MICROSURGERY

DISTAL NERVE TRANSFER FROM THE MEDIAN NERVE LUMBRICAL FIBERS TO THE DISTAL ULNAR NERVE MOTOR BRANCHES IN THE PALM: an anatomical cadaveric study

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Keywords:	HIGH ULNAR NERVE INJURIES, intrinsic hand muscle wasting, babysitting nerve transfer, radial lumbrical nerves, motor branch ulnar nerve

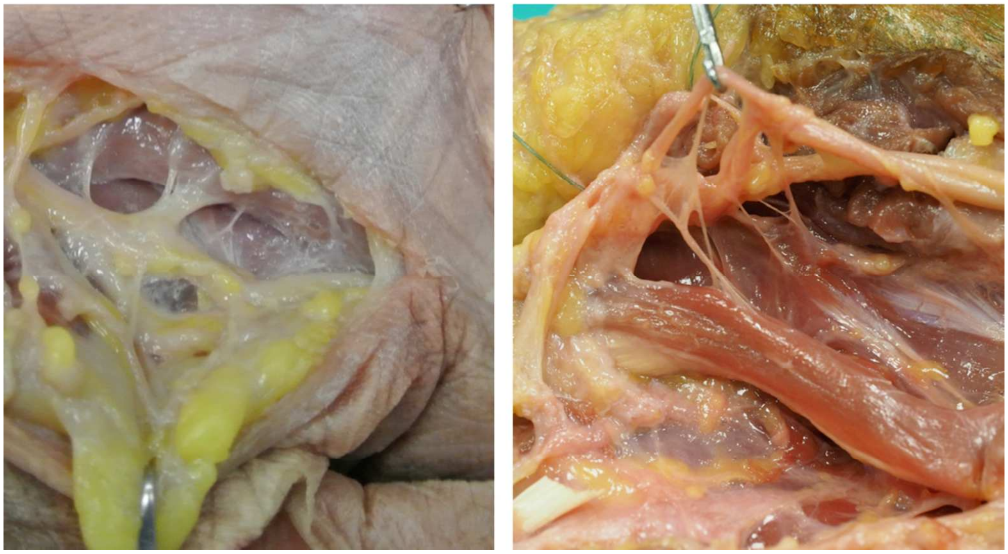

Fig 1 Left: surgical access parallel was performed to the thenar crease to the first and second common nerve trunks to isolate the branches for the 1st and the 2nd lumbrical nerves; right: dissection of the lumbrical nerves from the common trunks, was performed.

380x208mm (72 x 72 DPI)

Fig 2 The deep motor branch of the ulnar nerve was isolated through the 2nd intermetacarpal space (left) and its terminal branches in the first intermetacarpal space (right)

381x209mm (72 x 72 DPI)

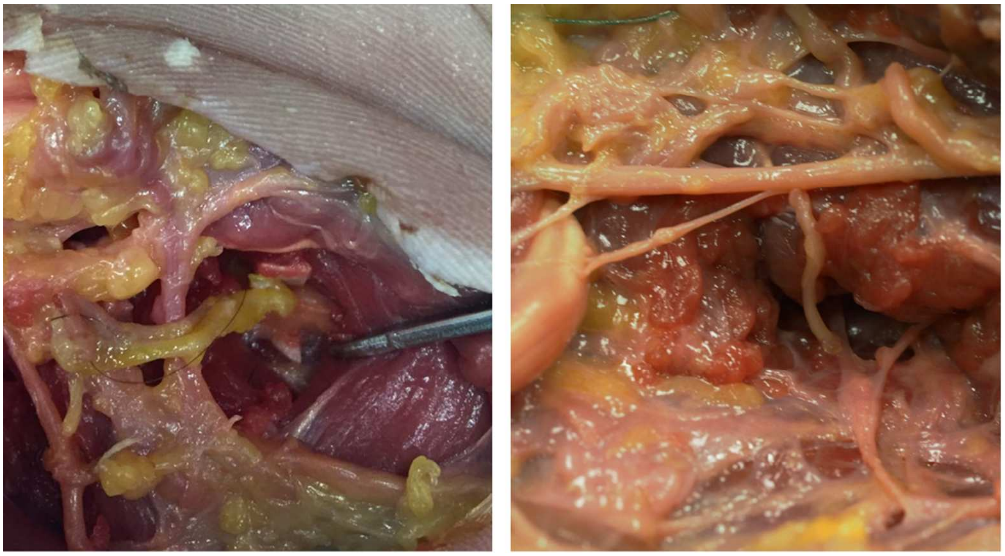

Fig 3 The nerve graft was put between the donor (more superficial) and the recipient (deeper) trunks, connecting to the deep motor branch of the ulnar nerve through the bluntly dissected adductor muscle in the 1st intermetacarpal space (left) or in the 2nd intermetacarpal space (right).

