ELECTRICAL STIMULATION OF BONE NONUNION WITH THE PRESENCE OF A GAP

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A total of 22 established nonunions was treated with a capacitively-coupled electrical signal. A gap of 0.5 cm or more between the fragments was present in all of these nonunions. After an average of 26 weeks of treatment with capacitive coupling, radiographic assessment showed solid bone union in 72.7% of the cases. The results were better when the fracture site was metaphyseal. When the site was diaphyseal, bone healing was mainly achieved by bone trabeculae invading the gap. When the site was metaphyseal, healing occurred by the formation of a peripheral callus. The results were not affected by the presence of infection. In 8 of the cases osteomyelitis occurred, but all healed.

Keywords : nonunion ; electrical stimulation ; capacitive coupling ; gap.
Mots-clés : pseudarthrose ; stimulation électrique ; couple de capacité ; écart.

INTRODUCTION

Multiple factors, such as viability of the tissues, initial treatment, production mechanisms and so on, are implicated in the healing of fractures. Final success depends on factors such as reconstruction of the anatomy, which is not always possible. Loss of bone, imperfect reduction, nonstable immobilization, a poorly performed osteosynthesis, etc. may result in the presence of a residual gap and the onset of nonunion.

Local factors that range from the physical barrier due to the interposition of soft tissues, to the local release of a hormone, as well as systemic influences, such as the deleterious side-effects of drugs, have to be taken under consideration (1, 10, 11).

The controversy arising at the time of analyzing the etiology is also present when we try to prescribe a treatment. Electrical stimulation as a treatment for bone nonunion has been studied with great interest for the last three decades. Its application is based on the revitalization, in terms of cellular stimulation, of the quiescent tissue occupying the gap, in order to unblock the process of consolidation (2). But all available possibilities (direct current, inductive coupling, capacitive-coupling fields) have been considered to be contraindicated when the gap at the focus is wider than 0.5 cm. There has not been a definite explanation for this, except for the observation of poor results in some cases (3, 6, 16).

The possibility of obtaining the consolidation of a fracture in which there is a gap wider than 1 cm has clearly been established by Urist (13). This paper records our experience with electrical stimulation for nonunions in which there was a gap wider than 0.5 cm.

PATIENTS AND METHODS

To be eligible for inclusion in this study, each patient had to have a well-established nonunion. Absence of

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union was demonstrated, clinically, by the presence of movement at the fracture site and, radiologically, by the presence of a fracture line. The fracture had to remain non united for at least 9 months from the time of injury, and there had to be no radiologic changes for the last 3 months.

The size of the gap was classified into four groups according to the widest distance between the fracture fragments over at least 50% of the contact area. In group 0 we included those cases in which there was a full contact. In group 1 the distance was narrower than 0.5 cm. Group 2 showed a 0.5 to 1 cm gap distance, and in group 3 gaps wider than 1 cm were included.

