Original Article

# Use of tubulization (nerve conduits) in repairing nerve defects in children

*Filippo Maria Sénès, Nunzio Catena, Jacopo Sénès*


## Abstract

**Background:** Direct neurorrhaphy, nerve grafting interposition and neurotization are the options for nerve repair in children, whereas few reports about using nerve conduits (tubulization) are referred to pediatrics in the literature. The authors present their experience about nerve repairing by means of nerve tubes during the developmental age when the harvesting of nerve grafts and also vein grafts of adequate caliber for bridging nerve defects is difficult. A critical review of their case series offers indications for using nerve conduits in pediatrics.

**Materials and Methods:** Fifteen patients were treated using the nerve tubulization; nine patients were affected by obstetrical brachial plexus palsy (OBPP) while six were suffering from peripheral nerve injuries (PNIs).

**Results:** In patients suffering from OBPP, we observed 1 good, 3 fair and 5 bad results. In the PNI group, we observed 4 patients who had good results while only 2 had a bad outcome. No fair results were observed.

**Conclusions:** In peripheral nerve repairing in children by using nerve conduits, the outcome has been widely effective even when dealing with mixed and motor nerve, thus nerve tubulization might be considered as an alternative to nerve grafting. Conversely, considering the uncertain result obtained in brachial plexus repairing, the conduits cannot be considered as a first choice of treatment in brachial plexus reconstruction.


**Key words:** Nerve defects, nerve lesions in children, nerve tubulization, brachial plexus, peripheral nerve
**MeSH terms:** Pediatrics, peripheral nerve injury, brachial plexus, nerve regeneration

## Introduction

Peripheral nerve lesions are not uncommon in children. The nerve damage is more common after brachial plexus injury coming up at birth or it follows nerve trunks injury that occurred for different causes.[1,5]

Primarily, options for the nerve repair are either direct neurorrhaphy or interposition of nerve grafting according to the appearance and the gap of nerve stumps. The neurotization is another technique of nerve repairing that offers an additional support for nerve recovery, especially in brachial plexus reconstruction.[6,7]

The insertion of nerve conduits (tubulization) for bridging a nerve defect has been recently proposed by many authors, who have obtained interesting results, mainly during adulthood.[8]

The tubulization can be carried out with two different kind of structure, namely biological or synthetic conduits. Among the biological conduits, vein graft represents a biological structure that, filled up with muscle or nerve inductors, connects the nerve stumps while among the synthetic tubes different materials have been proposed. During the years, many both reabsorbable and not reabsorbable (polylactic acid, collagen, silicon etc.) synthetic nerve conduits have been used.[9] Although several reports about nerve conduit substitution of sensitive nerve in the adult have been published, few papers about mixed nerve repair have been written.[10,11]

Moreover, despite the fact that bridging nerve defect is not a new technique, up to now few reports about the use of tubulization in children have been published, especially since the repair is mostly directed to mixed or motor nerves rather than the repair of sensitive nerve trunks.

Department of Head and Neck, Microsurgery and Hand Surgery Unit, Orthopaedic and Traumatology Unit, Istituto Giannina Gaslini, Largo G. Gaslini 5, 16147 Genova, Italy

**Address for correspondence:** Dr. Filippo Maria Sénès, Via San Bartolomeo Degli Armeni 23/2, 16122, Genova, Italy. E-mail: filipposenes@fastwebnet.it



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Although previous experiences in children have already been published, except for obstetrical brachial plexus reconstruction.[12,13] To the best of our knowledge there are no literature reports on upper and lower limb nerve repair by means of tubulization in pediatric age.

In 2006, the St. Louis group reported their experience in the use of re absorbable collagen nerve guides for primary repair of seven obstetrical brachial plexus lesions, performing a retrospective study on the first five cases. They concluded that their results were particularly encouraging considering that all patients had severe plexus lesions and hence they suggested that collagen nerve guides could be considered as an alternative to autologous nerve graft, especially in selected patients with limited nerve gap to repair.

