to be more at risk than the first year and the period four to six, according to what reported by a retrospective study on

a population of 344 injured hand in patients younger than 16 years of age <sup>5</sup>.

Cutting injuries affected the fingers and the palmar region in the majority of cases; glasses, knives, scissors and blades were the most common sources of wounds due to their wide presence in each home, where, eluding the parental control, children are often able to take possession of them <sup>6</sup>.

The second cause of trauma were crushing, firstly arising from getting the fingers stuck in home or car doors which must be considered as a hazard for children.

On the one hand they can close the door without being careful their fingers are free; on the other hand it is not uncommon a parent or relative are closing the door while the baby's fingers are still inside <sup>7</sup>.

When analyzing the location of the injuries in the cohort, index fingers was the most common site, followed by thumb and long fingers; it differs from other series where long finger and thumb were the main affected <sup>8,9</sup>.

Animal bites showed to be an additional source of trauma, with children being victims in more than half of cases; despite dogs continues to be the main source of bits, the spread of different pets, such as rabbits, cats, squirrels, explains how nearly one-third of animal bites in our cohort do not come from dogs <sup>10</sup>.

The therapeutic approach was little discussed in the articles published on the topics; in the analyzed series, 93 % of patients were managed in emergency room and followed in outpatients clinic while only 7 % underwent surgery.

All the surgical procedures regarded patients with tendon injuries, displaced fractures, wide fingertip injuries as well as children with simple wounds but so rambunctious that they cannot be managed under local anesthesia.

The analysis of the type of therapeutic procedures performed in the 390 children included in the study allows the authors to affirm that, although hand injuries are common in children in pre school age, they are often not so serious allowing to treat it without hospitalization.

In conclusion, hand injuries in pre school age are still common especially in home environment but, despite the relative high frequency, their management is often easy enough not to require hospitalization or lengthy treatment.

Educational programs against pediatric hand trauma should be created by institutions in order to make both adults and children aware of the mechanism and causation as well as potential long term repercussions both on function and esthetics of fingers and hand.

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## Surgical management of hand deformity in *Epidermolysis Bullosa*: our experience in a case series of pediatric patients

*Gestione chirurgica della deformità della mano in Epidermolisi Bullosa: la nostra esperienza in una serie di casi di pazienti pediatrici*

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Gli Autori dichiarano di non avere alcun conflitto di interesse con l'argomento trattato nell'articolo.

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### Summary

In this study we present 2 patients for a total of 2 surgically treated hands. Data were collected between 2017 and 2023 at Azienda Universitaria Policlinico di Modena (Modena, Italy). The postoperative follow-up period ranged between 12 months and 18 months, with an average duration of 15 months. The procedure performed on these patients involved a first web release for the thumb and/or pseudosyndactyly release for the remaining digits and/or the surgical treatment of camptodactyly with Malek cutaneous approach. Acellular dermal substitute (Matriderm®) was used to cover the remaining commissures, digits, and the remainder of the hand. Postoperative rehabilitation ensued. The patient's medical history, physical examination findings, and treatment are described. The outcome of surgical release and rehabilitation are discussed. Results: Long-term results are encouraging, demonstrating maintenance of functions.

**Key words:** epidermolysis bullosa, hand surgery, hand deformity, surgical management, anesthetic management, surgical technique

### Riassunto

In questo studio presentiamo 2 pazienti affetti da Epidermolisi Bullosa autosomica recessiva distrofica, per un totale di 2 mani trattate chirurgicamente. I dati qui presentati sono stati raccolti tra il 2017 e il 2023 presso l'Azienda Universitaria Policlinico di Modena (Modena, Italia). Il periodo di follow-up postoperatorio variava tra i 12 mesi e i 18 mesi, con una durata media di 15 mesi. La procedura eseguita su questi pazienti ha previsto l'apertura della prima commissura per il recupero di motilità del pollice e/o la correzione della pseudosindattilia per le restanti dita e/o il trattamento chirurgico della camptodattilia con l'approccio cutaneo di Malek. È stato utilizzato un sostituto dermico acellulare (Matriderm®) per coprire perdite di sostanza residue dall'apertura delle commissure. I

*pazienti qui destritti sono stati indirizzati verso un ben definito percorso di riabilitazione postoperatoria. Vengono descritti la storia medica del paziente, il trattamento e i risultati osservati. Si discute il risultato del release chirurgico e della riabilitazione. Risultati: i risultati a lungo termine sono incoraggianti, dimostrando il mantenimento delle funzioni recuperate (es funzione di pinza).*

**Parole chiave:** epidermolisi bollosa, chirurgia della mano, deformità della mano, gestione chirurgica, gestione anestesiologicala, tecnica chirurgica

## Introduction

Epidermolysis Bullosa (EB) was first described as 'erblichen pemphigus' by Von Hebra in 1870<sup>1</sup>. It is a group of rare skin conditions, that result in skin and mucous membranes fragility, which can be an acquired or inherited disorder.

Based on the site of formation of the blisters, it is possible to identify four types of EB:

- EB simplex (EBS);
- Junctional EB (JEB);
- Dystrophic EB (DEB);
- Kindler syndrome (KS).

Each type can be further classified based whether on the mode of transmission, or on the clinical phenotype or on the immunofluorescence, structural and molecular pattern<sup>2-3</sup>.

Alternatively they can be classified based on the splitting site:

- epidermolysis bullosa simplex: epidermis;
- junctional epidermolysis bullosa: within the lamina lucida of the basement membrane zone;
- dystrophic epidermolysis bullosa: within the dense sublamina;
- Kindler syndrome: variable<sup>4</sup>.

Hallmark of the EB is the blistering of the skin and mucous membranes. Blisters occur due to traumas, which lead to the development of chronic ulcers, often sparsely cicatrizing, with propensity to infections, pain and itch.

EB severity can range from mild to fatal. In mild cases the patients present superficial blisters, mostly located on the hands and feet, which do not influence their life span. On the other hand, in severe cases patients risk death in the first postnatal period due to infections or electrolyte imbalance. Furthermore, few types of EB have the propensity to develop aggressive squamous cell carcinomas which can quickly metastasise leading to premature death<sup>5</sup>.