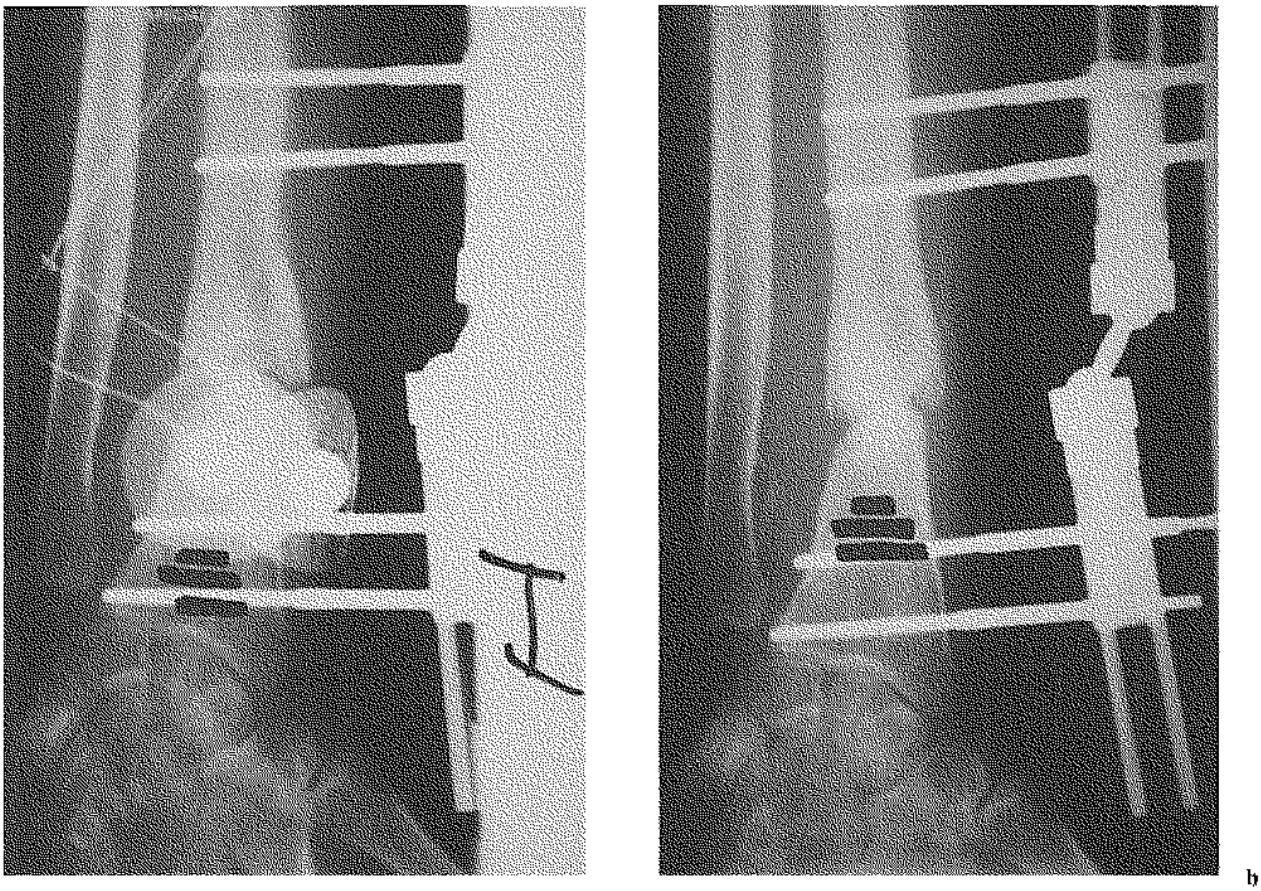
Twenty-two fractures within groups 2 and 3 were treated from 1990 to 1993. There were 16 male and 6 female patients whose age ranged from 17 to 70 years ; their average age was 35 years. The widest gap observed was 1.8 cm in 2 of the patients ; the bones involved were the tibia and the humerus. Data on the patients in this study are shown in Table I.

The tibia was the site of nonunion in 10 of the patients ; the humerus in 6 ; the radius in 2, and the