In 2007, the Norfolk group focused on the use of biological tubulization with autologous vein graft as a possible alternative technique for brachial plexus repair. These authors reported on a case of primary nerve repair and a case of late nerve surgery, using vein grafts filled with minced nerve tissue. Those authors reported a good recovery and concluded that tubulization techniques should be taken into account when autologous nerve grafts are insufficient for the reconstruction of extensive lesions or as an alternative to grafting in case of short nerve gap. They also added that the excellent results of reconstruction with veins filled with minced nerve tissue suggest the need for further studies of this technique in developmental age.

Taking into account the possibility of using more established techniques of nerve repair, aim of this study is to present the authors' experience of using nerve tubes for nerve repair during developmental age, providing a contribution to define indications and limits of the method in children notwithstanding the fact of dealing with nonhomogeneous case series of different nerve trunks.

## Materials and Methods

15 patients were treated using nerve tubulization between 2004 and 2012. Nine cases were affected by obstetrical brachial plexus palsy (OBPP) and six by peripheral nerve injuries (PNI) of upper and lower limbs. Eleven were males and four females. The right side was involved in 8 cases (4 OBP and 4 PNI) and the left side in 7 (5 OBPP and 2 PNI). According to the type of lesion, the time elapsed from the injury before nerve repair was logically different. With regard to OBPP patients, the damage was at birth and the time elapsed at the moment of surgery was 5.4 ± 1.50 months standard deviation (SD) (range 4–8 months), whereas it was 8.7 ± 5.07 years SD (range 2.8–13.2 years) for PNI patients, in which nerve injury had occurred in a period ranging from 6 h to 6 months before surgery. The surgical consent was taken from parents of all patients, explaining the technique and pointing out that the results of nerve surgery even with nerve grafts are unpredictable.

Nerve conduits chosen for nerve repair consisted of reabsorbable collagen matrix tubes (Neuragen®). In the OBPP group (nine cases), the surgical exploration of the brachial plexus was always carried out through a supraclavicular approach. Five cases were suffering from complete brachial plexus palsy, three cases had a triradicular involvement while only one case presented as a partial involvement of the superior roots. Four patients had an implant of a single conduit, three patients had two conduits while two had multiple insertions (three conduits). After a primary exploration of the lesion, we checked that whether a rupture or an avulsion had occurred or not, we proceeded to brachial plexus reconstruction.

After excision of neuroma, the nerve reconstruction was performed using a single or multiple nerve tubes for bridging the nerve gap in all the nine patients. Furthermore besides nerve conduits, five of them had nerve repairing by means of different techniques of nerve surgery. More precisely conduits were used for conjoining a direct nerve loss (i.e. C5–C6 – upper primary trunk), whereas nerve grafting was used for bridging and neurotizing different roots and trunks [Table 1].

Loss of nerve substance was observed in different proportions for each case. The mean nerve gap was 2.47 ± 0.65 cm SD (range 0.5–2.8) for obstetrical palsy patients, whereas we found a gap of 1.75 ± 0.33 cm SD (range 1.4–2.5) for peripheral nerve lesions.

Regarding PNI patients, we explored the injured nerve through the classical surgical approach to the specific nerve trunk. In selected cases, with a loss of nerve substance, which did not allow direct repair was observed, the reconstruction was performed using nerve conduits.

Equally the scheme of surgery is presented together with causes of injury and time elapsed from damage to surgery [Table 2]. As different nerves and sites of injury had to be tested, we assessed nerve injuries with different methods in order to measure the outcome and to define good, fair and bad results. The assessment of brachial plexus injuries was classified according to Mallet score for the shoulder, Gilbert score for the elbow and Raimondi score for the hand.[14-16]

The total brachial plexus injuries were evaluated as good for Mallet IV/Gilbert 4–5/Raimondi 4–5 values, fair for Mallet III/Gilbert 2–3/Raimondi 3 and bad for Mallet II/Gilbert 0–1/Raimondi 1–2.

