Arch Orthop Traumat Surg 96, 241–246 (1980)

Archives of Orthopaedic and Traumatic Surgery

Electrical Stimulation of the Callus Formation by Means of Bipolar Rectangular Pulse Sequences

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Summary. The clinical application of the electrical stimulation, lasting several weeks, for the callus formation is reported in 11 patients. Bipolar rectangular pulse sequences were used for the stimulation at a frequency of 1 Hz and a current intensity of ± 20 µamp.

The electrical stimulation was successfully employed after distraction osteotomies with a KDA-apparatus in shortening of the leg provoked by different causes or in the treatment of pseudarthroses.

The realignment of the newly formed callus and the osseous consolidation are stimulated and speeded up by the bipolar rectangular pulse sequences as it is also shown in the light of the roentgenograms of a case.

Zusammenfassung. Bei 11 Patienten wird der klinische, mehrwöchige Einsatz der Elektrostimulation mit bipolaren Rechteckimpulsfolgen mit einer Frequenz von 1 Hz und einer Stromstärke von ± 20 µamp zur Anregung der Kallusbildung beschrieben.

Nach Distraktionsosteotomien mit KDA-Anlagen bei bestehender Beinverkürzung verschiedener Genese oder bei der Therapie der Pseudarthrose fand dieses Verfahren der Elektrostimulation erfolgreich Anwendung.

Die Ausrichtung des neugebildeten Kallus und ossäre Konsolidierung werden durch die bipolaren Rechteckimpulsfolgen, wie auch Röntgenbilder einer Kasuistik zeigen, angeregt und beschleunigt.

At present there is great interest in the electrical stimulation of the callus formation. After basic research of the electrical behaviour of the bone and the description of the electrical polarization [5, 7, 11, 20, 22], it was especially Bassett [3] and Cieszynski [6] who investigated the transformation, the differention, and the lamellar structural change of the bony callus caused by the piezoelectrical potential. Weigert et al. [21] explored the growth-, fracture-, and deformation-conditioned potential in the bone. Thus, they made an essential contribution to a better insight into the connections between mechanical deformation and polarization. Both in animal experiments and in clinical tests different authors have been concerned with the electrical stimulation of the callus formation to achieve a speeding up in the healing of the fracture or the pseudarthrosis [1, 4, 12, 17, 19, 21, 23].

Direct current [2, 10, 15, 21] with unsatisfactory results [2], the application of unipolar rectangular pulses [9, 12, 17, 18, 23], the employment of medium frequency currents [8] or the effect of electrodynamic potentials on the bone [11, 14, 20, 21], all these methods are procedures which might favour the healing of the bone. Apart from the application of different electrodes [19, 21], the question of the needed intensity of frequency and the intensity of current, respectively, and the duration of action is the decisive one. Landa [12] and Romano [17] reported positive results with 1—5 Hz and 0.5—10 µamp in the application of unipolar pulse sequences.

According to Anisimow [1], Bauer [2], Romano [17], and others the stimulation by the cathode is considered to speed up the healing of the bone decisively.

However, it is also pointed out to the very disadvantageous osteolysis around the anode. To exclude this disadvantageous effect, Hellinger and Berndt[1] developed a stimulator delivering rectangular pulse

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0344-8444/80/0096/0241/$ 1.20

Table 1. Survey of patients in whom a transcutaneous electrical stimulation was performed

