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UNUNITED FRACTURES OF THE FORE-ARM

By

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Experimental animal research has shown that the osteogenic layers of the periosteum are of decisive importance in the appearance of bridging callus in fracture healing. With quantitative microradiography is is possible to follow the accumulation of bone salts in the callus areas and it was thus found that periosteal callus mineralises the most quickly and that it most rapidly reaches a degree of mineralisation which corresponds to that in normal bone (*Nilsonne*, 1959).

The factors which interrupt this normal mineralisation in pseudarthrosis formation are so far obscure. Uncertainty also prevails concerning the conditions under which a transplant placed in a pseudarthrosis heals, mineralises and changes to normal bone. It is also difficult as a rule to obtain sufficient material from clinical operations to study the distribution of mineral salts in a pseudarthrosis area before and after bone healing has occurred. The method initiated by *Nicoll* (1956) providing for radical resection of the pseudarthrosis, filling of the defect with an iliac crest block and internal fixation gives increased opportunity for the research indicated above. After consolidation the operation area can be inspected and test excisions can be performed while the osteosynthesis material is also extraced.

The present study comprises both clinical experience of 9 pseudarthroses operated on according to *Nicoll* (1956) and also micro-radiographic research into the resected pseudarthroses (10) and into six transplants, 4 after complete consolidation.

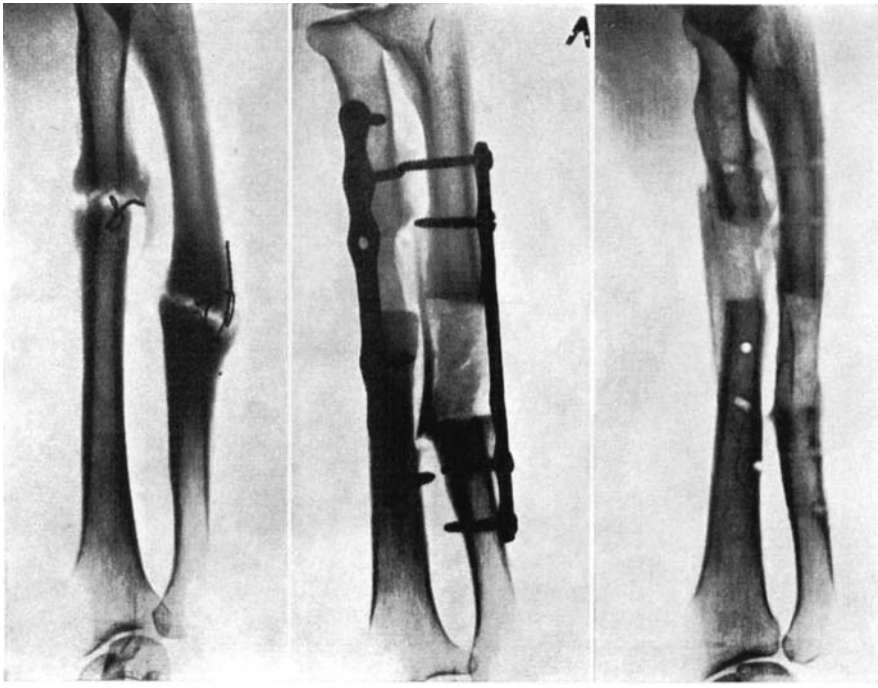
MATERIAL

7 patients are concerned; operated on during the period 1959–1961; three (cases 3, 6 and 7) had pseudarthrosis of the ulna only and four (cases 1, 2, 4, 5) had pseudarthrosis on both ulna and ralius. Nine of these pseudarthroses underwent radical