Table I. — Results

	Name	S	Age	Bone	Caract	Loca	WI	W. H.	GAP	PRE	INF	POS	CONS
1	VCC	F	70	tibia	SLB	M	EF		2	59		24	no
2	EEG	M	25	clavicle	T	D	PC		2	41		41	no
3	ARB	M	21	radius	COM	M	EF	EM	3	38	yes	18	yes
4	FCT	M	50	humerus	SO	D	EF	EM	2	48		23	yes
5	JMP	M	17	tibia	SO	D	EF	EM	3	35	yes	16	yes
6	JCE	M	31	tibia	SO	D	EF	EM	2	104	yes	36	yes
7	CSP	F	24	humerus	S	D	OT	C	3	38		28	yes
8	TSM	M	25	femur	COM	D	EF	EM	3	52		40	yes
9	JRT	M	43	tibia	COM	M	EF	C	3	66	yes	8	yes
10	APG	M	19	tibia	COM	D	EF	EM	2	78		14	yes
11	FHN	F	29	humerus	TF	D	PC		3	43		41	no
12	GMM	M	65	tibia	TF	M	EF	C	2	62	yes	42	yes
13	FFM	M	34	scaphoid	LO	D	PC		3	216		14	no
14	EGP	M	25	radius	COM	M	PC	C	2	41	yes	17	yes
15	ANT	F	34	humerus	T	D	PC	EM	3	51		32	yes
16	DES	M	25	tibia	SO	D	EF		3	30		26	no
17	RET	M	34	tibia	COM	D	EF	EM	3	121	yes	25	yes
18	POM	M	45	humerus	COM	D	EF	EM	2	41		32	yes
19	LIN	M	52	ulna	T	D	PC	C	3	56		42	yes
20	GFR	M	44	tibia	LO	M	OT	C	2	44	yes	12	yes
21	CSD	F	26	tibia	TF	D	EF	EM	2	67		12	yes
22	EUO	F	32	humerus	SO	D	PC		2	53		41	no

S : Sex ; M : Male ; F : Female ; S.L.B. : Segmental loss of bone ; T : Transverse ; COM : Comminuted ; S : Spiral ; SO : Short oblique ; TF : Third fragment ; LO : Long oblique ; M : Metaphyseal ; D : Diaphyseal ; EM : Endomedullary callus ; C : External callus ; W. H. : Way of healing ; PRE : Duration of previous treatment (in weeks) ; POS : Duration of electrical treatment (in weeks) ; INF : Infection ; CONS : Consolidation ; GAP : Gap type ; WI : Way of immobilization ; EF : External fixator ; PC : Plaster cast ; OT : Other treatment.



a b

Fig. 1a and b. — Case 3. Nonunion of the radius. Fig. 1a : Infected nonunion in the metaphyseal area of the radius ; 38 weeks of evolution ; b : Consolidation at the 18th week. Drainage stopped at the 7th week.

femur, ulna, clavicle and carpal scaphoid in one patient each. The average period of time between the original injury and the start of the capacitively-coupled electrical treatment was 62.7 weeks (range, 30 to 216 weeks).

Nine nonunions (41%) followed open fractures, and 12 (54.5%) closed fractures ; one (4.5%) was the result of a previous orthopaedic operation.

Eight patients had osteomyelitis at the time of treatment, and all of them had an actively draining sinus when the electrical therapy was started. Staphylococcus aureus was the dominant germ in 5 of them ; it was followed by Pseudomonas aeruginosa in 2 patients, and Acinetobacter in one patient.

During the entire electrical treatment, and until each nonunion was determined to be either healed or a treatment failure, the involved extremity was immobilized in all of the patients : in a plaster cast in 32%, using an external fixator in 59% and using other procedures in 9%. Ten operative procedures had been previously performed in 9 patients. None of the patients had previously undergone electrical stimulation.

All underwent capacitive coupling induced by an externally placed unit. The power source was supplied by a 9-V alkaline battery that was able to generate a frequency of 60 KHz and a symmetrical, sinusoidal wave form of an amplitude of 5 V peak-to-peak and an amperage that ranged from 5 to 10 mA RMS (root mean square) applied by two capacitor plates, attached to the skin overlying the nonunion site, placed on opposite sides of the patient's limb. The unit was used all day.

RESULTS

The results are shown in Table I. Sixteen of the nonunions achieved solid bony union (8 of the 10 tibial fractures, 4 of the 6 humeral fractures,

a

b

Fig. 2a and b. — Case 20. Nonunion of the tibia. Fig. 2a : Septic nonunion in the metaphyseal area of the tibia ; 44 weeks of evolution ; b : Consolidation by external callus at the 12th week. Drainage stopped at the 6th week.