No.	Name	Sex	Age	Bone	Diagnosis
1.	F.W.	male	25	femur	Infected talipes equinus pseudarthrosis with shortening of the right leg by 4 cm and Küntscher-nailing after fracture. KDA-application and lengthening by 3.5 cm. Repeated revision of the fistula, sequestrotomy, and irrigation-suction-drainage
2.	W.M.	female	21	tibia	Dysplasia of the right leg with aplasia of the fibula and shortening of the leg by 9 cm. Lengthening osteotomy of the right tibia, KDA-application, a lengthening of 8.5 cm obtained, removal of the KDA after 36 weeks
3.	M.M.	male	62	tibia	Talipes varus pseudarthrosis with varus deformity and a shortening of 6 cm after missile fracture. Distraction of the pseudarthrosis by means of a KDA, after having obtained a distraction of 3.5 cm an autogenous cancellous bone graft was performed. KDA removal after 56 weeks
4.	H.E.	male	48	femur	Secreting dislocated defective pseudarthrosis with varus deformity and a leg shortening of 12 cm after accident, KDA-application and correction of the position. After 4 weeks decortication and autogenous cancellous bone graft, AO-plating, a lengthening of the leg by 5.5 cm. Later on replating after fracture
5.	J.G.	male	23	femur	High luxatio coxae after infant coxitis with a leg shortening of 9.5 cm. Osteotomy, KDA-application, and employment of a distraction plate according to Soukop-Hoffmann. After having obtained a distraction of 6.3 cm, screwing was performed and an autogenous cancellous bone graft used
6.	P.W.	male	21	tibia	Osteomyelitis, talipes equinus pseudarthrosis and Crus varum et recurvatum with a leg shortening of 10 cm after distraction, autogenous cancellous bone graft, and AO-plating after fracture, fibula pro tibia operation, multi-stage correcting osteotomy and KDA-application, distraction of 9.5 cm
7.	H.J.	female	38	tibia	Infected talipes equinus pseudarthrosis after a plated fracture. Removal of the plate, application of an external pin fixation
8.	M.J.	male	24	tibia	Condition after poliomyelitis with a leg shortening of 6.5 cm. Distraction osteotomy and KDA-application. After 8 weeks plating of the distraction and autogenous cancellous bone graft
9.	L.D.	male	36	femur	Post-thrombotic osteomyelitis after AO-plating of a lengthening osteotomy (Wagner-distractor) with a leg shortening 10 cm, pseudarthrosis, DCP-plating and autogenous cancellous bone graft. After removal of the plate because of instability a 5-week KDA-application, thereafter replating, autogenous cancellous bone graft
10.	S.W.	male	54	tibia	Oligotrophic tibia defect pseudarthrosis after missile fracture with a leg shortening of 5 cm. KDA-application twice autogenous cancellous bone graft. After KDA-removal (after 7 months) fibula pro tibia operation and autogenous cancellous bone graft. A correction of the shortening by 3 cm was obtained
11.	R.W.	male	26	femur	Infected oligotrophic radiogenic supracondylar defective pseudarthrosis with a leg shortening of 9 cm. Autogenous fibula transplantation and autogenous cancellous bone graft after a 48-week application of a KDA and a leg lengthening of 8 cm had been obtained. Application of an external pin fixation according to Hoffmann-Vidal for a 4-week period

ES = electrical stimulation; KDA = compression-distraction-apparatus

Start of ES after application of the fixation	Duration of the ES in weeks	Result	Complication under ES	µamp	Duration of the ES till osseous consolidation/ weeks
14 weeks	13	Positive. Distinct callus realignment and osseous consolidation can be roentgenographically identified	Reimplantation of the electrodes	± 20	13
12 weeks	24	Positive. Callus realignment. Osseous consolidation can be roentgenographically identified	Electrodes twice reimplanted	± 20	24
6 weeks	31	Positive. Callus realignment. Advanced osseous consolidation can be roentgenographically identified	Electrodes twice reimplanted	± 20	52
37 weeks	9	Positive. Beginning realignment of the callus. An osseous consolidation is beginning under the treatment with ES	The infection persists	± 20	80
16 weeks	20	Positive. A distinct increase in the realignment of the callus and an osseous consolidation can be roentgenographically identified	Reimplantation of the electrodes	± 20	36
23 weeks	18	Positive. Well-structured bone structure with realignment of the trabeculae can be roentgenographically identified	Infection caused by the wire	± 20	26
Immediately	15	Positive. Osseous consolidation can be roentgenographically identified	No complications	± 20	15
8 weeks	16	Positive. Beginning realignment of the callus and osseous consolidation	No complications	± 20	26
40 weeks	22	Negative. An osseous consolidation cannot be roentgenographically identified	Repeated reimplantations of the electrodes	± 20	
19 weeks	48	Positive. Callus realignment and osseous consolidation can be roentgenographically identified	No complications	± 20	48
35 weeks	52	Positive. Distinct realignment of the callus can be roentgenographically identified	Reimplantation of the electrodes	± 20	