### **Hand deformity in patients affected by EB**

As explained above all EB types hit the hands, however the patients that need to undergo surgery and a therapeutic plan are the ones affected mainly by Dystrophic epidermolysis bullosa (DEB).

The hand is a delicate region, strongly prone to the development of blisters, ulcers and scars due to simple tangential forces and daily friction<sup>6-8</sup>.

Common deformities include thumb adduction contrac-

tures, digit pseudosyndactyly, flexion contractures of finger inter-phalangeal joints (IPJs) and metacarpal phalangeal joints (MCPJs) and wrist, occasional extension contractures of MCP joints from dorsal scarring.

A mitten deformity develops when the hand becomes encased in an epidermal cocoon. In Recessive Dystrophic Epidermolysis bullosa (RDEB) the risks of this developing are 98% by the age of twenty<sup>6-9</sup>.

All hand structures may be affected by the disorder. Cutaneous involvement results in dermal fibrosis, pseudosyndactyly, contractures, atrophy of finger and thumb tips, nail loss and dermal cocooning.

Musculotendinous involvement results in flexor tendon shortening and intrinsic muscle contractures. IPJs and MCPJs flexion causes collateral ligaments to contract and become fibrotic overtime. Constant abnormal stress and deforming pull on joints by contracting scar tissue causes destructive joint changes and subluxation. All web spaces become obliterated progressing to digit tips. Advanced hand deformity results in functional impairment including loss of fine motor manipulation<sup>8</sup>.

## Surgical indications

The evidence as to whether surgery improves hand function is not clear, due to the lack of large, controlled studies. However, it is proven by most data that surgery gives a chance of improvement in hand function in DEB cases both in severe and moderate stages of deformity<sup>8</sup>.

Obtaining a functional thumb-index pinch is the main goal of surgical treatment. The release of the thumb adduction contracture produces the most dramatic improvement in patients, together with surgical treatment of camptodactyly. The main goal would be the release of all fingers, if possible.

Surgery and release of pseudo syndactyly allow independent finger motion and improve aesthetic appearance of the hands. In particular, surgery in children may help prevent developmental and motor delay and hand atrophy<sup>11,12</sup>.

However, it needs to be taken into account that the positive effect of surgery is not constant, showing a Gaussian distribution curve, rising with healing, and decreasing in time with recurrence.

The decision to operate, therefore, needs to be taken based on several factors:

- good health status of the patient;
- rapid progression of hand contractures and pseudosyndactylies;
- loss of manual function;
- the patient's or parents' request;
- the effect on the psychosocial development of the patient.

It is preferred to operate initially before the patient turns eleven years old. It is in fact proven that the correction of contractures in children often leads to more satisfactory results rather than in adolescents or adults, due to the fact that joint deformities in the lasts present themselves as too difficult to be corrected completely<sup>14-16</sup>.

## Anesthesia

Considering the gravity and rarity of the disorder, it is strongly recommended that an experienced EB nurse is present during surgery, to highlight specific problems: previous anesthetic, airway, vascular access, or medical problems, and provide comfort and support to the individual.

In particular, their role is to advise and educate the anesthetic and theatre team on skin care, and what procedures to avoid (adhesive dressings, safe handling)<sup>8</sup>.

Taking into account anesthesia, the type used appears mainly related to age. Younger individuals are more likely to undergo General Anaesthetic (GA), and older individuals Regional Anaesthetic (RA) ± intravenous ketamine or sedation. Given that mouth opening tends to worsen with age, RA is increasingly preferred to avoid risks to the airway<sup>8</sup>.

In children when used flunitrazepam and ketamine and either an axillary or supraclavicular block, brachial plexus blocks, and ketamine were reported<sup>17</sup>.

## Pre-operative care

The patient is carefully placed on an operation table that must be well prepared to prevent pressure ulcers. Large padding should be used at the pressure zones, and repositioning of the patient during the procedure should be avoided. The skin is disinfected using a "buffering" technique or a spray of the preparation, preferably in nonalcoholic form<sup>8</sup>. Anesthetic creams such as EMLA (lidocaine-prilocaine) are usually used to provide local skin anesthesia before intravenous cannulation in children. Ultrasonography can be useful for vein cannulation or blood drawing<sup>8</sup>.

No adhesive tapes are used, soft bands are usually preferred. Skin fragility also poses an infection risk. Wound care management is done according to the DEBRA guidelines. Finally, the management of pain pre- and postoperatively

can be challenging in these patients due to the presence of chronic pain, reliance on analgesics, and physical stress intolerance in some<sup>8</sup>.

The anesthesiologist chooses the type of anesthesia most suitable for the patient. General anesthesia must be avoided. There exists a risk of complex intubation due to the presence of microstomy, fragility of the oral and nasal mucosa and laryngotracheal stenosis in some. Laryngeal masks are to be avoided. In our study, intravenous sedation (ketamine) coupled with locoregional anesthesia is the method of choice. Intravenous sedation and ketamine usually have the advantage to not cause oropharyngeal trauma. Ketamine, however, can increase oropharyngeal secretions that require special attention and monitoring<sup>8</sup>.

Perioperatively, the antibiotic most often given to patients is Augmentin® (amoxicillin + clavulanic acid). When hardware is placed (i.e., Kirschner wires), antibiotics of the cephalosporin family (first generation) are used. Antibiotics are not indicated postoperatively unless there are signs of infection<sup>8</sup>.

## Post-operative care

Fundamental in the first few weeks following surgery is to protect the surgical site by caring for the skin. If the skin was grafted, this must be closely monitored for integrity. Timing of skin reepithelization varies but has been reported to be achieved around 14-35 days postop<sup>11-18</sup>.

It is strongly recommended that the first dressing layer, in contact with the skin, consists of a non-adherent gauze such as Vaseline Petrolatum or Hollister Restore, or a soft silicone or foam product, such as Mepilex Lite, Mepitel or Mepilex Transfer. The first dressing layer should be arranged or cut in a fashion that covers all surgically affected skin maintaining web spaces.

Under specific indication of the surgeon, the silicone or foam layer may be covered with a thin layer of Vaseline in the manner of "buttering bread."