381x209mm (72 x 72 DPI)

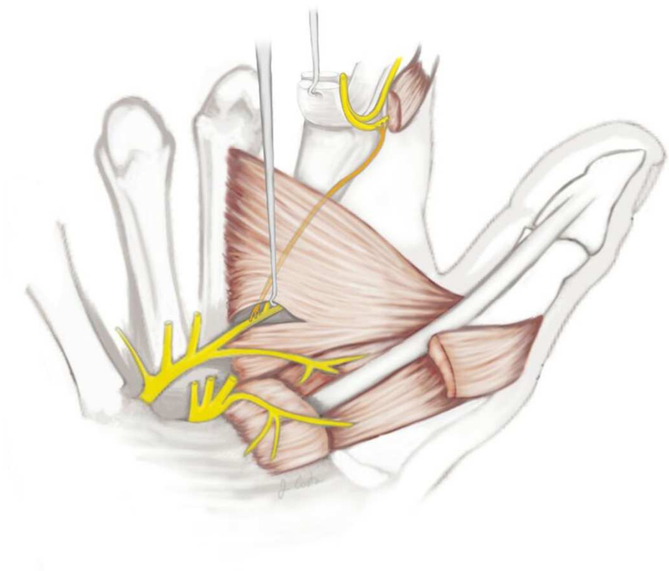

Fig 4 In a more superficial layer, the deep flexor tendon to the 2nd finger and the 1st lumbrical were cut and elevated with a hook; the nerve trunk to the lumbrical was marked in yellow.
In the deeper layer, the transverse head of the adductor muscle was opened and the terminal branch of the motor ulnar nerve was marked in yellow.
The connecting graft between the more superficial lumbrical nerve and the deeper terminal ulnar motor branch was marked in orange.

317x564mm (72 x 72 DPI)

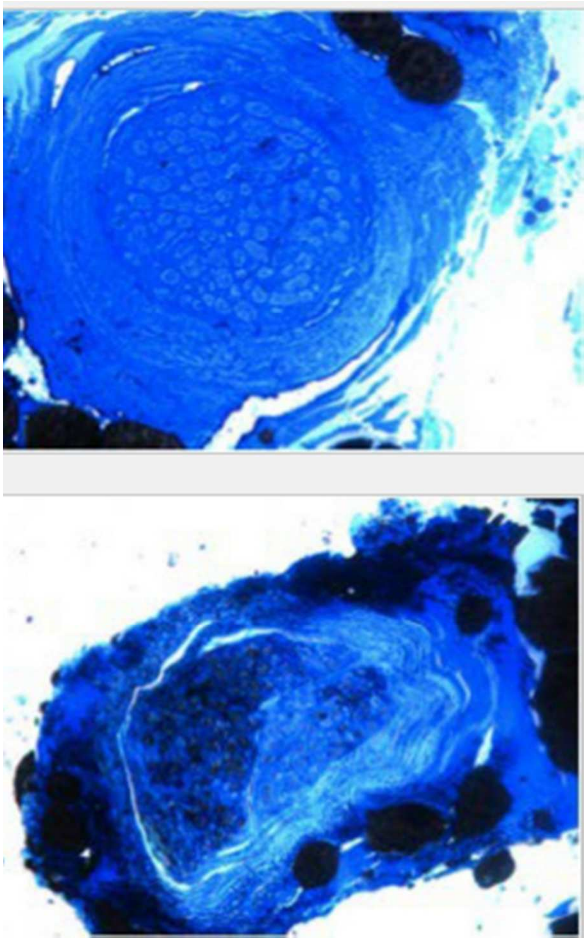

Fig 5 Histology of the 1st lumbrical nerve (top) and the 2nd lumbrical nerve (bottom) (Toluidine blue, 20 x): a sturdy 1st lumbrical trunk, rich in fibers, was documented, and a smaller but even richer in fibers, 2nd lumbrical trunk, were detected with their terminal muscular branches.

102x165mm (72 x 72 DPI)