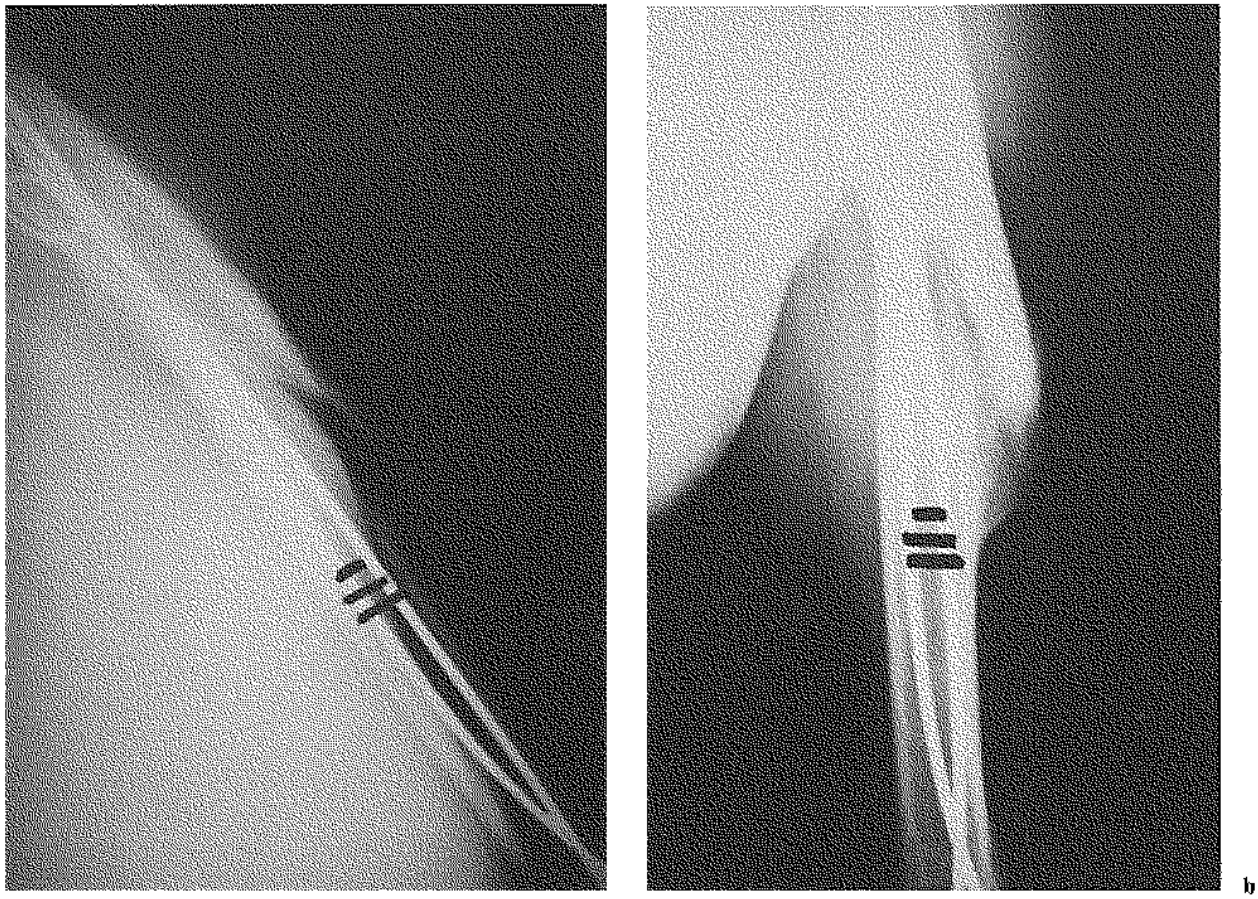
both radial fractures, the femoral and the ulnar). Two of the 10 tibial fractures, two of the 6 humeral fractures, the clavicle and the carpal scaphoid did not heal.