The base layer is held on by one-inch gauze wrapping in a secure, overlapping "boxer's wrap" fashion, including web spaces and digits. It is possible, if preferred by the patients, to wear a soft stockinette over dressings, with the wrapped thumb and fingers free to move<sup>10,13,17,19-22</sup>.

In addition, it is advised that post-operative hand orthoses/splints are worn to maintain the surgical gains and help delay contracture recurrence, as displayed by most articles. This should start as soon as individuals can tolerate the fabrication process, which may be while the hand is still fully dressed.

However, timing also depends on whether fixation (i.e., Kirschner wires) is used. The wounds may leak onto the splint/orthosis, so lining and strapping materials should

allow easy replacement or cleaning with soap and water<sup>10,13,17,19-22</sup>.

It is advisable to fabricate a hand or forearm based resting splint/orthosis including the fingers and thumb. The splint/orthosis should hold the fingers and thumb in maximum passive extension and abduction, as tolerated by the individual. It should be lined or padded to cushion the hand and protect the skin. Strapping should also be as soft as possible<sup>10,13,17,19-22</sup>.

Where only the first web space is released, the thumb should be positioned in abduction with a silicone elastomer putty spacer, held in place by a thermoplastic splint/orthosis or careful wrapping.

Based on past experiences, we recommend full time splint/orthosis wear from week three or four post-op, removing only for light activity and exercise<sup>23</sup>. Only from two to four months postop individuals may transition to use only at night<sup>13,22</sup>.

Individuals should begin to use their hands for function approximately four to five weeks post op.

### Material and methods

This was a retrospective review with data collected from the archives of Azienda Ospedaliera-Universitaria Policlinico di Modena. The data reviewed were collected between 2017 and 2023.

### Patient profiles

This study includes 2 patients with RDEB who underwent surgical releases of either thumb adduction<sup>1</sup> or the surgical treatment of camptodactyly of II and III IFP<sup>1</sup> with Malek cutaneous approach, including the use of dermal substitute Matriderm.

One female and one male patient, with an average age of 14 years (range: 13-15 years) were treated by a single operator (sg). Surgery was performed on 2 right hands. A total of 2 operations took place, with 2 hands having undergone a single procedure (100%). One patient underwent previous surgeries at other institutions.

A total of 2 hands had Matriderm 1 mm placed (100%). The postoperative follow-up period ranged between 12 months and 18 months, with an average duration of 15 months.

### Anesthesiology Management in EB patients

All EB patients have been evaluated by a highly skilled anesthesiology team given the complexity of this patient population and scheduled well in advance to facilitate multidisciplinary coordination and completion of preoperative testing. The extent of cutaneous involvement has been documented, with particular attention to the airways, eyes, and upper extremities. Patients with severe EB are expected to have limited mouth opening with smaller interincisive distance, dental caries, and limited neck extension from contractures, which is im-

**Table I.** Clinical characteristics and surgical treatment performed.

Patient number	Sex	Diagnosis	Previous treatment	Age when operated (y)	Hand operated	Artificial dermis	Kirschner wire	Anesthesia	Follow-up (months)	Comorbidities
1	F	Pseudosyndactyly: simple and complete	Yes	15	R	Matriderm	Yes	Locoregional	18	Esophageal strictures
2	M	Camptodactyly IFP II-III fingers	No	13	R	Matriderm	Yes	Locoregional	12	/

**Table II.** Anesthetic characteristics and corresponding management.

Paz (age)	Difficult airways	Regional Block technique	Perioperative Sedo-analgesia protocols	Postoperative analgesia	Complications
Pz 1 15 anni 37 kg	Yes Interincisive distance < 2 cm	ENS - Ultrasound guided brachial plexus via axillary block tot 95 .mg ropivacaine 0,475%	Midazolam 3mg i.v. Fentanyl 100 mcg iv Propofol 80mg	Paracetamol 500mg/8h Ketorolac 15mg rescue dose	no
Pz 2 13 anni 34 kg	Yes Interincisive distance < 2 cm	ENS - Ultrasound guided brachial plexus via axillary block tot 75 mg ropivacaine 0,475%	Midazolam 6 mg i.v. Fentanyl 30mcg iv	Paracetamol 250mg x3 Nurofen syrup 10ml ogni 88hy	no

portant for difficult airway planning. The presence of hoarseness or inspiratory stridor may suggest evaluation for laryngeal involvement. For hand surgery procedures, a combination of regional anesthesia and sedation was chosen to avoid potential complications associated with airway management. Careful planning and precautionary measures must be taken to minimize the risk of complications. Standard anesthesia monitors have been safely used in patients with EB with nonadhesive pulseoxymeters and a special gel pad that provides a conductive, nonadhesive barrier between the electrode and the skin. Blood pressure cuffs have been placed over cotton under-cast padding or existing dressings on the opposite arm.

### *Surgical technique*

In this study, hand surgery is performed under locoregional (with or without sedation) anesthesia.

### *Hand release*

Case 1. A 15-year-old DEB-diagnosed girl, who had previously undergone a first web release for the right thumb and pseudosyndactyly release presented recurrence of thumb adduction contractures, digit pseudosyndactyly and flexion contractures of finger inter-phalangeal joints (IPJs).

Under LR anesthesia, a cutaneous incision was performed on the dorsal aspect of the first interdigital space, between the 1<sup>st</sup> and 2<sup>nd</sup> metacarpal bones, then extended volarly to the base of the thenar region reaching the proximal palmar crease. We proceeded by plans isolating and protecting the nervous vascular structures, with the release of either fibrous tissues or soft tissues of the thenar region, incising the muscle fascia, improving as a consequence the opening of the 1<sup>st</sup> commissura. With the aid of the fluoroscope, a 1 mm Kirschner wire is inserted from the distal phalanx of the thumb to the 1<sup>st</sup> metacarpal locking it also to the trapezium bone. A second 1 mm Kirschner wire is inserted between the 1<sup>st</sup> and 2<sup>nd</sup> metacarpal bones. Accurate hemostasis was then performed, washing with physiological solution.