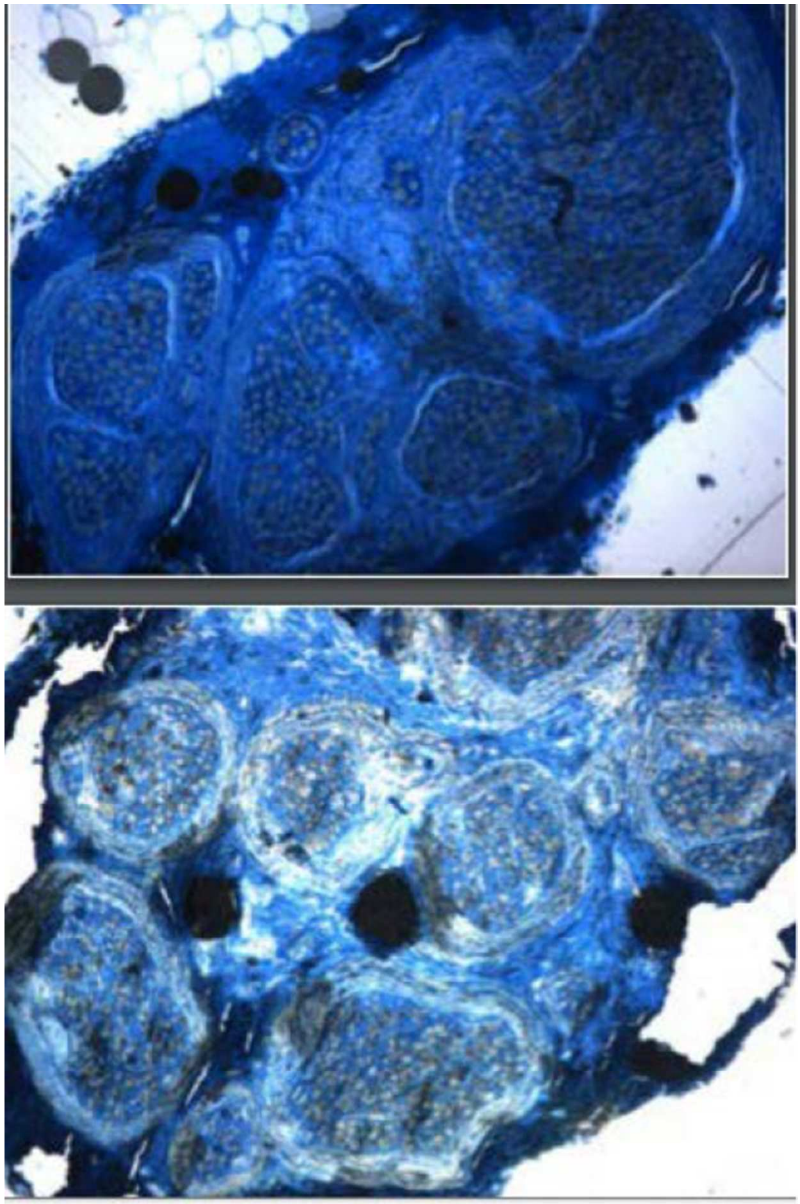

Fig 6 Histology of the deep motor branch of the ulnar nerve just before entering the adductor muscle (top) and of the motor branch of the ulnar nerve just distal to opponens tunnel (bottom) (Toluidine blue, 20 x): the adductor trunk showed a conspicuous number of fibers, whereas the deep motor branch of the ulnar nerve at its origin in the palm maintained a fascicular architecture.

202x305mm (72 x 72 DPI)

Nerve	Axons Density (Axon number/mm^2)	Section area occupied by axons (mm^2)	Total axon number
1st lumbrical	9126.50 ± 2923.41	0.17 ± 0.16	1410.56 ± 823.89
Ulnar motor branch distal to the opponens tunnel	7506.50 ± 1137.50	0.20 ± 0.02	2633.51 ± 410.00
Ulnar motor branch before terminal branching	7947.75 ± 1741.24	0.26 ± 0.20	2345.75 ± 2101.56

Number axons ratio L1/Ulnar motor branch distal to the opponens tunnel= 1:1.86
Number axons ratio L1/Ulnar motor branch in the 1st intermetacarpal space= 1:1.67

DISTAL NERVE TRANSFER FROM THE MEDIAN NERVE LUMBRICAL FIBERS TO THE DISTAL ULNAR NERVE MOTOR BRANCHES IN THE PALM: an anatomical cadaveric study.

Babysitting intrinsic hand muscles in proximal ulnar nerve injuries

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ABSTRACT

Background

The aim of the current study is to investigate the 1st and 2nd lumbrical nerves as potential fibers donors to the deep motor branch of the ulnar nerve to avoid intrinsic atrophy in high ulnar nerve injuries.

Methods

Sixteen fresh frozen cadaveric hands were dissected, the radial lumbrical nerves accessed, and a coaptation, either in reverse end-to-side or in double end-to-side through a bridge nerve graft, was created to the deep motor branch of ulnar nerve.

Semithin sections were taken from samples of donor and recipient nerves for qualitative (nerve architecture) and quantitative studies (fiber count and donor /recipient ratio).

Results

The 1st lumbrical showed a robust trunk and a superior axon density (9126.50± 2923.41 axons/mm^2) to the ulnar motor branch (7506.50 ± 1137.50 axons/mm^2 distal to the opponens tunnel and 7947.75± 1741.24 axons/mm^2 before its terminal branching); the ulnar motor branch showed a higher axon number (2633.51± 410.00 distal to the opponens tunnel and 2345.75± 2101.56 before its terminal branching) than the 1st lumbrical (1410.56± 823.89); section areas occupied by axons were higher in proximal (0.20± 0.16) and distal (0.26± 0.20) ulnar samples than the 1st lumbrical (0.17± 0.16).

Donor/recipient ratio 1st lumbrical/deep motor branch of the ulnar nerve were 1:1.86 (distal to the opponens tunnel) and 1:1.67 (at its terminal branching); data about the 2nd lumbrical were ruled out because of bias.

Conclusions

A transfer from the 1st lumbrical nerve to the deep motor branch of the ulnar nerve in palm is suitable to avoid intrinsic atrophy.

Key Words: high ulnar nerve injuries; intrinsic hand muscle wasting; babysitting nerve transfer; radial lumbrical nerves; deep motor branch ulnar nerve in the palm; end-to-side nerve coaptation and its variants

INTRODUCTION

Neurotmetic ulnar nerve injuries proximal to the elbow are unlikely to get an acceptable outcome; in particular, intrinsic muscles wasting produces important functional effects on grip, fine movements and globally impairs hand function.

In a recent retrospective epidemiologic analysis on high median, ulnar and median-ulnar injures, Hunderpool et al found that "male gender, higher age group and proximal lesions were significantly related to worse ulnar sensitivity" as well as "more injured structures and crush nerve injuries were unvariately found to be significantly correlated with worse ulnar motor recovery" [1].

"Babysitting" nerve fiber transfers can be defined as giving fibers from a healthy donor trunk to a denervated recipient trunk, in order to allow these fibers reach the distal effectors to avoid atrophy; such a procedure has originally been described together with partial neurotomy [2], and has been found to be efficient both in experimental and clinical studies [2,3,4,5].