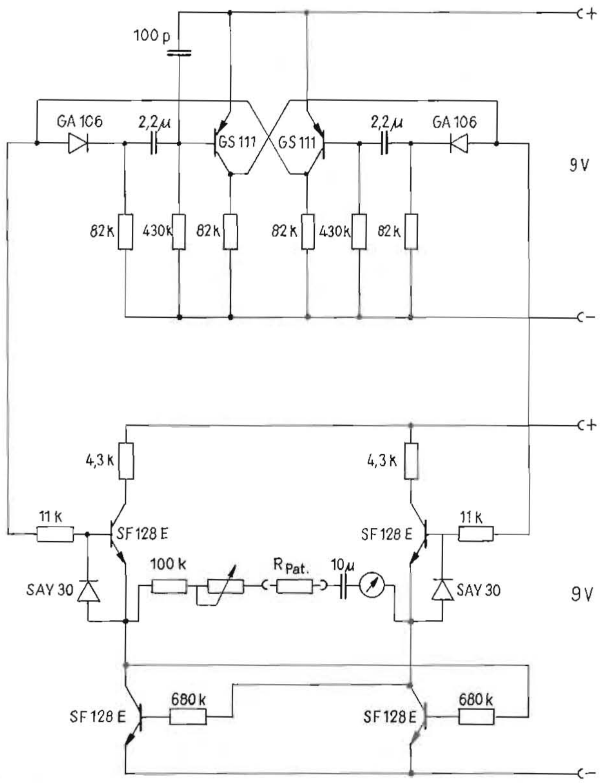


Fig. 1. Wiring diagram for the stimulator

sequences of 1 Hz, a pulse ratio of 1 : 1, and a variable current intensity (Fig. 1) for clinical purposes (1974). First clinical results and experiences are reported in this paper.

Methods

Proximally and distally to the area of the osteotomy or pseudarthrosis one KFI-cortical screw in each case was implanted as electrode distant from the plate. The electrodes were at least displaced to the AO-plate at an angle of 90°. The AO-plates were not insulated. The stimulation was also performed in external fixation (Hoffmann-Vidal-fixation) according to Jörgensen [9] or after the application of a KDA (compression-distraction-apparatus). The ends of the electrode wires lying at the cortical screw were silver-plated. The wires of the electrodes (were conducted through the skin) were percutaneously installed and connected to a portable battery-operated stimulator (9 V). The first model of this stimulator had a size of 11 cm × 6 cm × 7 cm. It was carried about with the patient in a leather-bag. There was a permanent stimulation over a period of several weeks (Table 1) with bipolar rectangular pulse sequences of 1 Hz, a pulse ratio of 1 : 1 and an intensity of current of 40 μamp (± 20 μamp, Fig. 2). After healing of the wound the patients were discharged from the hospital. The function of the stimulators and the placing of the electrodes were regularly checked in the outpatient care. For controlling, the course and the formation of callus roentgenograms were obtained regularly.