**Figure 1.** Case 1: pre-operative.



**Figure 2.** Case 1: post-operative.

In the following month the medication was renewed approximately every 4/5 days, at home or at our centre.

The first Kirschner wire was removed after approximately 10 days due to intolerance.

One month after the operations we proceeded to curettage and cleansing of the right hand. The patient was under sedation. We proceeded to the placement of a non-adherent dressing at the level of the first commissure and removal of ONE K-wire which showed signs of inflammation.

A silicone elastomer-based spacer was then placed over the Mepilex plates to keep the 1<sup>st</sup> interdigital space open while respecting the synthesis means. A plaster cast is applied to keep the wrist in a neutral position.

About a month later, under local anesthesia and sedation, surgical wound dressing of the right hand was performed and Kirshner's wire was removed.

Case 2. A 13-year-old DEB diagnosed boy was referred to us for camptodactyly of IFP II-III fingers.

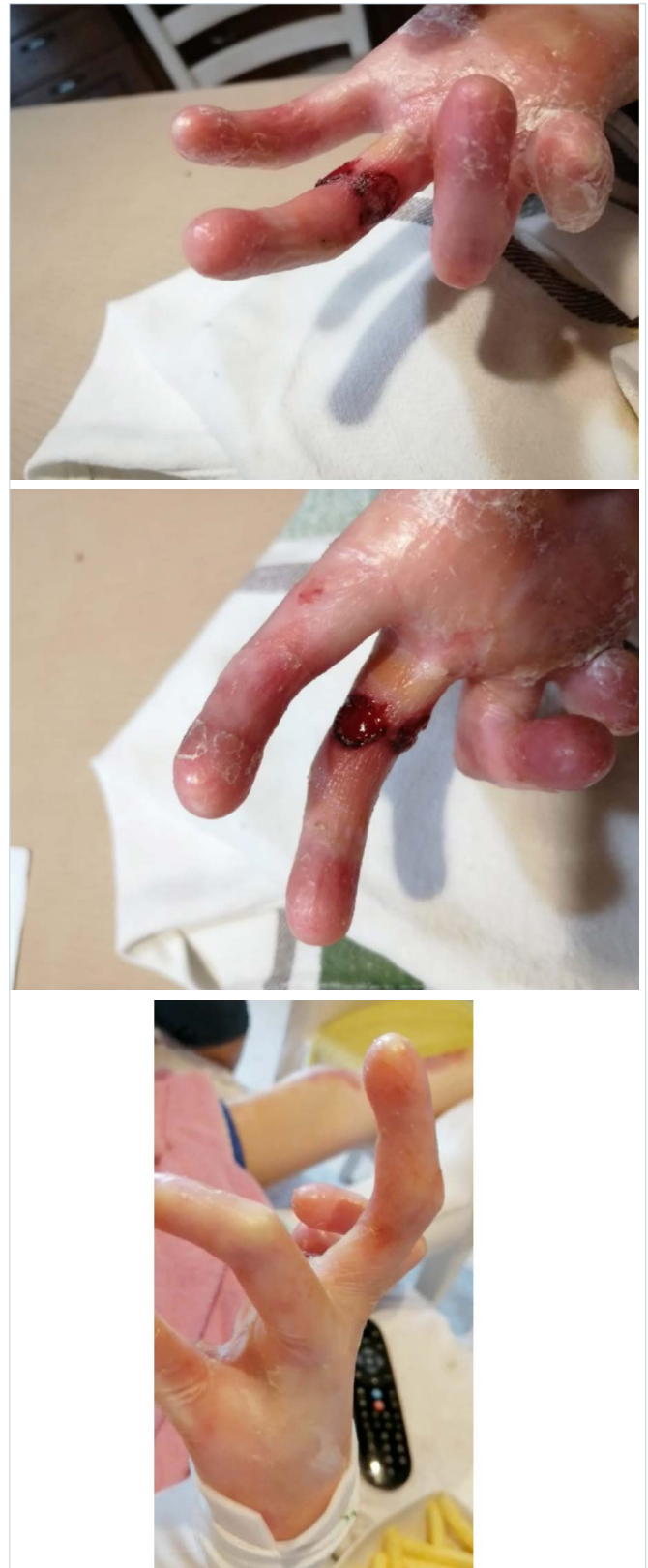
Preoperative antibiotic prophylaxis was administered. The patient was placed in supine position with a right upper limb



**Figure 3.** Case 2: pre-operative.

sterile field. Skin elongation plasty with volar flap according to Malek's technique was performed on the 2<sup>nd</sup> and 3<sup>rd</sup> finger: we proceeded in stages isolating and protecting the nervous vascular structures, releasing of the subcutis and tendon structures, with recovery of the almost complete passive extension of the fingers. In the operative room, each anatomical structure is assessed before the release to obtain the greatest possible extension. Satisfactory lengthening may require several surgical steps:

Step 1: the volar cutaneous retraction is treated by drawing a proximally based skin flap at the PIPJ, according to the Malek technique.



**Figure 4.** Case 2: post-operative.

Step 2: subcutaneous fibrous structures are released preserving the neurovascular bundles and are used as a coverage for the underlying flexor apparatus. Intra-operative assessment of PIPJ passive extension with extended metacarpophalangeal joint (MCPJ) is performed.

In the following month, the medication was renewed approximately every 4/5 days, at home or at our center.

About a month later, after antibiotic prophylaxis with Cefazolin 1 g, under sedation, surgical dressing of the right hand wound was performed and Kishner's threads removed. We proceed to packing the elastomer. Medication application.

**Defects coverage**

The technique of skin coverage varies. At the level of the first and second commissure of the hand a dermal substitute was used and our first choice was Matriderm (2 mm). The dermal substitutes is fixed with Rapid Vicryl 4/0 (Ethicon, Johnson & Johnson).

We then placed a below palm plaster valve along with a dressing of Urgotul + Mepilex Lite.

**Results**

Surgery was performed one hand at a time, to preserve the patient's autonomy as much as possible. Results of our retrospective study demonstrated more postoperative functional improvement in patients with RDEB of lower severity, who had good joint function and rigorous cooperation with postoperative rehabilitation.