**Table 1: Clinical details of OBPP patients**

| Case | Type of paralysis | Intraoperative lesion | Reconstruction | Results |
|---|---|---|---|---|
| 1 | Total palsy | C5 rupture/ C6–C7–C8–T1 avulsions | 1 tube (diameter 7 mm - length 30 mm) from C5 to upper, medium and lower trunk, accessory to suprascapular nerve and 3–4–5 IC to musculocutaneous nerve | Good (Mallet IV/Gilbert 4/ Raimondi 4) |
| 2 | Total palsy | C5–C6 rupture/ C7–C8–T1 avulsions | 1 tube (diameter 5 mm - length 20 mm) from C5 to upper and medium trunk<br>1 tube (diameter 5 mm - length 30 mm) from C6 to inferior trunk | Bad (Mallet II/Gilbert 1/ Raimondi 2) |
| 3 | Tri-radicular palsy | C5–C6–C7 rupture | 1 tube (diameter 5 mm - length 20 mm) from C5 to upper trunk<br>Neuroma resection and direct neurorraphy of medium trunk | Bad (Mallet II/ Gilbert 2) |
| 4 | Tri-radicular palsy | C5–C6–C7 rupture | 1 tube (diameter 4 mm - length 15 mm) from C5 to anterior part of upper trunk<br>1 tube (diameter 4 mm - length 15 mm) from C6 to posterior part of upper trunk<br>1 tube (diameter 4 mm - length 20 mm) from C7 to medium trunk | Bad (Mallet II/ Gilbert 2) |
| 5 | Upper palsy | C5–C6 rupture | 1 tube (diameter 7 mm - length 20 mm) from C5–C6 to upper trunk | Fair (Mallet III/ Gilbert 3) |
| 6 | Total palsy | C5–C6–C7–C8 rupture/T1 avulsions | 1 tube (diameter 7 mm - length 20 mm) from C5–C6 to upper trunk<br>1 tube (diameter 6 mm - length 25 mm) from C8 to lower trunk<br>Neurolysis of medium trunk | Bad (Mallet II/ Gilbert 1/ Raimondi 3)<br>We consider bad the results for upper trunk |
| 7 | Tri-radicular palsy | C5–C6–C7 rupture | 1 tube (diameter 6 mm - length 20 mm) from C5–C6 to upper trunk<br>Neurolysis of medium trunk | Fair (Mallet III/ Gilbert 3) |
| 8 | Total palsy | C5–C6–C7–C8–T1 rupture | 1 tube (diameter 5 mm - length 20 mm) from C5–C6 to upper trunk<br>1 tube (diameter 3 mm - length 20 mm) from C7 to medium trunk<br>Neurolysis of lower trunk | Fair (Mallet III/ Gilbert 2–3/ Raimondi 3) |
| 9 | Total palsy | C5–C6–C7–C8–T1 rupture | 1 tube (diameter 5 mm - length 20 mm) from C5 to upper trunk<br>1 tube (diameter 5 mm - length 20 mm) from C7 to medium trunk<br>1 tube (diameter 6 mm - length 20 mm) from C8–T1 to lower trunk | Bad (Mallet II/Gilbert 1/ Raimondi 1) |

The table shows the type of lesion, the surgical planning and the results for each patients. OBPP=Obstetrical brachial plexus palsy

**Table 2: PNI group, the causes of nerve injury, characteristics of the conduit inserted for reconnecting nerve stumps and results**

| Case | Side | Causes of paralysis | Reconstruction | Results |
|---|---|---|---|---|
| 1 | Sciatic nerve (thigh) | Gunshot lesion | 1 tube (diameter 6 mm - length 30 mm) | Bad (Sakellarides<M2/S2+) |
| 2 | Peroneal nerve (fibular head) | Cutting lesion | 1 tube (diameter 5 mm - length 20 mm) | Bad (Sakellarides<M2/S2+) |
| 3 | Radial nerve (humerus) | Iatrogenic lesion | 1 tube (diameter 5 mm - length 30 mm) | Good (Sakellarides>M4/S3+) |
| 4 | Median nerve (forearm) | Car accident | 1 tube (diameter 4 mm - length 20 mm) | Good (Sakellarides>M4/S3+) |
| 5 | Median nerve (wrist) | Cutting lesion | 1 tube (diameter 5 mm - length 20 mm) | Good (Sakellarides>M4/S3+) |
| 6 | Intermediate dorsal cutaneous nerve (foot) | Cutting lesion | 1 tube (diameter 3 mm - length 20 mm) | Good (British Medical Research Council: S4) |

PNI=Peripheral nerve injury

Similarly, upper or three-radicular brachial plexus injuries were assessed as good for Mallet IV/Gilbert 4–5, fair for Mallet III/Gilbert 2–3 and bad for Mallet II/Gilbert 0–1, without considering Raimondi's hand classification.

