CAUSES AND TREATMENT OF NON-UNION IN FRACTURES OF THE RADIUS AND ULNA

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This study of fractures of the radius and ulna was undertaken to investigate the incidence of non-union, the factors concerned in its development and the principles underlying its successful treatment.

MATERIAL FOR ANALYSIS

Three hundred and twenty-three consecutive cases have been reviewed, comprising 447 fractures—246 of the radius and 201 of the ulna. In 124 cases (39 per cent) both bones were fractured. Forty patients (12 per cent) had open fractures. Sixty-six patients (20 per cent) had comminuted fractures. In approximately 50 per cent of cases the fracture was in the middle third of the bone. Crack fractures and fractures without displacement were excluded from this survey because they follow a much more favourable course and do not present the same problems in treatment. Their inclusion would flatter the statistics and obscure the essential issues. Patients up to the age of seventeen were excluded for the same reason.

Sex, age and occupation—Eighty-five per cent of the patients were men and 15 per cent were women (Table I). About half the patients were under the age of forty and 87 per cent were under sixty. Seventy-eight per cent were engaged in heavy work, chiefly in the mining industry.

TABLE I
AGE, SEX AND OCCUPATION

Age	Number	Per cent	Sex	Number	Per cent	Occupation	Number	Per cent
17-40 years	153	47	Male	275	85	Heavy work	253	78
41-60 years	128	40	Female	48	15	Light work	70	22
Over 60 years	42	13						

The injury is therefore an important one because it affects predominantly young or middle-aged men engaged in heavy work, to whom the restoration of full function is of crucial importance.

MECHANISM OF INJURY AND SIGNIFICANCE OF DISPLACEMENT

The largest group of cases came from injuries at work in the mining industry and were usually associated with considerable direct violence such as a fall of roof, a crush between moving tubs or a blow by a flying pit prop. The next largest group resulted from road traffic accidents and usually involved either a motor cyclist or a cyclist. In these cases also there was a considerable element of direct violence. Increased violence leads to increased displacement and comminution, and it was thought at the outset that these might be significant factors influencing the rate of union. With increasing displacement there is more tearing of the soft tissues and therefore more likelihood of rupture or thrombosis of blood vessels. This must be prejudicial to the process of union.

In order to investigate this hypothesis the cases were divided into three groups according to the degree of initial displacement. In 47 per cent of cases there was minimal displacement (Group 1), in 36 per cent the displacement was moderate (Group 2) and in 17 per cent it was severe (Group 3). These groups were analysed separately in investigating the causes of delayed and non-union.

METHODS OF TREATMENT

Four methods of treatment were used in this series.

Manipulation under general anaesthesia followed by immobilisation in plaster—This was the usual treatment for fractures with only slight displacement, more often of one bone. It was tried first in nearly all cases. When reduction was either unsatisfactory or unstable, one of the following alternative methods was used.

Open reduction followed by immobilisation in plaster—This was used mainly for fractures of one bone, in which the reduction could be rendered stable by interlocking of the fragments. It was also used in compound fractures in which reduction was possible through the original wound and internal fixation was considered undesirable.

Open reduction and plating without immobilisation in plaster—In this group no plaster was applied after plating because the fixation seemed rigid and the aim was to achieve rapid and complete mobility by early active movement. This method has since been abandoned for reasons that will be referred to later.

Plating followed by immobilisation in plaster—In these cases a plaster was applied after operation, thereby increasing the rigidity of the fixation. The plaster was retained until radiological union was established.