The average period of treatment with capacitive coupling was 26 weeks (range, 8 to 42 weeks). The success rate and the time needed for healing were directly related to the site of the fracture and ranged from 20.62 weeks average for the healing of 80% of the tibias to 41 weeks for the treatment of clavicle nonunion, which eventually failed.

When the fracture was in the metaphysis, healing occurred through an endomedullary callus in 20% of the cases (fig. 1a and b) versus 80% of the cases in which the fracture healed through an external callus (fig. 2a and b).

In the analysis of the associated treatment we observed that the distribution was almost the same. Two out of the three fractures treated by electrical stimulation plus external fixation healed through an external callus (66.66%), and so did the fractures in which the associated treatment was a plaster cast or other. The other fracture in this group, in the metaphyseal area and treated with electrical stimulation in association with external fixation, healed through formation of an endomedullary callus.

When the fracture was in the diaphyseal area the percentages were reversed : 18% of the cases healed through the production of an external callus (fig. 3a and b) versus 82% which healed through an endomedullary callus (fig. 4a and b).



a b

Fig. 3a and b. — Case 7. Nonunion of the humerus. Fig. 3a : Aseptic nonunion in the diaphyseal area of the humerus ; 38 weeks of evolution ; b : Consolidation by external callus at the 28th week.

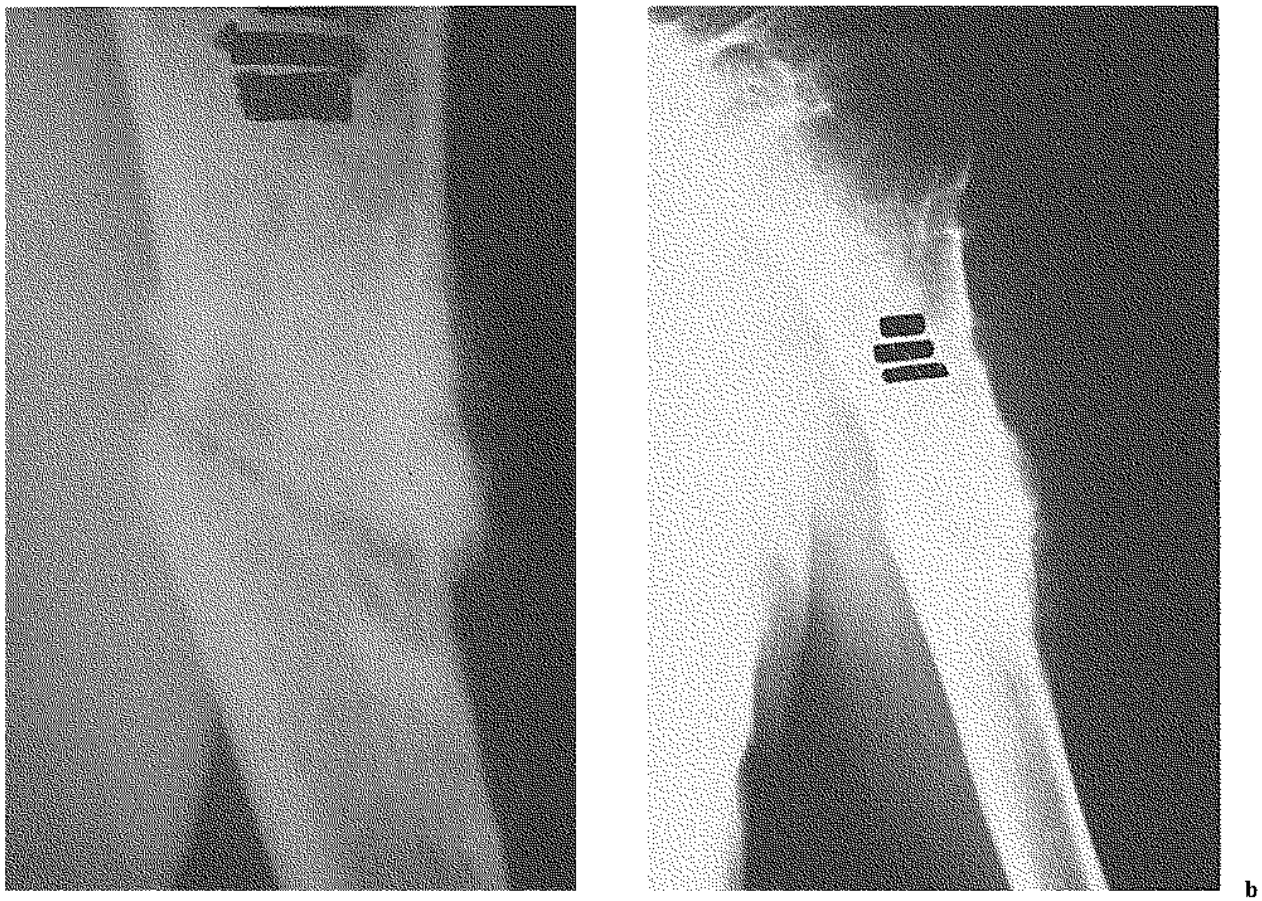
Nine fractures in this group received an associated treatment by external fixation ; 8 of them healed through an endomedullary callus and the other one failed to heal. Among 6 fractures in which the associated treatment was a plaster cast, 4 out of the 6 failed to heal and of the other 2, one healed through an endomedullary callus and the other one through an external callus. One last case was treated by another method of fixation in addition to electrical stimulation, and it healed through the formation of an external callus.