The results of sensory nerves repairing were assessed according the Nerve Injuries Committee scale of the British Medical Research Council, modified by Mackinnon and Dellon, while motor-sensory mixed nerves were evaluated by means of the Sakellarides' scale.[17,18]

The sensitive nerve results were assessed as good for values of S4/S3+, fair for (S3/S2+) and bad for <S2, while peripheral mixed nerves results were assigned as good for >M4/S3+, fair for >M3/S3−S2+ and bad for <M2/S2.

## Results

Patients' assessment and evaluation scales have been inserted in order to provide separately the results of brachial plexus palsy and PNI. Furthermore for each group the preoperative assessment, the operative planning and postoperative evaluation are shown in tables.

The mean followup was 5.2 ± 1.68 years SD (range 2.8–7.7 years) for OBPP and 4.08 ± 1.76 years SD (range 1.3–6.5 years) for PNI. In OBPP patients, we observed 1 good (11%), 3 fair (33%), and 5 bad (56%) results. In the PNI group, we observed four patients (67%) who had good results while only two (33%) had a bad outcome. No fair results were observed. Five OBPP patients, having presented a bad outcome, were in need of a second surgery, as usually happens after a failure of brachial plexus reconstruction [Table 3]. According to the recent trends of nerve repair in OBPP, a late nerve surgery was performed.

In some patients during the reoperation, we checked the previous effects of surgery. Particularly, in the suprascapular nerve neurotization by means of accessory spinal nerve, we explored a site close to the one where conduits had been applied during the first surgical procedure.

In three patients out of five, who underwent that specific neurotization, we constantly found a thick fibrosis and a pale yellowish thinned incontinuity structure as expression of the loosening of suture tension at the distal stump [Figure 1]. The electrical stimulation of this nerve structure, coming out of the presumable conduit remnant, did not demonstrate any distal muscle contraction.

In PNI group, bad outcome occurred in patients affected by sciatic nerve injury. One of the two patients who had undergone primary nerve surgery was lost at long term followup while the second patient underwent reoperation for nerve reconstruction with autologous sural nerve grafts.

## Discussion

Among reconstructive techniques, the tubulization might have technical advantages in the presence of wide nerve loss when conventional nerve grafts are insufficient to provide the filling of the defect. Therefore, the additional supply offered by nerve conduits can enlarge the reconstruction, overcoming the scarcity of nerve grafts, especially in young children.

In fact in small children, when the autologous nerve supply is poor, that is, in brachial plexus reconstruction, it is sometimes difficult to find veins with appropriate diameter to create biological nerve guides. In these cases, nerve guides might represent an additional resource for nerve substitution. Moreover, another advantage is the possibility of the sparing of autologous structures, which avoids the morbidity of the donor site and scars. Commonly neuroma resection and nerve grafts are considered the gold standard for nerve repair both in brachial plexus palsy and in PNIs.[19,20] The sural nerve is the most common