As far as it concerns proximal ulnar nerve injuries, babysitting by end-to-side nerve transfer has proven effective in one of the three series reported , where Colonna et al analyzed an alternative Martin Gruber-type connection created by a bridge nerve graft between median (donor) and ulnar (recipient) trunks in the distal forearm, which gave interesting, but not ideal results [6]; "supercharged" reverse end-to-side nerve transfers have been reported in latter studies [7, 8]. Battiston and Lanzetta reported seven cases of distal anterior interosseous to ulnar nerve end-to-end coaptation together with palmar cutaneous branch of the median nerve to the ulnar nerve above the wrist in a previous paper [9]; it has not yet been well-established whether end-to-end or end-to-side gives better results [6, 7, 8, 9]: nowadays, surgeons performing this type of surgery complain inconstant outcomes, maybe as an effect of the discrepancy between the number of fibers in donor nerves and those in the recipient one [10, 11].

The purpose of the present anatomical cadaveric study is to investigate whether the 1st and 2nd lumbrical nerves could be used as donor trunks in distal nerve transfers to the ulnar nerve in the palm.

MATERIALS AND METHODS

Twelve fresh frozen cadaveric hands were dissected at the International Center for Learning Orthopaedics in Arezzo (Italy) and four hands at the Department of Anatomy and Surgical Anatomy, School of Medicine of the Aristotle University of Thessaloniki (Greece). The study was approved by the Review Board for Anatomical Research of the Italian Association for Surgery of the Hand on October 14th, 2015 and by the Ethics Committee of the Aristotle University of Thessaloniki.

Access was obtained through a midpalmar incision placed parallel to the thenar crease on the 1st ray; the radial first two common nerve trunks were identified and isolated, together with the branches from the common trunk to the 1st and 2nd lumbrical nerves. Through a gentle radial divarication of this dissected package, and a careful intramuscular dissection of the transverse head of the adductor pollicis in the first intermetacarpal space, the terminal branches of the ulnar motor branch to the adductor, the first dorsal interosseous, the deep head of flexor pollicis brevis and carpometacarpal joint, were identified and isolated. Through the same gentle radial divarication of the flexor tendons together with the median nerve, a deep dissection was performed in the proximal half of the 2nd intermetacarpal volar space through the oblique head of the adductor pollicis muscle, the underlying deep palmar fat pad and the interosseous fascia to reach the deep horizontal motor branch of the ulnar nerve lying on palmar interossei.

A 5-cm nerve graft was obtained from the proximal part of the lateral cutaneous nerve of the forearm, and was inserted as a bridge graft that connected respectively either to the first common trunk from the median nerve at the origin of the 1st lumbrical branch to terminal branches of the motor branch of the ulnar nerve in the 1st intermetacarpal space, or to the second common trunk from the median nerve at the origin of the 2nd lumbrical branch to the motor branch of the ulnar nerve in the 2nd intermetacarpal space. This passage was performed directly through the adductor in the 1st space and under the flexor tendons in the 2nd space and care was taken to obtain a neither too tight nor too loose nerve graft (5 cm long) in a comfortable accommodation to avoid disruption from flexor tendon and lumbrical belly shortening during contraction; finally, an epineural window was opened in the donor and recipient trunks to which the graft was coapted end-to-side with glue and/or two or three sutures 10 or 11/0.

Nine samples of radial lumbrical nerves together with samples of the motor branch of the ulnar nerve, were taken for section size measures, histology and axonal count; in particular, lumbricals were taken just after their bifurcation from the main trunk, and motor branch of the ulnar nerve samples were taken a) just after the opponens tunnel and b) just before its terminal branching.

Nerve samples were fixed in glutaraldehyde 2.5% in 0.1M PBS (pH 7.4) for six hours; after post-fixation in osmium tetroxide 2% for two hours, they were dehydrated in ethanol and then washed in propylene oxide and embedded according to the Glauert's procedure (resin mixture composed in equal parts by Araldite M and Harter, which contained 0.5% of dibutyl phthalate plasticizer and 1-2% accelerator 964, DY064 8MercK , Darmstadt, D); semithin 2.5 μm sections were cut using an Ultracut UCT ultramicrotome (Leica Microsystems, Wetzlar, D), stained with toluidine blue (1%), and both qualitative and quantitative analysis were carried out using a DM4000B microscope equipped with digital camera DFC320 and IM50 Image Manager System (Leica); on one semithin section a random size of the cross-sectional area around the nerve was selected and 12-16 fields were chosen by systematic random sampling protocol, and to avoid distortions and "edge effect" errors, the two-dimensional dissector was applied. Axons density and total axon number were counted, and Section area occupied by axons was measured; in particular, the total number of axons in each nerve trunk (Total number) was estimated by multiplying the average axons' density in that nerve (Density) by the total cross-sectional area occupied by nerve fibers (Area); the coefficient of error also calculated the sampling scheme was established so as to keep the coefficient of error below 0.10.

RESULTS

The dissection took from fifteen to thirty minutes in the palmar region; the most care requesting passages were represented by the identification of the 1st and 2nd common nerve trunks from the median nerve, the single lumbrical branches (fig 1), and the deep motor branch of the ulnar nerve in its terminal branches (fig 2), also as they lie in different layers (fig 3, 4).

In our dissections radial lumbrical nerves together with the motor branch of the ulnar nerve or its branch to the adductor were easy to find and detectable; lumbrical nerves typically entered the muscle bellies in the proximal two middle third junctions, and in particular in their radial palmar aspect and lumbrical muscles were innervated through a single branch.