TABLE I

Summary of Operative Cases

Case Sex	Age	Trauma	Fracture Ulna	Fracture Radius	Initial Treatment	Status Period to Reconstruction	Reconstruction	
1 ♂	20	Gunshot 28 II 57	Compound	Compound	Wound Toilet + Open Reduction + Internal Fixation Subsequent Operations Due to Infection	13 VII 59 	23 XI 59 Op. 	
2 ♂	20	Industrial Accident (Direct Blow) 22 IV 59	Simple	Simple	Open Reduction + Cerclage	3 XII 59 	8 XII 59 Op. 	
3 ♂	49	Crushing Injury 3 VI 59	Compound	Simple	Wound Suture + Plaster	11 IV 60 	11 IV 60 Op. 	3 XI 60 Reop. 
4 ♂	23	Traffic Accident 2 VIII 59	Simple	Simple Disloc. Capit. Radii	1. Open Reduction + Cerclage 2. Reop. with Rush Pin 3. Resection Capit. Radii	4 V 60 	5 V 60 Op. 	19 IV 61 Reop. 
5 ♀	38	Traffic Accident 31 III 60	Simple	Simple	Open Reduction + Intramedullary Nail	11 X 60 	13 X 60 Op. 	
6 ♂	43	Traffic Accident 8 XI 59	Simple	Simple	Open Reduction + Rush Pin	9 II 61 	1 III 61 Op. 	
7 ♀	30	Traffic Accident 30 VII 59	Simple	Simple	Open Reduction + cerclage of ulna, reop. + bonegraft intramedullary nailing of radius	28 VII 61 	31 VII 61 Op. 	



A B C

Fig. 1.

A. Non-union of the forearm 8 months after injury in a man twenty years old (case 2).—*B.* Radical resection and internal fixation has been performed. The defects, measuring 3,5 and 2,5 cm resp. of ulna and radius has been filled by cancellous bone blocks from iliac crest. Opposite the plate on ulna an additional graft has been placed.—*C.* Metallic fixation has been removed 10 months after resection and bone grafting.

resection, fixation with Lane's plate and also filling of the defects with autogenous cancellous bone transplant in a block. One radial pseudarthrosis was left with plaster fixation only while the simultaneous ulnar pseudarthrosis was operated on (case 4). One radial pseudarthrosis was resected radically and the resection surfaces were adjusted to good contact without transplant and fixed with a plate (case 5). The primary fracture treatment, the initial point of reconstruction and the type of reconstruction are shown in Table 1.

The preparations obtained on resection of the pseudarthroses were emebedded in methylmetacrylate and thin sections were prepared. The sections were cut through the pseudarthrosis ends at varying distances from the pseudarthrosis gap and were afterwards subjected to microradiographic examination according to the technique used by *Nilsonne* (1959). Preparations from fully healed transplants, 10–15 months after operation (case 2 and 5), and also from partially healed transplants, obtained on re-operation, 6 and 11 months afterwards, were examined in an identical manner.

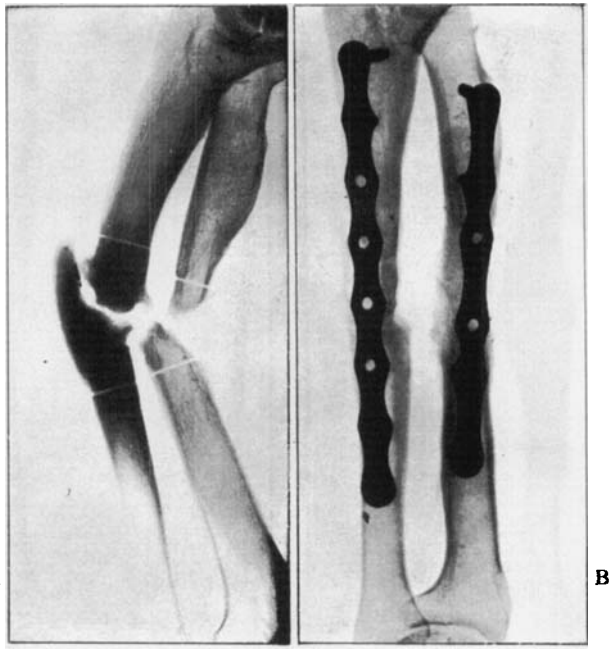


Fig. 2.

A. Non-union of the forearm 2½ years after compound fractures in a man twenty years old (case 1). Before referral the patient had an infected draining unstable non-union, classified as "non-operable". *B*. After resection, internal fixation and filling the gaps by autogenous cancellous bone block healing occurred in 6 months. Roentgenogram made 1½ year after bone grafting.