The dermal substitute Matriderm promoted tissue re-epithelialization in an average of about 30 days. The Kirschner wires were removed approximately 21 days after the first surgery. At the same time, a maintenance elastomer was set up in the operating room and patients were taught to keep it in place upon discharge.

At home, patients were instructed about the importance of keeping the elastomer in place as much as possible to maintain the opening of the first commissure, as well as the need to exercise the pinching function to aim for maintaining the functionality achieved post-surgery.

Our results are rather in favor of the release of digital pseudosyndactylies and camptodactylies, since based on our case observation, the opening and releasing of both appears to be maintained for over 1 year after the procedure, maintaining digital function.

The release of pseudosyndactylies is in our opinion, necessary when it is possible.

A rapid recurrence can sometimes be the result of noncompliance of the patient with postoperative reeducation. We believe that an appropriate surgical technique followed by rigorous rehabilitation, combined with an interdisciplinary overall management of these patients with RDEB, allowed us to succeed in the optimization of their manual function.

As soon as possible it is fundamental to start physiotherapy sessions, two or three times per week, proceeding as long as improvement is shown. In adults, physiotherapy appears to be more intense and therefore is continued based on the patients' tolerance. The goal remains to be able to overcome postoperative rigidity.

Furthermore during the postoperative physiotherapy evaluations of the second patient (Case 2) the following values concerning the evaluation of strength (using pinchmeter readings in Tip to Tip) and ROM were observed:

Furthermore camptodactyly pre-operative mean extension deficit was 65° (range 35°-100°) and post-operative mean extension deficit was reduced to 16.5° (range 0°-70°).

**Conclusion**

As sufficiently presented surgery is associated with functional improvement.

Nevertheless, the focus needs to be shifted also on the potential surgical complications (bleeding, infection, very rarely loss of fingers or phalanges), together with pain, loss of hand function while healing, and the risks related to the use of anesthesia.

In addition, even though surgery in children may help prevent developmental and motor delay and hand atrophy, the positive effect of surgery is not constant<sup>11-12</sup>.

Some ways to clinically monitor and assess hand function im-

**Table III.** Postoperative physiotherapy evaluations.

Left					Units (Kg)	Right				
Try 1	Try 2	Try 3	Avg	CV%: 0	Pinchmeter readings in Tip to Tip	Try 1	Try 2	Try 3	Avg	CV%: 0
2.1	2.1	2.1	2.1		ROM II finger IPI	1.4	1.4	1.4	1.4	
					ROM III finger IPI	FL: 40° EXT: 30°				
						FL: 40° EXT: 30°				



provement may include dexterity tests such as the nine-hole peg test, and quantitative strength tests such as grip strength or pinch tests. Further studies are certainly needed to evaluate their accuracy and validity as follow-up parameters<sup>24,25</sup>. In fact, improvement in hand function is temporary, with recurrence expected within 1-2 years, 50-53% occurring after 1 year, with approximately 50% requiring further procedures. In one series recurrence was 53 %, another 50 %, with repeated procedures every 2 years to maintain optimal function<sup>7-13-14-15</sup>.

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PREMIO MIGLIOR TESI CORSI SICM

# L'innesto osseo vascolarizzato dal radio distale basato sull'arteria interossea posteriore per il trattamento delle pseudoartrosi di radio: studio anatomico del PIA-DRG

*Posterior interosseous artery distal radius graft for radial nonunion: Anatomical study of PIA-DRG*

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Gli Autori dichiarano di non avere alcun conflitto di interesse con l'argomento trattato nell'articolo.

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#### Riassunto

Le pseudoartrosi dell'avambraccio rappresentano una sfida clinica complessa e spesso portano a dolore, limitazioni funzionali e disabilità. Il trattamento della pseudoartrosi dell'avambraccio richiede un'approfondita valutazione dei fattori associati al paziente, delle caratteristiche della frattura e delle opzioni chirurgiche disponibili. Gli innesti ossei vascolarizzati sono emersi come *gold standard* per il trattamento del mancato processo di guarigione ossea, offrendo una soluzione promettente per le pseudoartrosi atrofiche. L'obiettivo di questo studio è ampliare le indicazioni all'utilizzo dell'innesto osseo vascolarizzato basato sull'arteria interossea posteriore del radio distale (PIA-DRG) per il trattamento della pseudoartrosi diafisarie di radio. Questo innesto a flusso anterogrado, con il suo lungo peduncolo e ampio arco di rotazione, può raggiungere agevolmente sia la diafisi ulnare che quella radiale. Durante lo studio anatomico è stata valutata la lunghezza del peduncolo vascolare ed il diametro interno del vaso. L'innesto osseo vascolarizzato offre diversi vantaggi, tra cui un approccio limitato all'avambraccio e al radio distale senza morbidità a differenti siti donatori. A differenza degli innesti non vascolarizzati, che possono richiedere diversi mesi per guarire, il PIA-DRG, grazie al suo ricco apporto vascolare diretto, ha il potenziale per una guarigione rapida. Sebbene i trapianti vascolarizzati offrano tassi di unione più elevati e tempi di guarigione più rapidi, si tratta comunque di una procedura complessa che richiede una pianificazione e un'esecuzione meticolosa. In conclusione, il PIA-DRG rappresenta una preziosa alternativa alle procedure tradizionali di innesto osseo non vascolarizzato per casi selezionati di pseudoartrosi dell'avambraccio. Lo studio dimostra che può offrire una soluzione più efficiente e di successo per casi con piccoli difetti ossei, scarsa vascolarizzazione o insuccesso di trattamenti precedenti. Tuttavia, la dimensione del trapianto e la possibilità di danni vascolari in caso di precedenti interventi chirurgici devono essere presi in considerazione nella scelta di questa tecnica.

**Parole chiave:** innesto osseo vascolarizzato, pseudoartrosi di avambraccio, studio anatomico, posterior interosseous artery distal radius graft, dissezione.