In three cadaveric hands the nerve for the 2nd lumbrical entered the muscle belly from its dorso-ulnar aspect and one hand showed a deeper origin of the 1st lumbrical trunk, bifurcating before reaching the muscle belly, whereas bifurcation pattern coexisted with a normal radial palmar pattern of origin from the 1st common trunk in another hand; in five cadaveric hands two separate branches innervated the second lumbrical: no other significant anatomical variations were found.

Significantly, the 1st lumbrical nerve was a sturdy trunk, showing a large fiber count in all specimens; the 2nd lumbrical nerve also looked a robust trunk (fig 5): both lumbrical nerves were short, 8 to 12 mm.

The deep motor branch of the ulnar nerve just after the opponens tunnel maintained a fascicular architecture and its terminal branch in the first space showed a conspicuous number of fibers (fig 6); dealing with fiber count, our findings concerning the 1st lumbrical (donor) and the ulnar motor nerve in the palm and just before its terminal branching are summarized in table 1, as well as the axons count donor/recipient ratio is shown.

The 1st lumbrical showed a higher axon density (9126.50± 2923.41 axons/mm2) than the ulnar motor branch, whether taken just distal to the opponens tunnel (7506.50± 1137.50 axons/mm2) or before its terminal branching in the 1st intermetacarpal space (7947.75± 1741.24 axons/mm2), whereas the ulnar motor branch showed a higher axon number (2633.51± 410.00 and 2345.75± 2101.56 distal to the opponens tunnel and before its terminal branching, respectively) than the 1st lumbrical (1410.56± 823.89); section areas occupied by axons were higher in both proximal and distal ulnar motor branch (0.20± 0.02 and 0.26± 0.20, respectively) than the 1st lumbrical (0.17± 0.16).

Donor/recipient ratio 1st lumbrical/deep motor branch of the ulnar nerve were 1:1.86 (distal to the opponens tunnel) and 1:1.67 (at its terminal branching).

Unfortunately, five samples were found not ideal for morphological essays due to wrong conservation and ruled out; moreover, we detected some higher count values when the dissection of the lumbrical motor fibers had been performed proximally in the common trunk; a contamination of fibers from other fascicles could explain these data; these findings together with a too high fiber count of the 2nd lumbrical samples, produced their ruling out from the present study.

DISCUSSION

Proximal ulnar nerve injuries are a challenge for the hand surgeon, as it is well-known for its troublesome regenerative capability; in particular, preventing distal atrophy is very important, and several techniques, combined with tendon transfers, have been proposed [11]; babysitting and distal nerve transfers have been introduced in clinical practice, the last fifteen years, and have reached a sound popularity among experts [6, 7, 8, 9, 11, 12].

As far as it concerns clinical experiences with direct end-to-end neurotization in the forearm [9], some observations should be pointed out; first, distal anterior interosseous nerve is not a powerful donor (fiber ratio 1:4.8) [10] and only Battiston and Lanzetta seem to have reached the best outcome (M4 in 6 cases in a series of 7 cases, 85,7%) [9]. To date, the most important concern remains that a short and inadequately sizing donor branch should innervate 13 muscles, confirming that trying to reinnervate multiple target effectors with a limited number of donor axons cannot be successful [11].

Different approaches to this problem have also been attempted, such as babysitting procedures; Colonna et al [6] also described a bridge graft between median and ulnar nerve in the distal forearm (Martin Gruber like connection created by two coaptations through a bridge graft) in two cases of proximal ulnar nerve injuries, with poor results [6]. A further clinical review of the published series, in particular of the first Martin Gruber performed, has shown a surprising partial recovery together with documented ingrowth of nerve fibers through both distal forearm babysitting nerve bridge and the proximal ulnar nerve repair achieved through a sural graft above the elbow after seven years (unpublished data); this last finding might open some new scenario, but it will be analyzed in a future study.

Recent clinical papers [6, 12, 13] have pointed out the importance of distal babysitting, whose scientific base comes from recent studies, demonstrating that distal effectors give signals with exocytosis through the distal stump[13] : thus, a most distal babysitting will be more effective than proximal ones.

Such a procedure, connecting the uninjured median nerve to the deep motor branch of the ulnar nerve or its terminal radial branches, could rescue distal ulnar effectors from atrophy, avoiding contamination [12] from sensory fibers (even if this point has been debated and is still considered controversial [14, 15]), as the donor nerve should be purely motor. It could also produce a faster recovery through a faster colonization from donor nerve fibers, as nerve coaptation sites are closer to the muscle to be innervated, and minimize, as well, donor motor nerve fibers damage ("fibers escape" [12]) choosing a purely motor branch as one of the radial lumbrical muscle is.

Reviewing the literature, the original idea of Millesi and Schmidhammer proposed a short distal bypass in palm with the ulnar distal motor branches as donors to the median thenar branch of a proximally injured median nerve [11]; this technique was later used by Sherif and Amr [12]. Millesi and Schmidhammer started from a reflection on the Riche-Cannieu variant, and wrote that "useful functional results can be achieved through such a very peripheral nerve fiber transfer by end-to-side repair using terminal branches of the ulnar nerve with synergistic defined motor function to the median nerve innervated thenar muscles….. The deep head of the flexor pollicis brevis muscle innervated by the ulnar nerve revealed a synergistic function to other thenar muscles to oppose the thumb". [11]

The thenar branches of the median nerve have been used as donors for the ulnar motor nerve branch in the palm, and Gesslbauer et al [16] proposed a distal babysitting through a nerve graft bridge between the thenar branch of the median nerve (donor) and the ulnar nerve "just distal to the Guyon's canal"; this clinical series with a six-year follow up showed very good results of motor recovery after distal forearm ulnar injuries in three patients.

