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ORIGINAL ARTICLE

Repair of nerve injuries in the forearm using a silicone tube. Long-term clinical results

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KEYWORDS
Nerve;
Neurotube;
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Abstract
Objective: The aim of the present study is to evaluate motor and sensory results obtained after reconstruction of peripheral nerve injuries in the forearm, using silicone tubes.
Methods: A series of 16 injuries of forearm nerves (7 median, 7 ulnar, 1 radial sensory branch, 1 dorsal ulnar cutaneous branch) repaired with use of direct neurorraphy through a silicon tube were retrospectively studied. Eleven patients suffered associated arterial and tendinous injuries. Secondary nerve repair was performed in 3 cases and primary repair in 13, two of them in the context of re-implant of the upper limb. The series was evaluated using the functional scale described by Chanson.
Results: At a mean follow-up of 24 months, and having 2 cases excluded due to isolated injury of sensory branches, we obtained a 64% of good or excellent results, 28% of satisfactory results and 1 bad result. The tube was removed in 6 cases; 4 due to palpable painless tumour in the site of insertion, a case with compression symptoms after complete nerve function restoration and another that showed herniation of the stumps. In 5 cases the macroscopic restoration of the nerve was verified at the time of tube removal.
Conclusion: The use of silicone tubes in the reconstruction of acute, subacute and chronic nerve injuries in the forearm seems to give good results in most of the cases, with macroscopic anatomy restitution of the nerve and good functional recovery.

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PALABRAS CLAVE
Nervio;
Neurotubo;
Reparación nerviosa

Reparación de las lesiones nerviosas en el antebrazo con tubo de silicona. Resultados clínicos a largo plazo

Resumen

Objetivo: El objetivo del presente estudio es evaluar los resultados motores y sensitivos obtenidos tras la reparación de los nervios mixtos del antebrazo con tubo de silicona.

Material y métodos: Estudio retrospectivo de 14 pacientes afectos de 16 lesiones de los troncos nerviosos en el antebrazo (7 medianos, 7 cubitales, 1 rama radial sensitiva, 1 rama cutánea dorsal cubital) en los que se realizó neurorrafia directa con tubo de silicona. En 11 pacientes existieron lesiones asociadas arteriales y tendinosas. Se realizó reparación secundaria en tres casos y primaria en los 13 restantes, dos de ellos durante un reimplante de miembro superior. La valoración se realizó mediante la escala de funcional descrita por Chanson.

Resultados: Con un seguimiento medio de 24 meses y excluyendo dos casos que afectaban únicamente a ramos sensitivos, se obtuvieron un 64% de buenos o muy buenos resultados, 24% de resultados regulares y un caso de mal resultado. En 6 casos se retiró el tubo, por tumoración palpable no dolorosa en la zona de inserción en 4 pacientes, por la existencia de clínica compresiva y por herniación de los extremos nerviosos en el interior del tubo en otro. En todos los casos se pudo comprobar la restitución macroscópica de la estructura nerviosa.

Conclusiones: El uso del tubo de silicona en la reparación de lesiones agudas, subagudas y crónicas de nervios periféricos en el antebrazo parece aportar buenos resultados en la mayoría de los casos, con restauración macroscópica de la anatomía del nervio y restitución de la función.

Introduction

The final result of a nerve lesion is determined by the intensity of cellular damage produced, age and regeneration capacity of the subject. Also, the surgical repair technique used has a significant influence on the final result, although it does not always guarantee a correct neurological recovery. This is due to the existence of multiple cellular, biochemical and genetic factors which are involved in the process of regeneration and nerve repair which are hardly controlled by the surgeon.

Multiple techniques exist for the repair of peripheral nerve injuries. The results of all of them have been highly contrasted with the golden standard of nerve repair, direct termino-terminal suture in the case of primary repairs[1] or non-vascularized interfascicular graft as described by Millesi in the case of secondary repairs or those where the nerve defect is irreparable by means of direct suture.[2]

The use of nerve tubes has become more popular due to an improved knowledge regarding phenomena taking place in the sinus of the nerve during its repair and regeneration process.[3,4] In this sense, the first nerve tubulization attempts took place in 1909, when Wrede used a venous graft for the repair of a medium, ulnar and medial forearm cutaneous nerve injury, with a 7cm defect in a 27 year-old patient. From then on, multiple biological and synthetic materials have been equally used for that purpose.[5,6] In 1989, Merle published his clinical experience with the use of silicone tubes for the repair of 3 forearm nerves.[7] Subsequently, Lundborg presented his experience with the same type of tubes in the repair of nerve trunks in the forearm, as well as a prospective and comparative study with direct epineural suture.[8-10] In 1999, Braga da Silva published his results using the silicone tube in 26 patients with forearm median and/or ulnar nerve injuries, obtaining better results with the use of silicone tubes in the ulnar nerve.[9]

The present study investigates the results of a series of nerve trunk lesions in the forearm, all of which were treated using silicone tubes as a method for primary and secondary repair.