OPERATIVE TECHNIQUE

The forearm pseudarthroses were exposed under general narcosis in six cases and plexus anesthesia in one case. Resection of the pseudarthroses, including the sclerotic fracture ends, was performed with a Gigli saw to such an extent that the medullary cavity was plainly open in the resection surfaces. This means that 1–2 cms. were resected from every pseudarthrosis end. Lane's plates with two or three screws in each fragment restored stability and shape afterwards. The bone defects between the resection surfaces (tables I and II) were filled with an autogenous cancellous bone block, taken from the iliac crest (fig. 1). It was not necessary therefore for the resection to involve any shortening, even if it did concern pseudarthrosis defects (fig. 2).

In one case with a large angle between the fragments a certain shortening was however desirable, bearing in mind the soft tissue contractures (case 5). After the resections a good end-to-end contact was first established in this case between the radial fragments, which were fixed by plate and screws. Between the ulnar fragments a defect of 1.8 cms. remained. The fragments were fixed with Lane's plate. The defect was filled with cancellous bone from the iliac crest (fig. 3).

TABLE II
Size of the bone defects.

Case	Ulna	Radius
1	3.5 cms	2.5 cms
2	3.5 cms	2.5 cms
3	2.5 cms	–
4	2 cms	not explored
5	1.8 cms	contact between resection surfaces
6	1.8 cms	–
7	2 cms	–

COMPLICATION

In case 1 a minor necrosis arose on the operation scar above the radius with recurrence of previously troublesome eczema of the forearm, but the course of healing was not affected. Otherwise all operation wounds of the forearm healed without trouble. In case 3 healing of the wound above the iliac crest (site of graft) was delayed 2 weeks owing to staphylococcic infected haematoma.

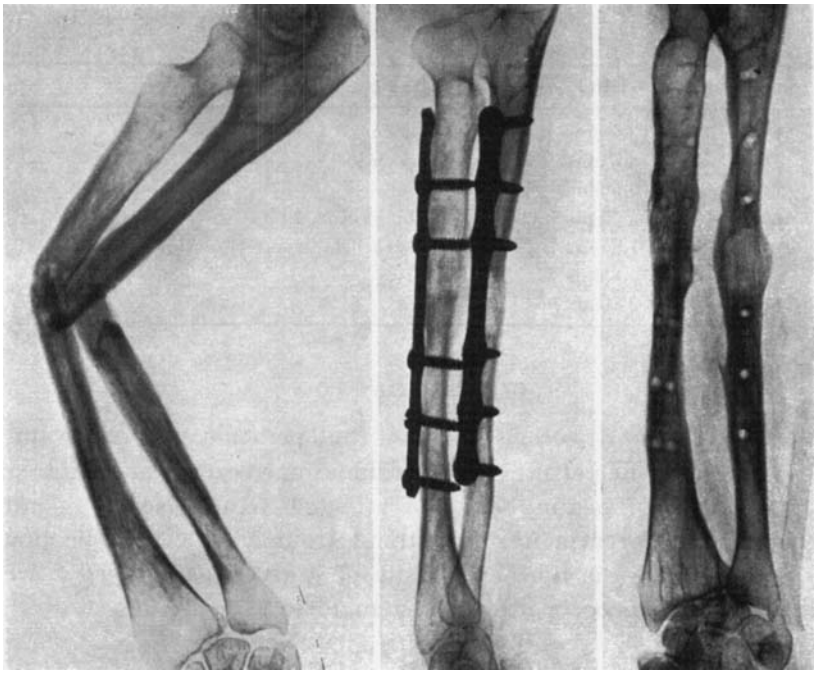
TABLE III
Healing of cancellous bone transplant.

Case	Postoperative plaster fixation mth.	Cancellous bone block healing acc. to X-ray			
		ulan		radius	
		prox.	dist.	prox.	dist.
1	4	+	+	+	+
2	3.5	+	+	+	+
3	4	—*	+	----------	
4	5.5	—§	+	union	
5	5	+	+	end to end...	
6	3	+	+	----------	
7	7	+	+	----------	

* healed after second intervention + improved fixation.
§ reoperation + improved fixation.