Starting from these viewpoints and experiences, Colonna found that lumbrical branches from the median nerve could fit the features required; the novelty of this study consists of investigating the anatomical and histological properties of the 1st lumbrical nerve as potential donor of fibers in nerve transfers to the recipient injured ulnar nerve in the palm to avoid intrinsic atrophy.

Moreover, 4th lumbrical denervation for motor thenar branch reinnervation had been proposed in 1972 [17] and lumbrical nerves show a mostly constant anatomy, according to previous Lauritzen et al [18] (minor variation) and present series.

As far as it concerns axonal count, some considerations should be addressed to its rationale and methods: the recipient nerve always shows a larger fiber account, however, according to Schenck et al "nerve transfers with a donor that is smaller than the target nerve can be successful, and axons in the proximal stump may undergo collateral sprouting that increases three or four times the number of axons" [10]. The same authors pointed out that clinical reports of satisfactory outcomes could be related to even poorer axon ratios and lower fiber count could be addressed by transferring the smaller donor to selected recipient fascicles.

Nothing is reported as far as it concerns quantitative morphology of thenar branch fibers, and, just to give a focus about that, in their anatomical study about distal end-to-side neurotization of ulnar nerve in Dejerine-Klumpke type paralysis or high ulnar nerve injury, Du et al [19] found that the cross-sectional area and the number of nerve fibers were 2.46 ± 1.03 mm^2 and 1. 30 ± 23 for the motor ulnar nerve, 2.62 ± 1.75 mm^2 and 1.63 ± 34 for the thenar branch of median nerve; there were no significant differences in the cross-sectional area and the number of nerve fibers between the motor ulnar nerve and the thenar branch of the median nerve, with a linear correlation. They concluded that low end-to-side neurorrhaphy of median nerve and ulnar nerve has perfect match in the cross-sectional area and the number of nerve fibers.

Concerning the 1st lumbrical nerve from median nerve as a donor, both histology and quantitative morphology showed us satisfactory results, characterizing it as a good donor; to achieve a better comparison, we followed the suggestion by Schenck et al [10], analyzing the nerves directly at their potential site of coaptation. Indeed, 1:3 still remains a threshold value for a useful motor recovery beginning, and our findings of ratios 1: 1.67 1st lumbrical/ ulnar nerve across its terminal branching; and 1: 1.86 1st lumbrical/ulnar nerve just after the opponens tunnel both fit the threshold.

Data from the 2nd lumbrical nerve from the second specimen were ruled out and should be reviewed in further studies.

Some considerations should also be deserved to the anatomy of the lumbrical nerves and deep motor branch of the ulnar nerve, and to the technique for nerve coaptation between donor and recipient trunks, due to important anatomical variations.

First, end-to-side coaptation could produce axon migration from the donor to the recipient nerve; moreover, it has been reported to be successful when applied to distal purely motor or sensate branches [20, 21, 22].

Second, connecting different anatomical layers may also be difficult as the deep motor branch of the ulnar nerve and its divisions [23, 24] are fixed under the interosseous fascia, whereas more superficial radial lumbrical nerves are more mobile; thus it is quite difficult to dissect the deep motor branch of the ulnar nerve in the radial part of the deep palm for a segment long enough to be mobilized and finally to create a classical end-to-side with the recipient nerve cut and coapted to the healthy donor nerve. As an alternative, a reverse end-to-side between a cut lumbrical nerve coapted on the deep motor branch of the ulnar nerve or an end-to-end procedure could be claimed (denervating radial lumbrical muscles).

Third, some anatomical concerns should be pointed out about feasibility of performing an end-to-side directly to lumbrical nerves: especially in females, lumbrical nerves can be too thin, and the ulnar motor nerve can be located too proximal in the deep palm (unpublished data); in these cases, perhaps the nerve graft bridge should better be coapted directly to the ulnar motor nerve after opponens tunnel.

Last, our macroscopical observations (fig 1) showed that both 1st and 2nd lumbrical nerves are short and give their terminal branches to the muscles too soon, as also reported by Lauritzen [18]. Because of this shortness, they cannot reach directly the deep motor branch of the ulnar nerve and we did not take measures of their length. We can overcome this problem either with a nerve bridge graft or a proximal elongation of the lumbrical nerves to be cut and coapted in a reverse end-to-side.

Technical variations with intraneural dissection and donor nerve elongation could interestingly be used, a true nerve transfer reaching the ulnar motor nerve in palm even proximally, just distal to its emergence from the opponens tunnel. The procedure could be completed connecting the donor (smaller) nerve to the recipient one in end-to-side under the structures (flexor tendons and median nerve) running throughout the carpal tunnel. However, even in this case a complete radial lumbrical denervation is required.

As an alternative, two end-to-side coaptations, with regenerating fibers running through a bridge graft, may be used, if sacrifice of the lumbrical nerves (through a classical end-to-end or a reverse end-to-side) should be avoided; a bridge graft with two end-to-side coaptation has proven to be effective in bringing axons from a donor to a recipient nerve through epineurial windows in the rat [25], and in two clinical series [6,12], as well.