The patients who at the time of treatment had active drainage from an infection at the site of the nonunion achieved solid bony union. Drainage stopped after 8 weeks, and healing of the fracture took place after an average period of 21.7 weeks.

The placement of the capacitor plates was considered adequate in 83% of the cases. Among the reasons for improper placement we can point out the site of the infection drainage, cutaneous intolerance in 28.6% of the cases and cutaneous damage and skin graft in 43%. All of them belonged to the group which finally healed.

DISCUSSION

Many factors are involved in bone fracture healing. Persistence of the fracture gap has classically been identified as a cause of nonunion (14). Nowadays it is not distinguished as a particular form of nonunion but rather as a transitory stage



a b

Fig. 4a and b. — Case 4. Nonunion of the humerus. Fig. 4a : Aseptic nonunion in the diaphyseal area of the humerus. 48 weeks of evolution ; b : Consolidation by endomedullary callus at the 23rd week.

towards connective tissue bridging or overt pseudarthrosis (5, 9).

The impossibility of overcoming gaps wider than 1.5 cm has been proved through experience, and we have to bear in mind that all the experimental models are able to respond with a greater capacity to the formation of a peripheral callus than human bone (4, 9, 15, 16, 17). The tissue that fills in the gap might be the reason for this. Interposition of muscle has sometimes been found (8). However, many fractures that had interposing muscle, fascia, tendon, nerve or even cartilage eventually healed. In such cases, the interposing tissue usually necrotized, it became fibrous or it was reabsorbed and did not interfere with healing (12).

Bearing in mind the possibility of interposition of multiple tissues, we analyzed the results of electrical stimulation in those fractures in which the presence of a wide fracture gap had been established. Attempts were made by others to demonstrate the effectiveness of electrical stimulation in promoting osteogenesis using a homogeneous patient population. In all of these studies capacitive coupling stimulated fracture healing. However these studies were not performed on fractures in which the common factor was a gap wider than 0.5 cm between the bone ends.

Our study showed contradictory results in cases in which fractures with wide gaps were treated by electrical stimulation. We observed that some fractures in which the gap was wider than 1 cm

healed easily, while others became recalcitrant, delaying consolidation for months, or eventually failing to heal.