RATE OF UNION

In any discussion of fractures of the long bones it is fallacious to think in terms of a certain number of weeks as being the "normal" rate of union for a particular bone—ten weeks for a tibia, twelve for a femur, eight for a humerus and so forth. There are so many variable factors—age, site of fracture, comminution, displacement, infection, loss of substance, method of treatment—that what may be normal in one set of circumstances is totally abnormal in another. One can only hope to predict what may be "average" in a given set of circumstances. If these are taken into account and the time for union significantly exceeds

TABLE II
RATE OF UNION

Weeks taken for union	Number of cases	Per cent of total
8	128	40
9-12	82	25
13-16	47	15
17-20	16	11
21-26	14	
27-36	7	
Non-union	29	9
Total	323	100

what is conceived to be the average, then it is justifiable to speak of "delayed union." Unfortunately, so little is known of the effect of all these variable factors that the distinction is at its best intelligent guesswork and at its worst purely empirical. The same applies to the question when delayed union becomes non-union. In practice this is when the surgeon believes that a continuation of conservative treatment will not lead to bony union, and individual judgment and experience must of necessity play a large part. The issue is further complicated by the fact that in some patients fibrous union is so firm as to be symptomless under normal stresses and clinically indistinguishable from bony union. Three such patients in the present series are engaged in heavy work, all showing non-union radiographically. At the other extreme are cases of true pseudarthrosis, a term that is loosely applied on the Continent to any kind

of non-union, but which should be reserved for the relatively few cases with a true false joint containing fluid and surrounded by a pseudo-capsule.

In the present series bony union occurred within sixteen weeks in 80 per cent of all cases (Table II), and 91 per cent of fractures had united by thirty-six weeks. Non-union occurred in 9 per cent of all patients and in 7.3 per cent of all fractures. These figures are further analysed in subsequent tables.

On a purely arbitrary basis for purposes of analysis, sixteen weeks was therefore regarded as the period of normal union and anything in excess of that as delayed union.

RESTORATION OF MOVEMENT

On the whole, there was no difficulty in regaining movement after union. Two hundred and ninety-four patients (91 per cent) recovered full or almost full movement in all joints and there was no case of stiffness in the fingers or shoulder, which were exercised continuously throughout. In the remaining 9 per cent of cases the residual limitation of movement was moderate in 6 per cent and severe in 3 per cent. The movement most frequently affected was rotation (Table III).

TABLE III
RESIDUAL JOINT STIFFNESS

Joint	Moderate limitation	Severe limitation	Total
	Number of cases	Number of cases	
Shoulder	Nil	Nil	Nil
Elbow .	7	2	9
Wrist .	3	3	6
Rotation	17	7	24
Fingers .	Nil	Nil	Nil
Total .	27	12	39
These limitations occurred in twenty-nine patients, ten of whom had more than one movement affected.			

SIGNIFICANT FACTORS IN NON-UNION

Many factors were investigated for their possible significance in relation to non-union, including the age of the patient, the type of fracture, the degree of initial displacement and the method of treatment. In computing the significance of any one factor, it is therefore necessary to take the others into account, particularly those which were subsequently found to be significant, such as the degree of displacement, the method of treatment, comminution, open as opposed to closed fractures, and fractures of both bones as opposed to single bone fractures.

Age of the patient—Does the patient's age influence the rate of union? It has long been known that fractures in children unite much more rapidly than in adults: non-union is rare in children and confined to special cases such as the lateral condyle of the humerus. It has often been assumed from this that the process of osteogenesis diminishes in the elderly and causes delayed union, but this assumption is not justified (Table IV).

These figures seem to show that the rate of union is *better* in elderly patients, but a simple comparison by age groups is not valid. In the group of patients over sixty the degree of displacement and the methods of treatment were comparable with other groups but there

were fewer compound and comminuted fractures. When these were excluded from the comparison the difference in the rate of union was not significant (Table V).

Other things being equal, there is no reason to suppose that the process of union is retarded in elderly patients.

Degree of displacement—It has already been pointed out that greater violence produces greater displacement and that this in its turn causes more damage to soft tissues and blood supply. The initial displacement was found to be an important factor in non-union (Table VI).