CLINICAL RESULT

Out of 9 pseudarthroses, treated according to Nicoll, 7 healed within 3–7 months, 2 after re-operation and a further 6 months plaster fixation. A radial pseudarthrosis treated with radical resection, end-to-end contact and internal fixation without bone transplant healed in 5 months, (case 5). A radius pseudarthrosis, not explored, healed in 4



A B C

Fig. 3.

A. Non-union of the forearm with dislocation 6½ months after simple fractures in a woman thirty-eight years old. *B.* The system was shortened by resection and end-to-end adaption of the radius. The defect of the ulna after resection was filled by cancellous bone block. Healing occurred in 5 months. Roentgenogram made 7 months after the reconstructive surgery *C.* Plates and screws removed 15 months after reconstructive surgery.

months with simultaneous immobilisation of the ulnar pseudarthrosis (case 4) See table III.

The clinical study comprises 11 diaphysial forearm pseudarthroses in 7 patients. All healed with a good anatomical result, i.e., with full stability without deformity of the forearm. Varying degrees of muscle atrophy could be observed and also a certain reduction of the strength of the hand grip (Table IV). All are able to work.

MICRORADIOGRAPHY OF RESECTED PSEUDARTHROSES

The microradiographic appearence of the pseudarthrosis ends, some mms. from the actual pseudarthrosis gap, showed a large number of

TABLE IV
Follow up 1962

Case	Shortening	Atrophy	Elbow	Prona-tion	Supina-tion	Handmobility
1	The same as before last op.	++	180°–40°	30	–30	Dorsalfl. 40° Volarfl. 30°
2	—	+	180° 40°	30	10	Dorsalfl. 45° Volarfl. 15°
3	—	+	170° 60°	45	45	Dorsalfl. Volarfl.
4	—	+	180° 45°	45	0	Dorsalfl. 55° Volarfl. 30°
5	+	++	160°–40°	15	0	Dorsalfl. 20 Volarfl. 15
6	—	+	175°–70°	10	10	Dorsalfl. 20 Volarfl. 10
7	—	+	170°–40°			

resorption cavities, (fig. 4). In the bone substance there remained osteones with a mineral salt distribution which could be described as normal. In other words the distribution of mineral salts was of the same type as that in quite healthy bone and of the same type as in sections taken at longer distances from the pseudarthrosis zone.

In the intermediate regions between the Haversian systems an inhomogeneous distribution of bone salts occurred.

The sclerosis of the pseudarthrosis ends observed on macroscopic X-rays found no correspondence on a microscopic level in the form of hypermineralised regions.

The build-up of periosteal callus was formed by closely lying trabeculae. Here the mineralisation was analogous with that found in relatively late stages of normally healing fractures.

All the pseudarthroses displayed the same type of microradiographic pictures whether they were being studied in cross sections or longitudinal sections. Fig. 5 is an example of a microradiogram from a longitudinal section through a pseudarthrosis (case 2). The black zone in the centre corresponds to the pseudarthrosis gap, where mineralisation is completely absent. This gap is sorrounded by intermediately-lying callus consisting of partly very fine trabeculae. The mineral salt distribution in these areas changes and large local variations occur.