Material and method

A total of 14 patients affected by 16 nerve trunk lesions located between the flexion folds of the elbow and wrist were treated by direct tubulization with a silicone tube at our centre between 1996 and 2003.

The series consisted of 13 men and one woman, with a mean age of 32.4 (range: 20-59) with lesions in 7 medians, 7 ulnae, one sensitive radial branch and one cutaneous dorsal branch of the ulnar nerve.

In two cases, the nerve injuries were generated in an isolated way without the existence of associated vascular or tendinous injuries. In 11 cases there were associated lesions in: radial artery (2), ulnar artery (3), flexor tendons (7) and extensor tendons (1). Two tubulization cases were carried out during the process of reimplanting an upper limb.

In 13 cases, the repair was primary, being performed less than 24 hours after the injury took place, while in another 3 it was secondary, executed 2, 3 and 21 months after the injury (table 1).

Table 1 Evolution and results of nerve lesions

Case	Gender	Age	Aetiology	Nerve	Suture	Follow-up	Chanson		EMG	Ex
							M-S-F	T		
1	M	33	I	C	P	42	4-2-4	10	+	+
2	M	33	I elbow	C	P	23	0-0-2			+
3	M	32	I	C	S (2 m)	36	3-3-4	10	+	
4	M	59	R	C	P	10	2-2-2	6		
5	M	45	I	C	P	52	1-1-2	4		
6	F	31	I	M (p)	S (21 m)	17	5-3-3	11		
7	M	20	I	M	P	21	3-3-4	10	+	+
8	M	33	R	M	P	14	1-2-2	5		
9	M	24	I	M	P	13	4-2-4	10	+	
10	M	25	I	R sen	P	9	(5)-4-5	14		
11	M	33	I	M	P	47	3-3-3	9	+	
12	M	33	I	C	P	47	3-3-3	9	+	
13	M	39	I	M	P	34	1-1-2	4		+
14	M	19	I	C	P	18	3-3-4	10		+
15	M	19	I	C sen	P	18	(5)-4-4	13		+
16	M	28	I	C	S (3 m)	17	3-3-4	10		+

C: ulnar nerve; F: female; Ex: tube removal; M: man; I: incise; M: median nerve; P: primary suture; R: reimplantation; R: radial nerve (sensory branch); S: secondary suture.

Table 2 Functional evaluation scale proposed by Chanson

	Motor function	Sensory function	Pain and functionality
0 points	M0, no contraction	S0, insensitivity	F0, pain and incapacity to carry out any function
1 points	M1, slight contraction	S1, protective sensitivity, discrimination > 20 mm	F1, pain and poor function
2 points	M2, movement against gravity	S2, partial recovery, painful sensitivity, discrimination 1 5-20 mm	F2, slight pain and precarious function
3 points	M3, movement against resistance	S3, partial recovery, sensitivity to pain, discrimination 10-14 mm	F3, sporadic pain and poor function
4 points	M4, independent movements	S4, tactile sensitivity, discrimination 9-5 mm	F4, no pain and function with occasional problems
5 points	M5, complete recovery	S5, total recovery, discrimination < 5 mm	F5, normal function

Excellent: from 13 to 15 points.
Very good: from 10 to 12 points.
Good: from 7 to 9 points.
Regular: from 4 to 6 points.
Poor: from 1 to 3 points.

We have retrospectively analyzed the functional results using the scale proposed by Chanson[10] for the evaluation of motor, sensory and functional function of the injured limb (table 2).

Electromyographic monitoring was not available in all cases.