## Summary

Forearm pseudoarthrosis represents a complex clinical challenge and often leads to pain, functional limitations, and disability. The treatment of forearm pseudoarthrosis requires a thorough evaluation of patient-related factors, fracture characteristics, and available surgical options. Vascularized bone grafts have emerged as the gold standard for treating failed bone healing, offering a promising solution for atrophic pseudoarthrosis. The aim of this study is to expand the indications for the use of vascularized bone graft based on the posterior interosseous artery of the distal radius (PIA-DRG) for the treatment of diaphyseal radial pseudoarthrosis. This anterograde flow graft, with its long pedicle and wide rotational arc, can readily reach both the ulnar and radial diaphysis. During the anatomical study, the length of the vascular pedicle and the internal vessel diameter were assessed. Vascularized bone grafting offers several advantages, including a limited approach to the forearm and distal radius with no morbidity at different donor sites. In contrast to non-vascularized grafts, which may take several months to heal, the PIA-DRG, thanks to its rich direct vascular supply, has the potential for rapid healing. Although vascularized grafts offer higher union rates and faster healing times, it remains a complex procedure that requires meticulous planning and execution. In conclusion, the PIA-DRG represents a valuable alternative to traditional non-vascularized bone graft procedures for selected cases of forearm pseudoarthrosis. The study demonstrates that it can offer a more efficient and successful solution for cases with small bone defects, poor vascularization, or previous treatment failures. However, the graft's size and the possibility of vascular damage in cases of previous surgeries should be taken into consideration when choosing this technique.

**Key words:** vascularized bone graft, forearm non union (pseudoarthrosis), anatomical study, posterior interosseous artery distal radius graft, cadaveric dissection

## Introduzione

Le pseudoartrosi dell'avambraccio rappresentano un problema clinico complesso che può causare oltre che dolore, limitazioni funzionali e disabilità. Questa condizione si sviluppa tipicamente a seguito di una mancata guarigione ossea di una frattura per un insieme di condizioni biologiche e meccaniche. La pseudoartrosi può essere classificata in due categorie: ipertrofica e atrofica. La non unione ipertrofica è caratterizzata dalla presenza di un callo ben definito, ma esuberante ed inadeguato a garantire stabilità alla frattura ed adeguata guarigione. La motivazione principale dello sviluppo di questa forma di pseudoartrosi è dovuta a problematiche di natura meccanica come per esempio una sintesi non sufficiente stabile per garantire la guarigione ossea. Mentre la non unione atrofica è caratterizzata dalla mancanza di formazione del callo la cui causa risiede in problematiche di natura biologica legate sia all'individuo che alle caratteristiche della frattura e della scarsa vascolarizzazione del sito di frattura<sup>1</sup>.

Il trattamento della pseudoartrosi dell'avambraccio è complesso e richiede una attenta valutazione dei fattori del paziente, delle caratteristiche della frattura, delle cause alla base e delle opzioni chirurgiche. Il trattamento non operativo, come l'immobilizzazione, l'aumento della stabilità del costrutto di osteosintesi e la stimolazione elettrica, può essere efficace per alcuni casi di pseudoartrosi ipertrofica, ma è generalmente meno efficace per le atrofiche che richiedono invece un trattamento chirurgico con stimolazione biologica utilizzando innesti ossei<sup>2</sup>.

L'utilizzo di innesti ossei rappresenta il *gold standard* nel trattamento di mancata guarigione ed in particolare gli innesti vascolarizzati costituiscono una promettente opzione

di trattamento nei casi di pseudoartrosi atrofica. L'innesto osseo vascolarizzato fornisce un ricco apporto di sangue al sito di pseudoartrosi, il che favorisce una stimolazione biologica della guarigione ossea volta a ripristinare l'integrità strutturale dell'osso stesso<sup>3</sup>.

In generale, i tassi di non unione per le fratture diafisarie di radio sono relativamente bassi, con tassi segnalati che variano dal 2% al 10%<sup>4</sup>. Tuttavia, alcuni fattori possono aumentare il rischio di pseudoartrosi, come fratture esposte, trattamento ritardato o inadeguato e il fumo.

L'obiettivo di questa tesi è quello di ampliare le indicazioni all'utilizzo dell'innesto osseo vascolarizzato basato sull'arteria interossea posteriore del radio distale (PIA-DRG) per il trattamento delle pseudoartrosi diafisarie di radio. Il lungo peduncolo e l'ampio arco di rotazione consentono all'innesto di raggiungere l'intera diafisi ulnare come descritto in letteratura, ma anche l'intera diafisi radiale.

## Materiali e metodi

L'innesto osseo vascolarizzato prelevato dal radio distale può essere basato sull'arteria carpica volare, sull'arteria intercompartimentale sovra-retinacolare 1-2 (ICSRA), sull'arteria del quarto e quinto compartimento estensore (ECA) ed è indicato nella pseudoartrosi dello scafoide, nella malattia di Preiser e nella malattia di Kienböck<sup>5</sup>.

L'innesto con PIA-DRG è indicato per il trattamento della non unione della diafisi ulnare in presenza di piccoli difetti ossei (massimo 2 cm). La selezione attenta dei pazienti è fondamentale, in particolare se è stata eseguita una precedente chirurgia con la possibilità di lesioni vascolari al sito donatore<sup>6</sup>.

L'anatomia chirurgica del distretto del radio distale oltre che la tecnica chirurgica del PIA-DRG è stata dettagliatamente descritta da Pagnotta et al per le non-union di ulna. Quattro vasi forniscono arterie nutrienze al radio: 2 dei vasi sono superficiali, situati sulla superficie dorsale del retinacolo degli estensori tra il primo e il secondo e tra il secondo e il terzo compartimento dorsale (ICSRA 1,2 e ICSRA 2,3, rispettivamente), mentre 2 vasi sono profondi, situati sul pavimento dei compartimenti dorsali del quarto e del quinto (ECA quarto e ECA quinto, rispettivamente).

L'ECA quarto si trova direttamente adiacente al nervo interosseo posteriore sul lato radiale del quarto compartimento estensore. Il vaso può anche essere trovato all'interno del setto tra il terzo e il quarto compartimento per la maggior parte del suo percorso, come descritto in precedenza. Prossimalmente, questa arteria ha origine dall'arco anastomotico tra la divisione posteriore dell'arteria interossea anteriore (pAIA) e la PIA. Forma una anastomosi distale con l'arco intercarpale dorsale e anche con l'arco radiocarpale dorsale. L'ECA quarto è la fonte di numerose arterie nutrienze per la metafisi distale del radio; il suo diametro interno medio è riportato essere di 0,38 mm<sup>5</sup>.