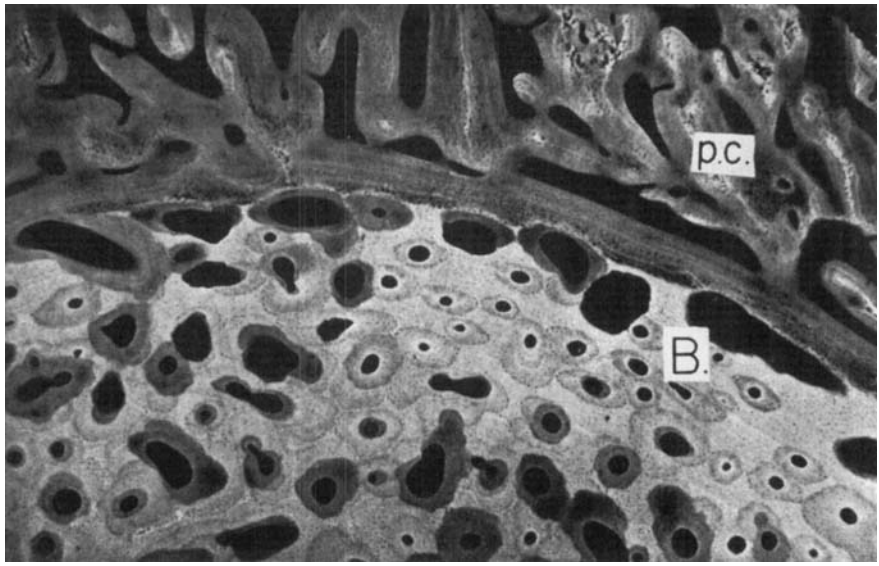


Fig. 4

Microradiogram of a cross section of the ulna at a distance of a few millimeters from the pseudarthrosis gap. (case 2).
B = bone; pc = periosteal callus.

MICRORADIOGRAPHY OF THE AUTOTRANSPLANT

Islands of necrotic bone were observed in the six preparations examined which were obtained from test excisions. On the microradiogram these necroses emerged as strongly mineralized zones (fig. 6). Haversian systems of varying degrees of mineralisation proceeding in both transverse and longitudinal directions were encountered in several places. The arrangement of the osteones and the pattern of mineralisation indicated that an active build-up of the transplant was proceeding.

DISCUSSION

There is probably widespread agreement that adequate fixation over a sufficiently long period can promote healing of certain contact pseudarthroses and that the provision of osteogenetic material hastens bone healing (*Matti* 1936, *Phemister* 1947, *Urist* (& coworkers) 1954, *Küntscher* 1959).

As to the opposite problem, the defect pseudarthroses, the difficulties

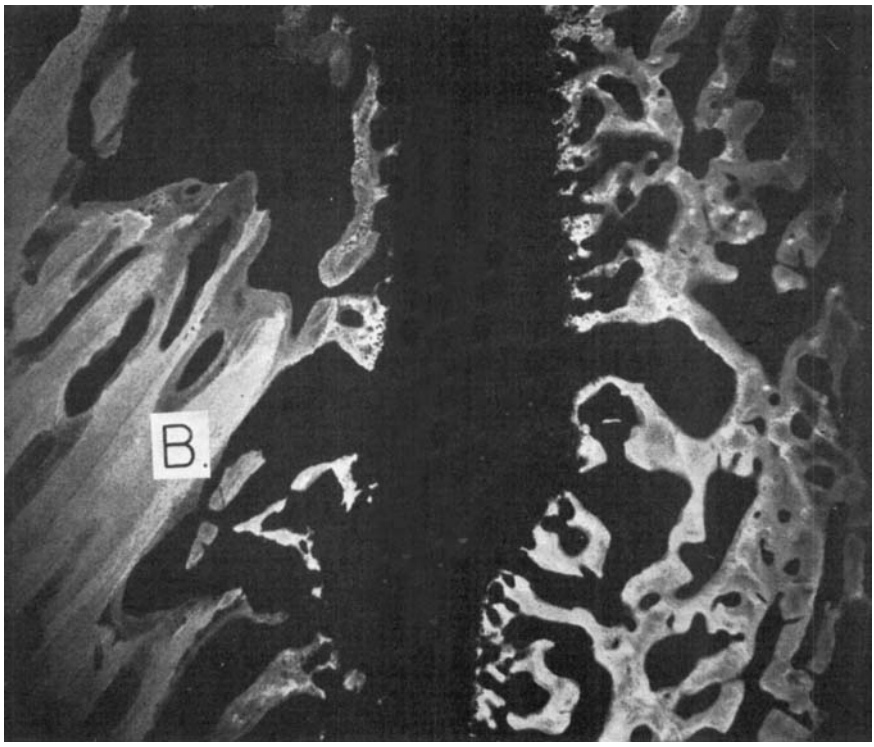


Fig. 5.
Microradiogram of a longitudinal section through the pseudarthrosis of ulna (case 2). B = bone. The black area in the center reprents the non mineralized zone of pseudarthrosis.