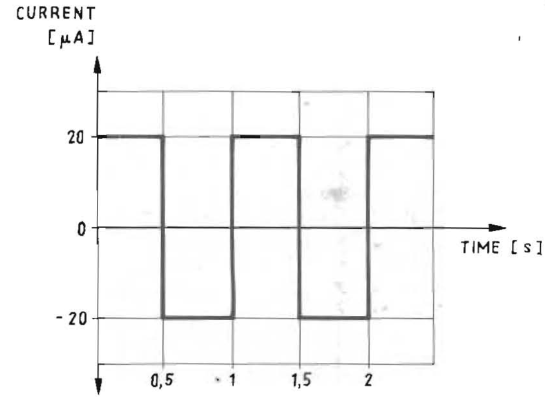


Fig. 2. Bipolar type of current

Results

Up until now the treatment has been terminated in 11 patients in whom the electrical stimulation was applied according to the above-mentioned method. Table 1 gives a summarizing survey of the results which were positive in all but one cases.

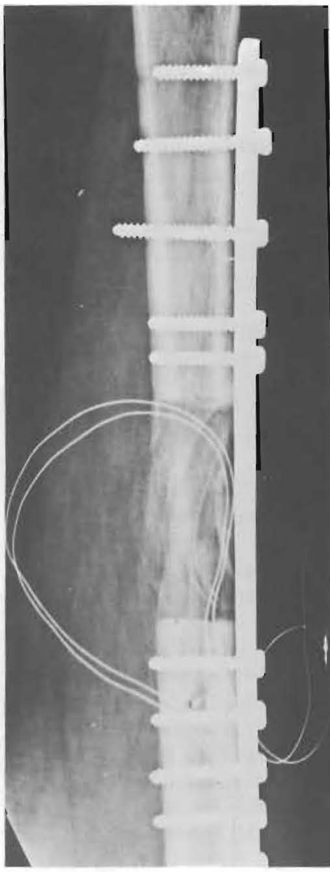
In the following, the application of the electrical stimulation is reviewed in a case report. The case of patient 5 (Table 1) is compared to that of patient Je.F. in whom no electrical stimulation was applied during the entire treatment.

Patient 5, J.G.: male, 23 years old
Diagnosis: Shortening of the right femur by 9.5 cm in a high Luxatio coxae after an infant coxitis.

Therefore, a distraction osteotomy in the right femur, an application of a KDA (compression-distraction-apparatus), and a distraction plate according to Soukop-Hoffmann were performed. After obtaining a lengthening of 6.3 cm by distraction, the plate was screwed, the autogenous cancellous bone graft performed, and the electrodes installed. The electrical stimulation has been performed for 20 weeks without any interruption (Fig. 3). Thirty-six weeks after the beginning of the stimulation partial weight-bearing of the leg was achieved, and full weight-bearing was possible in the 49th week of treatment (Fig. 4). This corresponds to the 65th week after the application of the KDA.

Patient Je.F.: male, 22 years old
Diagnosis: Post-traumatic coxarthrosis with a shortening of the left leg by 5.5 cm after the patient had an accident in 1967.

After performing a distraction osteotomy in the left femur and applying a distraction plate according to Soukop-Hoffmann and a KDA, there was a distraction up to the full length for a 7-week period. After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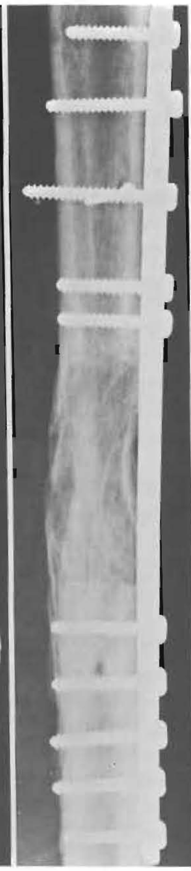
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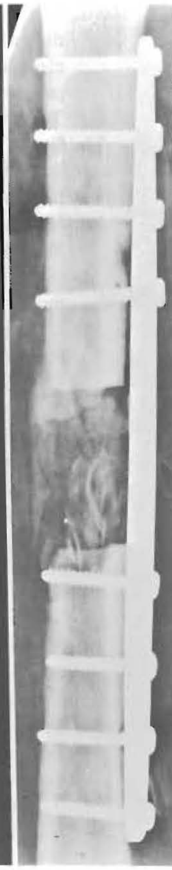
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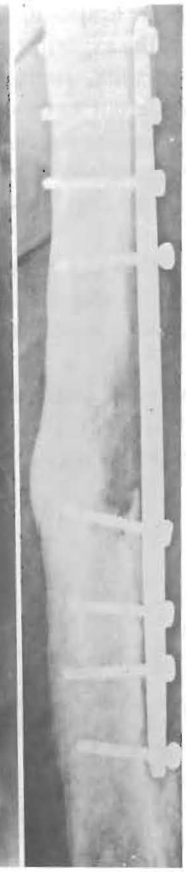
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Fig. 3. Nine weeks after the beginning of the bipolar electrical stimulation a roentgenologically distinctive regular callus formation also near to the plate can be identified. The bone structures are realigned