TABLE IV
AGE RELATED TO RATE OF UNION

Union	17-40 years		41-60 years		Over 60 years		Total	Per cent
	Cases	Per cent	Cases	Per cent	Cases	Per cent		
Normal union	114	74.6	105	82.2	38	90.6	257	80
Delayed union	23	15.0	12	9.3	2	4.7	37	11
Non-union	16	10.4	11	8.5	2	4.7	29	9
Total	153	100	128	100	42	100	323	100

TABLE V
EFFECT OF AGE (CLOSED FRACTURES WITHOUT SEVERE COMMUNITION)

Union	17-40 years		41-60 years		Over 60 years	
	Cases	Per cent	Cases	Per cent	Cases	Per cent
Normal union	84	77.0	85	87.6	30	90.9
Delayed union	20	18.4	8	8.3	1	3.0
Non-union	5	4.6	4	4.1	2	6.1
Total	109	100	97	100	33	100

TABLE VI
EFFECT OF DISPLACEMENT

Degree of displacement	Number of cases	Rate of non-union (per cent)
Minimal	151	4
Moderate	117	7
Severe	55	15

The incidence of non-union rises steeply in the severely displaced fractures.

Type of fracture—Non-union was almost twice as frequent after fractures involving both bones as after single bone fractures. There was a somewhat higher rate of non-union in the ulna than in the radius (Table VII).

It is clear from the above figures that the stabilising effect of an intact bone on a fracture of the other bone is considerable and is favourable to union. There is no foundation for the view held in some quarters that if one bone is intact it prejudices union in the other bone by

preventing coaptation of the fragments after absorption has occurred at the fracture site. The same argument has been used in the case of the fractured tibia with an intact fibula, and some surgeons have even advocated osteotomy of the fibula. There is no support for this in the present review. The stabilising effect of one intact bone, either in the leg or forearm, clearly outweighs any of the theoretical disadvantages.

The effect of comminution was also investigated. This is another factor related to the degree of violence causing the injury. It was found that in comminuted fractures the rate of

TABLE VII
TYPE OF FRACTURE RELATED TO RATE OF NON-UNION

Type of fracture	Number of cases	Number of fractures	Number of fractures with non-union	Per cent of total
Radius only . . .	122	122	5	4
Ulna only . . .	77	77	5	6.4
Radius and ulna . .	124	248	23	9.2
Total . . .	323	447	33	7.3

TABLE VIII
EFFECT OF COMMUNITION

	Comminuted fractures		Rest of series	
	Cases	Per cent	Cases	Per cent
Normal union	46	70	211	82
Delayed union	7	10	30	12
Non-union . .	13	20	16	6
Total . . .	66		257	

TABLE IX
OPEN AND CLOSED FRACTURES

	Open fractures		Closed fractures	
	Cases	Per cent	Cases	Per cent
Normal union	23	57.5	234	82.8
Delayed union	4	10	33	11.6
Non-union . .	13	32.5	16	5.6
Total . . .	40		283	

non-union was three times higher than the average for the rest of the series (Table VIII). Comminution is therefore comparable with displacement in its retarding effect on union.

There was an even greater discrepancy when closed and open fractures were compared (Table IX). Non-union was six times more frequent in open than in closed fractures; indeed it affected approximately one-third of all open fractures. This is yet another factor related to direct violence. Moreover, this high incidence is not attributable to infection, because there were only three cases of infection in the whole series. These were all in open fractures, and

two were associated with plating. There were no cases of infection after operation on closed fractures.

Method of treatment—A simple comparison of the four methods of treatment adopted is not valid because the group of cases treated by manipulation and plaster contains a much higher proportion of closed fractures with minimal displacement (62 per cent) than the cases treated

TABLE X
TREATMENT RELATED TO DEGREE OF DISPLACEMENT

	Minimal displacement		Moderate displacement		Severe displacement		Total
	Cases	Per cent	Cases	Per cent	Cases	Per cent	
Conservative treatment	139	62	63	28	23	10	225
Operative treatment	12	12	54	55	32	33	98
Total	151		117		55		323

TABLE XI
GROUP II (MODERATE DISPLACEMENT): 36.2 PER CENT OF THE CASES

Method of treatment	Cases	Fractures	Non-union		
			Cases	Fractures	Per cent
Manipulation and plaster	63	93	4	4	4
Open reduction and plaster	8	13	2	2	15
Plating and plaster	29	48	3	3	6
Plating without plaster	17	26	3	4	15
Total	117	180	12	13	7.2