are greater. From the healing point of view many consider the pseudarthrosis tissue and the sclerotic bone as of lesser value (*Magnus* 1937). Direct adaptation of the fracture ends after radical resection always means shortening, which especially with defect pseudarthroses is severe. On the forearm moreover there are the further difficulties of obtaining precise adjustment and fixation for both ulna and radius. A large bone graft as on-lay graft on both forearm bones not infrequently promotes difficulties from the standpoint of skin covering.

In the method initiated by *Nicoll* (1956) which was tried out here, all pseudarthrosis tissue and sclerotic bone ends are removed and form and stability can be restored smoothly without shortening. The defect is filled by a well-fitting block from the iliac crest consisting chiefly of cancellous bone and with only one cortical surface. Here therefore ex-

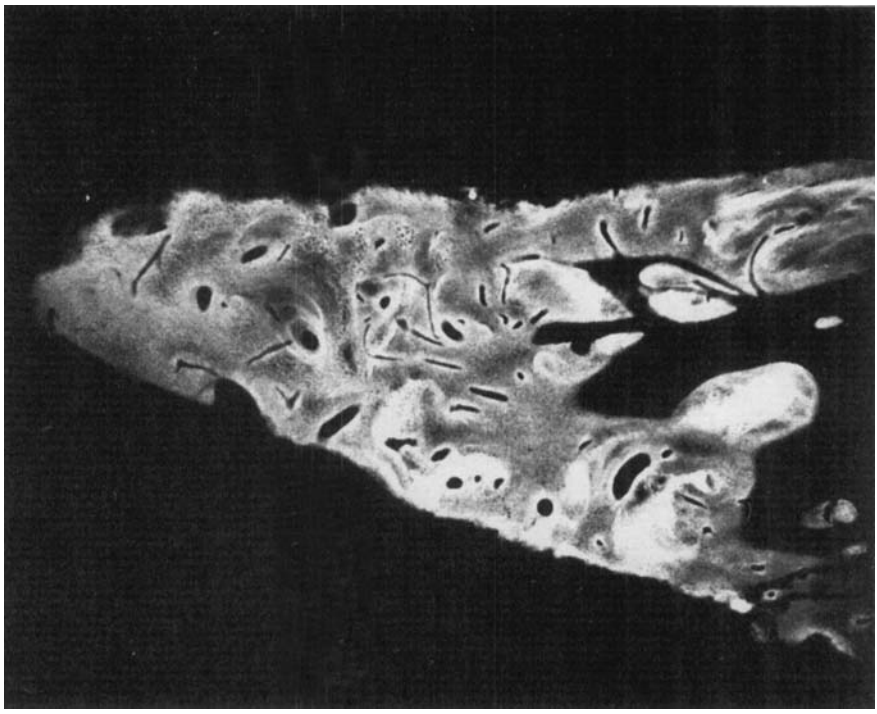


Fig. 6.
Microradiogram of a longitudinal section through the center part of the autogenous bone transplant of the ulna 10 months after implantation (case 2). Necrotic islands can be observed in normal internal structures of bone, which seems to be under restitution.

tremely good conditions are present for vascularisation of the cancellous structure of the transplant by means of the normal surrounding muscles and the resection surfaces of the bone ends with their open medullary cavities. In addition the periosteum is stimulated into activity in a way which is analogous with normal fracture conditions. Cases 1, 2, 5, 6 and 7 show that fine healing may occur in this manner. Clinically and radiologically, consolidation was complete as a rule after 3 to 5 months. On extraction of the osteosynthesis material and the simultaneous test excision from the graft area, the cancellous bone transplant could not be macroscopically distinguished from the host bone. Whether the incorporation of the cancellous bone block occured by means of new bone formation, beginning chiefly from the resection ends and the periosteum, or from the surroundings could not be decided.