La tecnica di prelievo utilizzata se eseguita su vivente va svolta con loupes e con controllo dell'emostasi tramite fascia ischemica ma senza esanguinare l'arto con fascia di Esmarch, in modo che i piccoli vasi rimangano visibili.

Viene effettuata un'incisione a forma di L, partendo da circa 5-10 mm prossimale al tubercolo di Lister, raggiungendo l'articolazione radio-ulnare distale e proseguendo longitudinalmente e prossimalmente tra il radio e l'ulna per esporre il radio distale, la membrana interossea, la PIA e il sito di pseudoartrosi. Successivamente, vengono aperti i compartimenti estensori quarto e quinto e i tendini estensori vengono retratti ulnarmente per esporre la metafisi radiale distale. Viene segnato e sollevato un blocco osseo di 2x2 cm a 10-15 mm dall'articolazione radiocarpica, includendo le ramificazioni periostali e l'ECA quarto, evitando danni alle connessioni periostali. Successivamente, vengono identificate le connessioni tra il quarto compartimento estensore, l'ECA quinto, la pAIA e la PIA sulla membrana interossea, la pAIA viene legata prossimalmente e l'ECA quinto distalmente, per avere un flusso diretto verso l'innesto osseo basato sulla PIA<sup>6</sup>.

Infine, il blocco osseo viene sollevato e la PIA viene dissezionata prossimalmente, sviluppando un peduncolo da 3 a 15 cm, secondo necessità per ruotare il trapianto osseo nel difetto radiale nel caso descritto. Grande importanza si pone alla bonifica del sito di non unione per eliminare eventuali tessuti necrotici o fibrosi fino ad ottenere tessuto osseo vitale. Si procede poi inserendo il PIA-DRG nel sito ricevente, creando una stabile osteosintesi mediante placca e viti a stabilità angolare.

Una volta che l'innesto osseo è libero sul suo peduncolo, il laccio emostatico può essere brevemente allentato per dimostrare il sanguinamento presso il VBG.

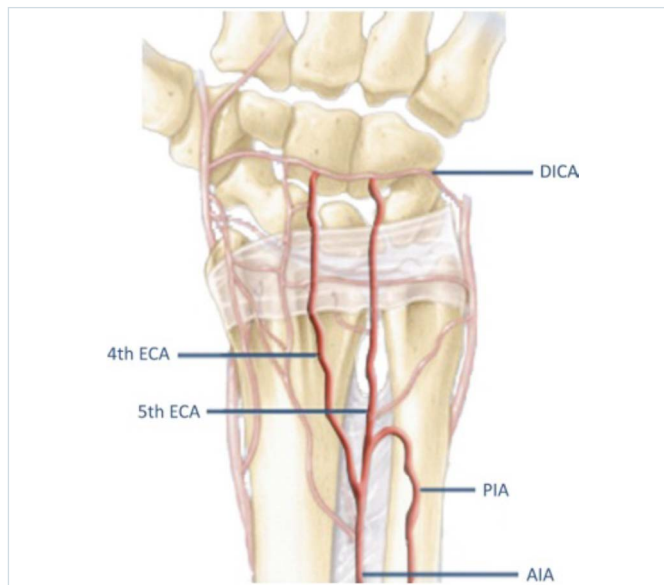
Sono stati valutati durante lo studio anatomico la lunghezza che il peduncolo vascolare può raggiungere per colmare gap a livello del radio ed il diametro interno dell'ECA quarto.

## Discussione

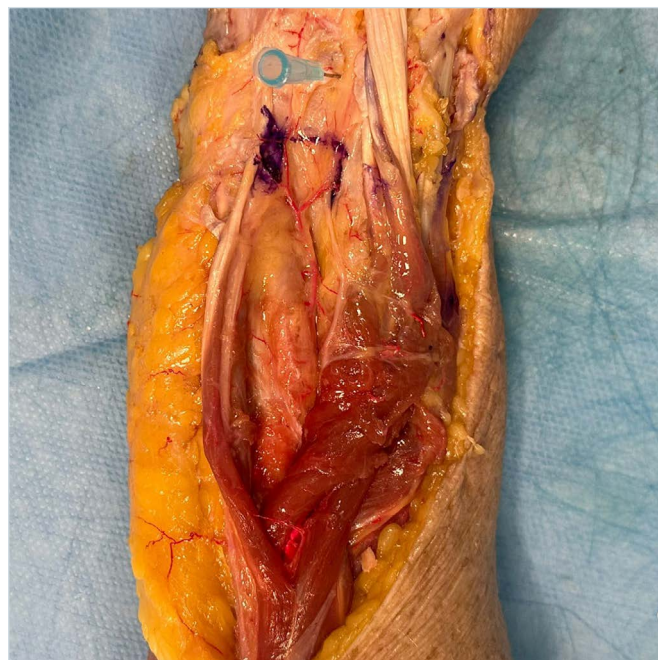
L'innesto osseo vascolarizzato consente al tessuto osseo vitale di essere trasferito in una posizione adiacente o a distanza e di sopravvivere grazie al mantenimento o al ripristino del flusso sanguigno. L'incorporazione di un innesto osseo non vascolarizzato avviene attraverso la creeping substitution, un processo di crescita vascolare graduale, riassorbimento e sostituzione dell'osso necrotico andando a svolgere attività prevalentemente di scaffold e di osteoconduttività<sup>7</sup>. Nel VBG, il processo di incorporazione dell'innesto osseo attraverso la sostituzione graduale viene eluso. Il risultato finale è una guarigione più rapida, l'ipertrofia ossea in risposta allo stress applicato può verificarsi in tempi brevi e l'incidenza delle fratture da stress è inferiore rispetto ai trapianti ossei autologhi o allogenici non vascolarizzati. L'idea che il VBG offra proprietà biologiche e meccaniche superiori rispetto al trapianto osseo non vascolarizzato è stata ampiamente accettata in pubblicazioni precedenti<sup>8</sup>.