**Table 3: The scheme of reconstruction for primary and late nerve surgery**

| Case | Type of paralysis | Primary reconstruction | Results after primary surgery | Secondary reconstruction | Results after secondary surgery |
|---|---|---|---|---|---|
| 1 | Total palsy<br>C5–C6 rupture/ C7–C8–T1 avulsions | 1 tube (diameter 5 mm - length 20 mm) from C5 to upper and medium trunk<br>1 tube (diameter 5 mm - length 30 mm) from C6 to inferior trunk | Bad (Mallet II - Gilbert 2 - Raimondi 1) | Late neurotization<br>XI to suprascapular and 3–4–5 intercostals to musculocutaneous | Good (Mallet IV - Gilbert 4 - Raimondi 1) |
| 2 | Tri-radicular palsy<br>C5–C6–C7 rupture | 1 tube (diameter 4 mm - length 15 mm) from C5 to anterior part of upper trunk<br>1 tube (diameter 4 mm - length 15 mm) from C6 to posterior part of upper trunk<br>1 tube (diameter 4 mm - length 20 mm) from C7 to medium trunk | Bad (Mallet II - Gilbert 2) | Neuroma resection and reconstruction using autologous sural nerve grafts | Good (Mallet IV - Gilbert 4) |
| 3 | Total palsy<br>C5–C6–C7–C8 rupture/ T1 avulsions | 1 tube (diameter 7 mm - length 20 mm) from C5–C6 to upper trunk<br>1 tube (diameter 6 mm - length 25 mm) from C8 to lower trunk<br>Neurolysis of medium trunk | Bad (Mallet II - Gilbert 1 - Raimondi 3) | Late neurotization<br>XI to suprascapular and 3–4–5 intercostals to musculocutaneous | Good (Mallet IV - Gilbert 4 - Raimondi 3) |
| 4 | Total palsy<br>C5–C6–C7–C8–T1 rupture | 1 tube (diameter 5 mm - length 20 mm) from C5 to upper trunk<br>1 tube (diameter 5 mm - length 20 mm) from C7 to medium trunk<br>1 tube (diameter 6 mm - length 20 mm) from C8–T1 to lower trunk | Bad (Mallet II - Gilbert 1 - Raimondi 1) | Neuroma resection and reconstruction using autologous sural nerve grafts | Bad (Mallet II - Gilbert 1 - Raimondi 1) |
| 5 | Tri-radicular palsy<br>C5–C6–C7 rupture | 1 tube (diameter 5 mm - length 20 mm) from C5 to upper trunk<br>Neuroma resection and direct neurorraphy of medium trunk | Bad (Mallet II - Gilbert 2) | Late neurotization<br>XI to suprascapular and oberlin procedure | Fair (Mallet III - Gilbert 3) |

OBPP=Obstetrical brachial plexus palsy

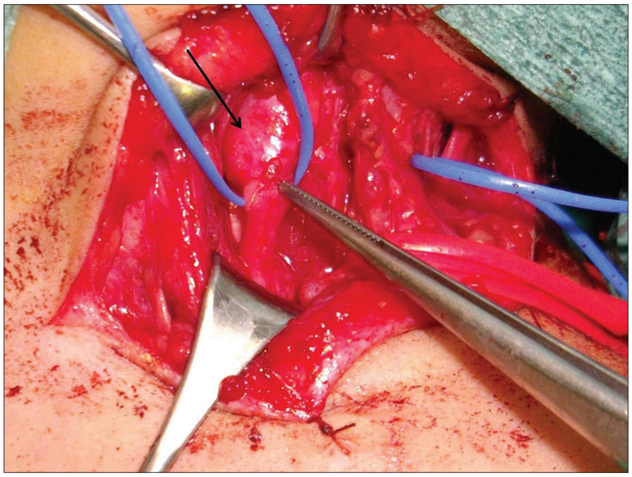

**Figure 1:** Peroperative clinical photograph of a patient who underwent neurotization showing thick fibrosis. The arrow is showing the residual of nerve conduit, while the forceps is indicating the presence of useless regenerated nerve

donor nerve[21,22] but one must be aware that anatomical variations of the nerve are often present. Additionally the incision at the calf for harvesting the nerve represents a further unexpected lesion that parents are dimly prepared to accept, especially because skin incisions produce very often excessive scarring. Biological tubulization has been rarely proposed in childhood, because of the scarcity of vein supply, feasible for bridging nerve defects. Indeed, harvesting vein grafts of adequate caliber useful for tubulization is challenging in young children. So as, although tubulization obtained both with biological and synthetic structures is not a new proposal referring to the adult, a few reports have reported about using nerve conduits in pediatrics. Moreover, nerve lesions in pediatric age group are mostly related to mixed nerve injuries, on this subject there is no complete agreement of management, even for adult patients.