We must underscore the positive response of nonunion to stimulation when the site was metaphyseal, where the muscle mass surrounding bone is much less abundant than in the diaphysis, regardless of the size of the gap. In such cases we consider that in the gap occupied by cancellous tissue, electrical stimulation may start the release of the consolidation stopped at Bassett's fourth stage (2), bringing on consolidation by a peripheral callus. In these cases the success rate was 83%. Our findings have led us to conclude that the behavior of the callus depends on the anatomic site. When the site is metaphyseal and there is a wide gap (> 0.5 cm), healing takes place by an external callus.

In diaphyseal fractures, which are surrounded by abundant muscle mass, and where the interposition of soft tissue between the bone fragments is more frequent, the success rate was 69%. In these cases consolidation was achieved by the gap being filled by endomedullary callus instead of peripheral callus.

Nine out of 16 diaphyseal fractures eventually healed. Of the 6 fractures in which healing was not achieved, 5 were in the diaphyseal area, and one was in the metaphysis.

Contrary to what we thought, those fractures in the diaphysis treated by external fixation healed through the formation of an endomedullary callus. However, this should be regarded as just an observation because it is not statistically significant.

Other studies mention a success rate from 65% (6, 7) to 80 to 85% (3), but there are no statistics about cases where a gap wider than 0.5 cm is present.

We did not have the opportunity to study the kind of tissue that occupied the gap, so we could only speculate about the reasons for such a difference in the results. We hypothesize that when the gap is filled with a tissue such as muscle, tendon, nerve (which frequently happens in the diaphysis), the result is worse than when the gap is filled with just fibrous or fibrocartilaginous callus.

The success rate when treating a nonunion with electrical stimulation by capacitive coupling in a gap wider than 0.5 cm is not different from the rate of success obtained in cases in which the gap is narrower. The kind of tissue occupying the gap, rather than the distance, may be the reason for failure of the treatment.

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SAMENVATTING

P. ZAMORA-NAVAS, A. BORRAS VERDERA, R. ANTELO LORENZO, J. R. SARAS AYUSO, M. C. PEÑA REINA. Electrische stimulatie van pseudarthrosen met belangrijke diastase.

Tweeëntwintig pseudarthrosen met een interfragmentaire afstand gelijk aan of groter dan 5 mm werden met uitwendige electrostimulatie behandeld. Bij 72,7% van de gevallen werd een röntgenologische konsolidatie na gemiddeld 26 weken behandeling verworven.
De resultaten waren beter bij de metafyse frakturen. Voor de diafyse frakturen werd de konsolidatie slecht na opvulling van de diastase met botenten bekomen. De metafysaire pseudarthrosen konsolideerden met een perifere callus.
De resultaten werden niet beïnvloed door een eventuele infectie ; 8 gevallen et osteïtis konsolideerden vrij behoorlijk.

RÉSUMÉ

P. ZAMORA-NAVAS, A. BORRAS VERDERA, R. ANTELO LORENZO, J. R. SARAS AYUSO, M. C. PEÑA REINA. Stimulation électrique des pseudarthroses avec écart fragmentaire important.

Un traitement par stimulation électrique externe a été appliqué à 22 pseudarthroses qui présentaient un intervalle interfragmentaire égal ou supérieur à 5 mm. Après un traitement de 26 semaines en moyenne, la consolidation radiologique a été obtenue dans 72,7% des cas. Les résultats étaient meilleurs dans les fractures métaphysaires. Dans les fractures diaphysaires, la consolidation a surtout été obtenue par comblement de l'intervalle interfragmentaire par des trabécules osseuses. Les pseudarthroses métaphysaires ont consolidé par un cal périphérique.
Les résultats n'ont pas été affectés par la présence éventuelle d'une infection : il existait une ostéite dans 8 cas, qui ont tous consolidé.