In questo articolo, descriviamo un VBG dal radio distale incanalato sulla PIA per la pseudoartrosi radiale dopo che esso è stato già descritto per la pseudoartrosi ulnare. La lunghezza del peduncolo (fino a 15 cm) consente all'innesto di raggiungere l'intera diafisi ulnare e radiale. Dallo studio anatomico eseguito su cadaveri iniettati durante le 3 settimane del corso di dissezione anatomica della SICM abbiamo osservato che il diametro interno dell'ECA 4 è risultato circa 0.10 mm più grande di quanto descritto in letteratura avendo osservato un diametro medio di 0,48 mm (range 0,27 e 0,69) e che in caso di peduncolo di lunghezza superiore a 9 cm ci sia un aumento alla tendenza di kinking del peduncolo il che potrebbe ridurre l'apporto vascolare alla zona di pseudoartrosi. Questo lembo ha un flusso anterogrado ed è una modifica del lembo ECA quarto e quinto a flusso inverso descritto da Moran et al per il trattamento della malattia di Kienböck. Il flusso retrogrado dall'ECA quinto viene convertito in direzione opposta nell'ECA quarto mediante legatura della pAIA. Tra i vantaggi del PIA-DRG per il trattamento delle fratture di avambraccio riscontriamo un approccio limitato all'avambraccio e al radio distale e l'assenza di morbilità a differenti siti donatori come la cresta iliaca o il perone.

L'innesto non vascolarizzato è una soluzione tradizionale per i difetti ossei di varia natura, ma il processo di guarigione nella pseudoartrosi di avambraccio potrebbe richiedere



**Figure 1.** anatomia vascolare regione dorsale del polso.



**Figure 3.** Identificazione e demarcazione innesto basato sulla ECA quarto.



**Figure 2.** Innesto osseo su gap di 2x2 cm.



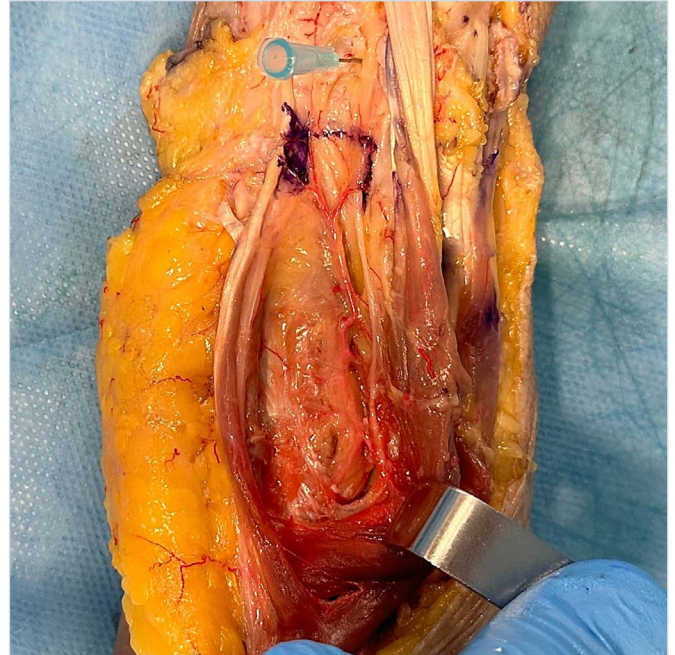
**Figure 4.** Dissezione dell'arteria interossea posteriore.



**Figure 5.** Dettaglio della rotazione del peduncolo vascolare.

tempi lunghi da 4 a 6 mesi. Essendo il PIA-DRG vascolarizzato da un flusso diretto e abbondante, ha il potenziale biologico per ottenere una rapida guarigione, grazie al suo apporto intrinseco. L'innesto osseo vascolarizzato da radio distale quindi rappresenta una soluzione promettente per la pseudoartrosi con piccoli difetti ossei in presenza di necrosi, vascolarità inadeguata dei tessuti circostanti o insuccesso di un precedente innesto.

Tuttavia il principale svantaggio della procedura è la piccola dimensione dell'innesto (lunghezza massima 2-3 cm, in base all'anatomia del radio), che ne limita le indicazioni per la perdita ossea di piccole dimensioni. Inoltre, la vascolarizzazione del innesto può essere danneggiata da precedenti interventi chirurgici. Dovrebbero essere considerate diverse procedu-



**Figure 6.** Template innesto a 10-15 mm dall'articolazione radio-carpica.

re in tutti quei casi per esempio in un cui è stata eseguita una sintesi del radio distale per via dorsale o accessi posteriori al carpo.

In generale, è stato dimostrato che l'innesto osseo vascolarizzato (VBG) presenta tassi di unione più elevati e tempi di guarigione più rapidi rispetto alle tecniche tradizionali di innesto osseo non vascolarizzato. Ad esempio, una revisione sistematica e meta-analisi pubblicata nel 2023 ha riscontrato che il VBG aveva un tasso di unione significativamente più elevato (85,4%) rispetto alle tecniche di innesto osseo non vascolarizzato (75,5%)<sup>9</sup>. Un altro studio pubblicato nel 2019 ha evidenziato che il VBG aveva un tasso di unione più elevato e tempi di guarigione più rapidi rispetto alle tecniche di innesto osseo non vascolarizzato per le non-unioni dello scafoide<sup>10</sup>.

Tuttavia, è importante notare che il VBG è una tecnica chirurgica complessa e impegnativa che richiede una pianificazione e un'esecuzione attente. Il successo della procedura dipende da diversi fattori, tra cui la competenza e l'esperienza del chirurgo, lo stato di salute generale del paziente e gli obiettivi funzionali, nonché le caratteristiche specifiche della non-unione o del difetto osseo in trattamento. Possiamo concludere affermando che il PIA-DRG può essere utilizzato con successo per gestire casi selezionati di pseudoartrosi di avambraccio sia di radio che di ulna. Questo VBG è una valida alternativa alle procedure tradizionali di innesto osseo non vascolarizzato e innesto osseo vascolarizzato libero.

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