Particularly brachial plexus reconstruction is difficult because the large number of nerve graftings are commonly required. Brachial plexus injuries in the children are mostly dependent on perinatal lesion rather than traumatic damage caused during infancy. Conversely PNI of upper or lower limbs are more common in pediatric trauma occurring during growth.[23]

Peripheral nerve lesions differ on the type and the localization of trauma: Open injuries are immediately treated while in closed lesions a waiting attitude is mandatory in order to evaluate a possible spontaneous recovery. Considering the problems of nerve supply in pediatrics and taking into account that tubulization is a well-accepted technique in the adult, we decided to use nerve conduits in order to find out a solution to repair the nerve gap in the child. We were encouraged from several articles on the topic. Most of the papers were related to the sensory nerve, but some articles were concerning mixed nerve repair in the adult, particularly in the upper limb.[24-26] During the years, many authors have studied alternative methods for filling nerve gap,[27,28] so as nerve tubulization is nowadays widely used for digital nerve reconstruction in adulthood.[29] In this sense tubulization has become a validated procedure that is now proposed as a good alternative for the repair of small nerve defects (<30 mm). Nerve repair by means of conduits during developmental age has been sparsely reported, even if two groups of researchers have obtained satisfactory results by using nerve conduits for obstetrical brachial plexus reconstruction. They proposed different conduits, namely collagen nerve guides and vein grafts, having drawn the same conclusions, recommending the conduits as an alternative to nerve grafting. However, none of the two groups has outlined contraindications in using nerve conduits in pediatric age.

We have decided using collagen reabsorbable matrix conduit (Neuragen) on the basis that this structure consists of a material commonly used in medical practice (i.e. suture, devices etc.,) and because it has been already experienced by one of the two groups of researchers.

Comparing our results with those of the two reports, we observed a high rate of failure (56%) in using conduits in brachial plexus repair. More precisely, in our case series of nine OBPP patients, five cases required a new surgical approach. Giving more details, three of those (60%), who had the surgical repair in a site close to the previous surgery, showed that the presumable remnant of the conduit appeared thinned as if there were a loosening of suture tension at the distal stump. This useless regenerated nerve did not show any distal response after electrical stimulation. During the second surgery in all cases, we performed selective neurotizations targeting specific muscles, according to the late nerve surgery nowadays preferred.

The presence of thick fibrous tissue in the site of conduit implant has explained the regeneration failure, even though, in brachial plexus repair, the main problem is the particular anatomy of nerve axons and their continuous reorientation that turns out failure even with the conventional nerve graft. Furthermore, another reason of failure possibly has been the length of the gap because, the longer the gap, the higher the risk of failure for the depletion of nerve regeneration.

Even if we did not need a nerve tube of extra length, the length of nerve conduits might represent a limit to the application of the method, particularly for the limited possibility of adapting the nerve gap. It is also important to mention that even brachial plexus reconstruction by means of sural nerve graft sometimes shows unsatisfactory results. In fact regardless of the technique of the repair many variable parameters influence the outcome of brachial plexus reconstruction (i.e., extension and severity of the lesions). The small group of patients treated with tubes does not allow to draw conclusion but, in our opinion, the use of tubulization should not be considered as a first choice in brachial plexus reconstruction in children, especially for long defects, as experimentally demonstrated.[30] The situation has been different in PNIs repair, where positive outcomes were generally observed. Nevertheless we had failures in a few cases.

Since the main nerve trunks of upper limb and sensory nerves of the hand have demonstrated satisfactory responses, the reliability of using nerve tubes can be affirmed, both in terms of the quality of and the time of the recovery.[31]

Conversely bad results occurred only in the lower limb, particularly in sciatic nerve repair, both at the thigh and at fibular head level.

The reasons of these negative results have been probably the same as those causing the bad results in brachial plexus repair, namely the vast anatomical complexity of the sciatic nerve, which presents a continuous axonal reorientation (particularly in the thigh) and the long distance between the site of lesion and the corresponding muscular groups. In addition, the failure of mixed nerve is higher than the sensory nerve.

## Conclusion

Nerve tubulization for repairing nerve lesions in developmental age (children) can be considered as a valid alternative to nerve grafts in PNI, especially of the upper limb. Conversely, repair by means of nerve conduits in great trunks of the lower limb should be more cautious. This suggestion is based on the inconsistent results we observed in our case series.

Equally in brachial plexus repair, the tubes can increase the possibility of nerve repair when conventional techniques are insufficient that is, in case of large nerve gap, especially in total palsy, but cannot be considered as a first choice of treatment.

Finally in nerve reconstruction planning, the high cost of the tube should always be considered, although in harvesting nerve grafting, the possibility of avoiding the donor site morbidity is not an insignificant detail.

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