Surgical technique

The procedure and surgical technique were similar in all cases. Antibiotic prophylaxis was always used and associated lesions were resolved. Regarding nerve repair, nerve ends were resected using a Weber neurotome and by means of a

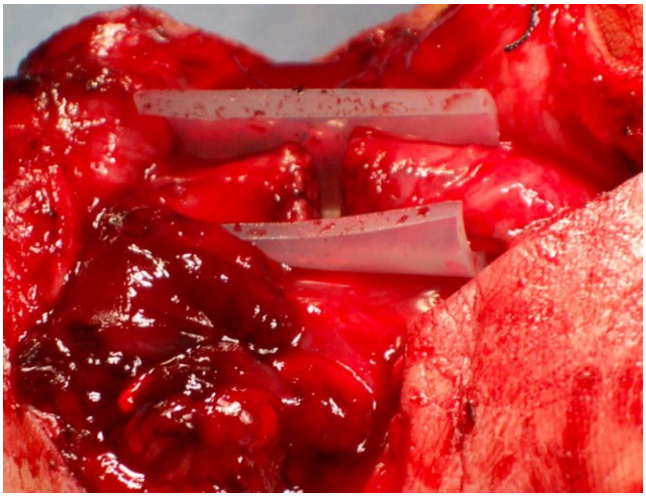

Figure 1 Resection of nerve endings, placement face to face and subsequent epineural fixing and closure of the tube.

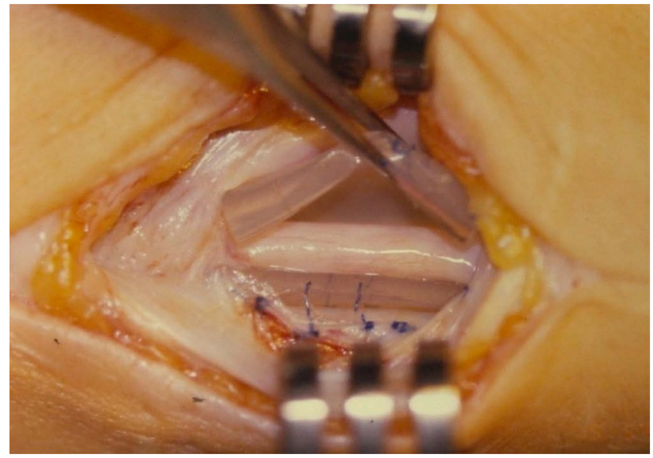

Figure 2 Ablation of the silicone tube. Complete nerve regeneration.

Rosselet manoeuvre. Next, the ends were introduced into the tube in such a manner that the distance between them never exceeded 5mm. In order to do so, nerve stumps were fixed to the side of the tube with epineural polar points (fig. 1).

The measurement of the diameter of nerve ends using the neurotome allowed selection of the diameter of the silicone tube among three available sizes. We attempted to use that whose diameter was approximately 30%wider than that of the injured nerve. Once the stumps were fixed inside the tube, isotonic saline serum was injected into it in order to minimize their dryness.

The wrist and/or elbow were placed in a cast in an immobile, medium flexion position for a period of 3-4 weeks. Subsequently, immobilization was removed and rehabilitation exercises were started in those cases where lesions were associated to tendons or free mobility of the limb was reinstated in the case of isolated nerve lesions.

Results

The average follow-up period was 24 months (range: 9-47). No local or systemic complications caused by the silicone were detected during this time. There was no evidence of hyperesthesia in any case and Tinel's sign was negative in the area of the lesion.

Tube ablation was carried out in 6 patients. In 4 of them due to pain in the insertion zone, with palpable subcutaneous tumour (2 median and 2 ulnar). One case (ulnar) required an exo-endoneurolysis for the resolution of clinical and electromyographic persistence of a compressive syndrome after the nerve recovery. A complete anatomical recovery of the nervous structure was observed in these 5 cases (fig. 2). The sixth tube removal was linked to a case of ulnar nerve injury with a poor evolution, with herniation of the proximal nerve stump inside the tube and formation of a neuroma which required a repair through interfascicular graft. This was the only negative result observed in the present series.

Two nerve repairs, medium and ulnar, were executed in the context of a reimplanted forearm (cases 4 and 8). Although these were long procedures, the tubulization of the injured nerves shortened the surgical time. Sensitive and functional recovery signs were observed after 10 and 14 months follow-up, with a regular score being obtained in the evaluation scale by the end of the follow-up period.

Excluding the 2 cases of sensory branches where the score obtained was excellent due to the lack of an affected motor function, 64% of medium and ulnar nerves repaired by means of tubulization obtained results which were evaluated as good or very good. Another 24% of them obtained regular results and only 7% (one case of ulnar nerve injury) obtained a bad result (table1 and table 3).