The easiest way to perform this bridge graft should be through the 1st volar intermetacarpal space, branching to the terminal branches of the ulnar motor nerve in this region, that is the reverse connection from that proposed by Millesi and Schmidhammer [11] . At the end of the procedure, there are two end-to-side between a more superficial structure (lumbrical nerve) and a deeper one (either the deep motor branch of the ulnar nerve or its terminal branches): a new Riche-Cannieu type connection, consisting of a short nerve bridge between two trunks which face each other lying in different layers.

Indeed, connecting two structures lying in different anatomical layers (more superficial lumbrical nerves to deeper distal motor branch of the ulnar nerve or its terminal branch to the adductor) could result into a weaker point, as more superficial flexor and/or deeper adductor contraction could pull both nerve bridge and microsutures and the role of scarring in case of intramuscular tunnel should be taken into account. On the other hand, Millesi and Schmidhammer reported seven cases of performed end-to-side in the deep radial region of the palm, into a prefabricated tunnel [11], with a high rate of successful reinnervation of the thenar muscles (total six cases: only one M1, and the other three M4 and one M3+).

Shall we get problems with flexion movements, when the third finger flexes and the lumbrical runs proximally into the carpal tunnel? Shall these movements break down our anastomoses? We attempted to give a comfortable position to the nerve bridge, allowing it a reasonable length (5 cm) to easily fit this anatomical change of layer.

The work by Gesslbauer and co-authors [16] confirms our idea of a very distal babysitting and agrees with the proposal of a double end-to-side coaptation; yet, distal splitting of the nerve graft and multiple coaptation could be adapted to our technique to connect both lumbrical nerves.

Finally, dealing with connection direct to the terminal branches of the recipient motor nerve, it proved to be clinically effective in the clinical series from Millesi and Schmidhammer [11], where a distal nerve coaptation was used and proven in the radial deep palm; this consideration may encourage the use of our technique as an alternative, provided that a satisfying fiber ingrowth through the nerve bridge may grow retrograde from the coaptation site.

On the other hand, our study point out the usefulness of the 1st lumbrical nerve as a donor of fibers, as well as its main limitations, represented by its shortness and the need to connect to the deeper ulnar motor branch; further morphological and clinical studies are needed to highlight the feasibility of the proposed transfers in relation to the 2nd lumbrical, measures and sizes of both donor and recipient trunks, as well as to their clinical efficacy.

CONCLUSIONS

As a consequence of the present anatomical cadaveric study and of quantitative morphometry and fibers count, we can suggest that the 1^{st} lumbrical nerve could be applied as donor of fibers to the deep motor branch of the ulnar nerve in palm to avoid intrinsic atrophy. This transfer could be in reverse end-to-side, sacrificing the innervation to the 1^{st} lumbrical muscles, or double end-to-side, without denervation of the 1^{st} lumbrical. This babysitting on the radial palmar side could also be combined to other techniques on the ulnar side and above the wrist.

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REFERENCES

1. Hundepool CA, Ultee J, Nijhuis TH, Houpt P; Research Group 'ZERO', Hovius SE. Prognostic factors for outcome after median, ulnar, and combined median-ulnar nerve injuries: a prospective study. J Plast Reconstr Aesthet Surg. 2015; 68: 1-8.
2. Terzis JK, Tzafetta K. "Babysitter" procedure with concomitant muscle transfer in facial paralysis. Plast Reconstr Surg 2009; 124: 1142–1156
3. Liu HF, Chen ZG, Lineaweaver WC, Friel MT, Zhang F. Molecular Mechanism of the "Babysitter" Procedure for Nerve Regeneration and Muscle Preservation in Peripheral Nerve Repair in a Rat Model. Ann Plast Surg. 2017 ; 78: 704-711
4. Liu HF, Chen ZG, Lineaweaver WC, Zhang F. Can the Babysitter Procedure Improve Nerve Regeneration and Denervated Muscle Atrophy in the Treatment of Peripheral Nerve Injury? Plast Reconstr Surg. 2016; 138: 122-131
5. Liu HF, Chen ZG, Shen HM, Zhang H, Zhang J, Lineaweaver WC, Zhang F. Efficacy of the end-to-side neurorrhaphies with epineural window and partial donor neurectomy in peripheral nerve repair: an experimental study in rats. J Reconstr Microsurg. 2015; 31: 31-38.
6. Colonna MR, Russo A, Delia G, Galeano M, Pajardi GE, Stagno d'Alcontres F**:** "Babysitting" procedures in proximal nerve trunk injuries: A review of graft bridging techniques at the level of forearm and a personal approach. Plastic Aesthetic Res 2015; 2: 208-212
7. Barbour J, Yee A, Kahn LC, Mackinnon SE. Supercharged end-to-side anterior interosseous to ulnar motor nerve transfer for intrinsic musculature reinnervation. J Hand Surg Am. 2012; 37: 2150-2159
8. Baltzer H, Woo A, Oh C, Moran SL. Comparison of Ulnar Intrinsic Function following Supercharge End-to-Side Anterior Interosseous-to-Ulnar Motor Nerve Transfer: A Matched Cohort Study of Proximal Ulnar Nerve Injury Patients. Plast Reconstr Surg. 2016; 138:1264-1272.