In cases 3 and 4, which were operated on secondarily after 5 and 11 months respectively, owing to absent consolidation, the defective healing was localised not to the centre of the transplant but to the proximal border between transplant and host bone. Otherwise the transplants were macroscopically changed to vital bone.

At a microscopic level scattered necrotic islands could be observed in these transplants and also in fully consolidated blocks up to 15 months after the transplantation. The localisation of the necrotic areas gave no definite guide in deciding how the transplant was replaced by the newly formed bone tissue. Nor can the point be excluded that certain areas of the autogenous cancellous bone block may in fact have survived. That autogenous cancellous bone transplants in suitable environments may preserve their vitality has been shown by *Levander* (1941) amongst others. Continued research into transplants in different stages of healing employing biophysical techniques is planned, so that further light may be thrown on these problems.

That the clinical result was not equally as good primarily in all cases is probably due to technical deficiencies. The internal fixation by plate must be extremely reliable and ought to comprise at least 3 screws proximally and 3 distally. Another factor which is certainly also of fundamental importance is the insertion of the cancellous bone block—it must be pressed in and must not be too small. The transplant must in other words take up a stable position between the resection ends.

The significance of mechanical strain, especially the torsion forces of high ulnar fractures and their pseudarthroses has been pointed out by several authors, amongst others, *Rehnberg* (1953), *Boyd* and others (1961), *Moberg* (1961). In order to avoid carrying on rotatory movements of the upper arm to the fracture and pseudarthrosis area proximally on the ulna, the fixation should comprise a thoraco-brachial plaster.

SUMMARY

Out of 11 forearm pseudarthroses in 7 patients, 10 underwent radical resection + internal fixation by plate. In one case where shortening was desirable, end-to-end contact was established; in 9 cases the bone defects were filled with autogenous cancellous bone blocks. All healed with good anatomical and functional results, but 2 ulnar pseudarthroses only healed after re-operation. In the remaining cases consolidation occupied 3–7 months. The resected parts were examined by microradiographic technique for the distribution of mineral salts and comparative

mineralisation studies were performed after test excisions on healed transplants.

The clinical experience obtained by using this operative method and the microradiographic findings are discussed.

RESUME

Sur 11 pseudarthroses de l'avant-bras chez 7 malades, il a été pratiqué chez 10 une résection radicale + fixation interne par plaque. Dans un cas, le racourcissement était désirable, un contact entre les extrémités fut établi; dans 9 cas, les défectuosités de l'os ont été remplies par des blocs d'os autogène dur.

Dans tous les cas guérison avec de bons résultats anatomiques et fonctionnels, mais pour 2 pseudarthroses ulnaires seulement après réopération. Dans les autres cas, la consolidation s'est opérée entre 3 et 7 mois. Les parties extirpées ont été examinées suivant la technique microradiographique pour établir la distribution des sels minéraux et des études comparative de minéralisation ont été pratiquées après l'excision de prélèvements des transplantations guéries.

L'expérience clinique acquise par l'utilisation de cette méthode opératoire et de ces trouvailles microscopiques est discutée.

ZUSAMMENFASSUNG

Von 11 Unterarmpseudarthrosen bei 7 Patienten wurden 10 einer radikalen Resektion und internen Fixation mittels Platten unterzogen. In einem Falle, in dem eine Verkürzung wünschenswert war, wurde ein Een zu End Kontakt errichtet. In 9 Fällen wurde der Knochen-defekt mit autogenen Spongiosablöcken ausgefüllt.

Alle heilten mit gutem anatomischen und funktionellen Ergebnis, aber 2 Ulnapseudarthrosen heilten nur nach Reoperation. In den übrigen Fällen nahm die Konsolidierung 3 – 7 Monate in Anspruch.

Die resezierten Teile wurden mittels einer mikroradiographischen Technik zur Feststellung der Verteilung von Mineralsalzen untersucht und vergleichende Mineralanreicherungsstudien wurden nach Probeexcisionen von geheilten Transplantaten ausgeführt.

Die klinische Erfahrung, die anlässlich der Verwendung dieser Operationsmethode erhalten wurde, und die mikroskopischen Befunde werden besprochen.

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