Fig. 4. Forty-nine weeks after the beginning of the stimulation an osseous consolidation can be identified. Full weight-bearing is possible. A regular realigned callus formation is universally shown in the area of the previous region of distraction

Fig. 5. Seven weeks after screwing the distraction plate and performing an autogenous cancellous bone graft there is a roentgenologically still not realigned and partially cloudy structure of the spongiosa. No callus formation can be perceived

Fig. 6. The picture of a "stress protection" gap, especially in the region of distraction, can be roentgenologically identified under the plate in the 48th week. Near the plate the callus shows an irregular density, the callus structure is not realigned. Distant from the plate there is an exuberant callus reaction

another 4 weeks there was the KDA-removal, the screwing of the distraction plate, and the performing of an autogenous cancellous bone graft (Fig. 5).

A beginning osseous consolidation can be identified roentgenologically not till the 36th week after the distraction has been terminated. The patient is allowed to do a partial weight-bearing with 10 kg after the X-ray control in the 48th week (Fig. 6).

Discussion

For obtaining a quick and good healing of fractures and pseudarthroses the internal of external fixation is an indispensable method.

Up until now it has been proved in many cases [1, 2, 5, 9, 10, 17, 18, 21] that the electrical stimulation has a stimulating effect on the callus formation, thus promoting the tendency of healing. The electrical stimulation, however, is no substitute for a fragment stabilization [23]. Jörgensen has pointed out [9] that an essential shortening of the duration of the treatment is possible by means of the electrical stimulation.

We believed the application of a bipolar pulse current to be especially suitable since no osteolysis, as described by Bauer et al. [2] and Friedenberg et al. [7], can be identified in the bone among the anode caused among others by a permanent change in the poles. The effect can be seen from the very good realignment of the newly formed callus as the radiographs of the cases given in Table 1 revealed. Some authors [4, 12, 13, 18] agreed with the conception that the effect of a pulse current is principally superior to the effect of a direct current. It can be stated, however, that there are still questions concerning the frequency to be employed, the optimal pulse duration, and the current intensity. Brighton et al. [5] hold the opinion that no pulsed current produced a better callus formation than a permanent direct current of 20 μamp. The authors, however, refer to a unipolar pulsed current.

We preferred a bipolar rectangular pulsed current and observed no clinically disadvantageous effects under a permanent stimulation at a frequency of 1 Hz and a current intensity of ± 20 μamp. Several authors [9, 12, 17, 18, 21, 23] could gain favourable clinical and animal-experimental experiences with these mentioned frequencies and, however, unipolar pulse amplitudes. Considering the theoretical reflections, the experimental findings and the published clinical results, we have no doubts about the efficiency of the different methods of the electrical stimulation. We believe the bipolar rectangular pulses of our system to be especially effective since their effect is proportional to the area under a pulse.

We did not find any disadvantage in the transcutaneous application, the stimulator, however, has been essentially scaled down in the meantime because of its unwieldiness for the patient[2].

For the present, we do not intend to discuss the implantation of the system since this depends on reflections in connection with the duration of its application.

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Received June 28, 1979 / Accepted January 16, 1980