Despite the association with other tendinous and arterial lesions, as well as forearm amputations, the motor and

Table 3 Final results obtained according to the evaluation using the Chanson scale

	Excellent 13 to 15	Very good 10 to 12	Good 7 to 9	Regular 4 to 6	Poor 1 to 3
Ulnar (8)		4	1	2	1
Median (6)		3	1	2	
Cubital sen (1)	1				
Radial sen (1)	1				

Table 4 Factors affecting nerve regeneration

Anatomical factors
Cellular factors
Neuronal survival
Neurotrophic and neurotropic
Basal lamina
Membrane receptors
Genetic expression
Integrity of terminal organs
CNS factors

functional function obtained were generally good. No irreducible claws or flat hands were observed by the end of the follow-up period, with an acceptable function of the intrinsic musculature of the hand being achieved. Only one case (case 5) required palliative surgery due to Digiti Quinti Abductor paralysis which was treated through transposition of the Digiti Quinti Extensor.

Discussion

Through an increasingly precise knowledge of the phenomena following neurotomy, we know that the complex regeneration mechanism of the different injured fibres depends on multiple factors (table 4).[3,4,11]

The complex funicular structure of the nervous trunk, its decussations and anastomosis make a direct suture very difficult to reproduce. The existence of different nerve fibre types inside the same trunk impedes their precise union by simple direct suture.

The recovery process of the injured nerve fibres starts once neurotmesis has been achieved. This implies changes in both the distal and proximal stumps, to the point where survival of the neuronal body located in the anterior shaft of the spine or in the spinal ganglion may be interesting. The reaction of Schwann cells is responsible for the elimination of cellular detritus and spare myelin, and for the formation of a new basal plate and myelin sheath. This is critical for the growth of the axonal regeneration front. In the same way, the presence of other cellular lineages such as macrophages, fibroblasts and platelets, is also necessary in the regeneration process.

The existence of different cells involved in nerve repair is related to the presence of substances which will encourage it. There is an action sequence established for different neurotrophic and neurotropic factors during the repair process. These factors not only encourage the growth of an axonal regeneration front by means of neurotomy (neurotrophic), but also allow the reordering of fibres and a specific repositioning of homonymous fibres (neurotropic).

The existence of neuromodulating substances depends on the level of genetic expression of the cells involved in their synthesis. The behaviour of these substances must follow chemical concentration gradients, as it depends on the expression of membrane receptors in specific locations in order to take place. The existence of high concentrations of messenger RNA during the nerve regeneration process has been proved.

The whole process of regeneration and repositioning must take place in a short period of time in order to avoid irreversible atrophy of terminal organs. Once the terminal organs have been successfully reinnervated, a relearning and restructuring period of the CNS functions starts.

Therefore, nerve repair using tubes is based on the concept of creating a closed chamber between the nerve endings where the accumulation of different neurotrophic and neurotropic factors will favour a better nerve regeneration and repair.[4,5,12,13]

Different experimental and clinical works have determined that any intercalary defect below 4cm can be resolved with the use of tubes where the creation of a nerve chamber can fill in the existing defect.[13-15]

Regarding the original objective of creating an ideal tube, both the physical and chemical properties of the tube walls have been modified, as well as the internal environment. Reabsorbable tubes made of collagen or polyglycolic acid have presented less adverse local effects, such as compressive syndromes or pain in the insertion zone.[15,17,18] The modification of intraluminal conditions by adding different cellular, matrix o biochemical factors has created a synthetic nervous graft which enables the repair of increasingly large intercalary defects.[14,15]

The sequence of cellular and biochemical changes which take place in the nervous trunk after its section leads us to think that a simple microsurgical suture is not enough to guarantee satisfactory nerve repair. In the present series, the use of silicone tubes allowed acceptable anatomical and functional repair of the injured nerves at the forearm level. The technique is useful in emergency situations and in secondary repairs, where the intercalary defect is small. Tinel's sign did not appear during the repair process. This effect is considered beneficial, due to the absence of neuropathic pain, which does not interfere in the rehabilitation process of associated injuries. Complications deriving from the use of silicone tubes made it necessary to extract them in 6 cases, with painful and compressive symptoms being resolved. The tubulization of forearm nerves during reimplantation may shorten surgery time. Furthermore, comparative studies with other nerve repair methods and between different types of tube and their different, commercial cellular or matrix contents would offer information regarding the advantages and disadvantages of each of them.

Conclusions

The use of silicone tubes in the repair of acute, subacute and chronic injuries of the peripheral nerves in the forearm seems to offer good results in most cases, with a macroscopic restoration of nerve anatomy and an acceptable restitution of nerve function.

Level of evidence

Level of evidence IV.

Conflict of interest

The authors declare no conflict of interest.

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