9. Battiston B, Lanzetta M. Reconstruction of high ulnar nerve lesions by distal double median to ulnar nerve transfer. J Hand Surg Am. 1999; 24 :1185-1191

10. Schenck TL, Stewart J, Lin S, Aichler M, Machens HG, Giunta RE. Anatomical and histomorphometric observations on the transfer of the anterior interosseous nerve to the deep branch of the ulnar nerve. J Hand Surg Eur 2015; 40: 591-596

11. Millesi H, Schmidhammer R. Nerve fiber transfer by end-to-side coaptation. Hand Clin. 2008; 24: 461-483

12. Magdi Sherif M, Amr AH. Intrinsic hand muscle reinnervation by median-ulnar end-to- side bridge nerve graft: case report. J Hand Surg Am. 2010; 35: 446-450

13. Wood MD, Mackinnon SE. Pathways regulating modality-specific axonal regeneration in peripheral nerve. Exp Neurol. 2015; 265:171-175

14. Beck-Broichsitter BE, Becker ST, Lamia A, Fregnan F, Geuna S, Sinis N. Sensoric protection after median nerve injury: babysitter-procedure prevents muscular atrophy and improves neuronal recovery. Biomed Res Int 2014; 2014: 724197

15. Nghiem BT, Sando IC, Hu Y, Urbanchek MG, Cederna PS. Sensory protection to enhance functional recovery following proximal nerve injuries: current trends. Plast Aesthet Res 2015; 2: 202-207

16. Gesslbauer B, Furtmüller GJ, Schuhfried O, Roche AD, Sporer M, Aszmann OC. Nerve grafts bridging the thenar branch of the median nerve to the ulnar nerve to enhance nerve recovery: a report of three cases. J Hand Surg Eur Vol. 2016; 31. pii: 1753193416675069.

17. Schultz RJ, Aiache A. An operation to restore opposition of the thumb by nerve transfer. Arch Surg 1972; 105: 777-779

18. Lauritzen RS, Szabo RM, Lauritzen DB. Innervation of the lumbrical muscles. J Hand Surg Br 1996; 21: 57-58

19. Du Y , Liu D , Wang B , Han X. Anatomical studies on low end-to-side anastomosis of median nerve and ulnar nerve in repair of Dejerine-Klumpke type paralysis or high ulnar nerve injury. Chin J Repar and Reconstruct Surg 2010; 24: 332-334

20. Tos P, Geuna S, Papalia I, Conforti LG, Artiaco S, Battiston B. Experimental and clinical employment of end-to-side coaptation: our experience. Acta Neurochir Suppl. 2011; 108: 241-245.

21. Papalia I, Magaudda L, Righi M, Ronchi G, Viano N, Geuna S, Colonna MR. Epineurial Window Is More Efficient in Attracting Axons than Simple Coaptation in a Sutureless (Cyanoacrylate-Bound) Model of End-to-Side Nerve Repair in the Rat Upper Limb: Functional and Morphometric Evidences and Review of the Literature. PLoS One. 2016 12;11: e0148443

22. Geuna S, Papalia I, Ronchi G, d'Alcontres FS, Natsis K, Papadopulos NA, Colonna MR. The reasons for end-to-side coaptation: how does lateral axon sprouting work? Neural Regen Res. 2017;12:529-533.

23. Atkins SE, Logan B, McGrouther DA The deep (motor) branch of the ulnar nerve: a detailed examination of its course and the clinical significance of its damage. J Hand Surg Eur 2009; 34: 47-57

24. Gil YC, Shin KJ, Lee SH, Koh KS, Song WC. Anatomy of the deep branch of the ulnar nerve. J Hand Surg Eur. 2016; 41: 843-847

25. Iwakura N, Ohtori S, Kenmoku T, Suzuki T, Takahashi K, Kuniyoshi K. Single versus double end-to-side nerve grafts in rats. J Hand Surg Am. 2012;37:261-269

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FIGURE LEGENDS

Fig 1 Left: surgical access parallel was performed to the thenar crease to the first and second common nerve trunks to isolate the branches for the 1st and the 2nd lumbrical nerves; right: dissection of the lumbrical nerves from the common trunks, was performed.

Fig 2 The deep motor branch of the ulnar nerve was isolated through the 2nd intermetacarpal space (left) and its terminal branches in the first intermetacarpal space (right)

Fig 3 The nerve graft was put between the donor (more superficial) and the recipient (deeper) trunks, connecting to the deep motor branch of the ulnar nerve through the bluntly dissected adductor muscle in the 1st intermetacarpal space (left) or in the 2nd intermetacarpal space (right).

Fig 4 In a more superficial layer, the deep flexor tendon to the 2nd finger and the 1st lumbrical were cut and elevated with a hook; the nerve trunk to the lumbrical was marked in yellow.

In the deeper layer, the transverse head of the adductor muscle was opened and the terminal branch of the motor ulnar nerve was marked in yellow.

The connecting graft between the more superficial lumbrical nerve and the deeper terminal ulnar motor branch was marked in orange.

Fig 5 Histology of the 1st lumbrical nerve (top) and the 2nd lumbrical nerve (bottom) (Toluidine blue, 20 x): a sturdy 1st lumbrical trunk, rich in fibers, was-documented, and a smaller but even richer in fibers, 2nd lumbrical trunk, were detected with their terminal muscular branches.

Fig 6 Histology of the deep motor branch of the ulnar nerve just before entering the adductor muscle (top) and of the motor branch of the ulnar nerve just distal to opponens tunnel (bottom) (Toluidine blue, 20 x): the adductor trunk showed a conspicuous number of fibers, whereas the deep motor branch of the ulnar nerve at its origin in the palm maintained a fascicular architecture.