TABLE XII
GROUP III (SEVERE DISPLACEMENT): 17 PER CENT OF THE CASES

Method of treatment	Cases	Fractures	Non-union		
			Cases	Fractures	Per cent
Manipulation and plaster	23	38	3	4	10
Open reduction and plaster	9	15	2	2	13
Plating and plaster	15	28	3	4	14
Plating without plaster	8	13	3	4	31
Total	55	94	11	14	15

by operative methods (12 per cent) (Table X). It is only justifiable to compare conservative with operative treatment if the degree of displacement is taken into account. In Group I cases (minimal displacement) in which the overall rate of non-union was 4 per cent there were only twelve out of 151 cases treated by operative methods, so comparison is not valid.

If the different treatments are compared (Tables XI and XII) in Groups II and III (moderate and severe displacement) it is seen that the lowest incidence of non-union was in

cases treated conservatively (4 per cent and 10 per cent). In cases treated by plating and plaster it was slightly higher (6 per cent and 14 per cent), but in cases treated by plating without plaster it was three times higher (15 per cent and 31 per cent). This method was adopted in order to achieve full mobility, and it did in fact do so in all the cases in which it was used. However, at the cost of such a high rate of non-union it is not justified, particularly when it is considered that approximately 85 per cent of the limbs treated in plaster also regained full mobility. It is significant that when plaster fixation is carried out in the absence of traumatic exudates, no stiffness results. As Watson-Jones (1955) has pointed out, "oedema is glue," and if glue is allowed to organise, then stiffness results. The natural mechanism for dispersing

TABLE XIII
FRACTURES OF BOTH BONES
GROUP I (MINIMAL DISPLACEMENT): 22 CASES—44 FRACTURES

Method of treatment	Number of cases	Number of fractures	Non-union	
			Number of fractures	Per cent
Manipulation and plaster .	19	38	2	5
Open reduction and plaster	—	—	—	—
Plating and plaster . . .	3	6	—	—
Plating without plaster .	—	—	—	—
Total	22	44	2	4.5

TABLE XIV
FRACTURES OF BOTH BONES
GROUP II (MODERATE DISPLACEMENT): 63 CASES—126 FRACTURES

Method of treatment	Number of cases	Number of fractures	Non-union	
			Number of fractures	Per cent
Manipulation and plaster .	30	60	3	5
Open reduction and plaster	5	10	1	10
Plating and plaster . . .	19	38	2	5
Plating without plaster .	9	18	4	22
Total	63	126	10	7.9

oedema is by the pumping action of the muscles; hence the value of exercises in plaster. Nicoll's (1961) present routine after plating is to allow free movement for ten days after operation, while the fixation is most rigid, in order to disperse oedema, and then to apply plaster till union is sound. In this way the danger of stiffness through organised exudates is minimised.

Of all the factors influencing union, treatment is the only one over which the surgeon has any control. Conservative treatment gives the lowest rate of non-union and is used in general for open fractures and for closed fractures with minimal or moderate displacement, in which a stable reduction has been achieved. Combined plating and plaster are complicated by a somewhat higher rate of non-union, and in general the method is used for closed fractures

with moderate or severe displacement. It is then an excellent method which, in experienced hands, gives good results. Open reduction and plaster has been carried out in cases where plating is contra-indicated: for example, in fractures too near a joint and compound fractures. Plating without plaster has been abandoned for the reasons already stated.

Fractures of both bones—In this series there were 124 cases with fractures of both bones (39 per cent of all cases). In every respect they were more severe fractures. They included twenty-eight open fractures (22·5 per cent against 12 per cent for the rest of the series); forty comminuted fractures (32·2 per cent against 20 per cent for the rest of the series); and 102 fractures with moderate or severe displacement (82 per cent against 35 per cent for the rest of the series).

TABLE XV
FRACTURES OF BOTH BONES
GROUP III (SEVERE DISPLACEMENT): 39 CASES—78 FRACTURES

Method of treatment	Number of cases	Number of fractures	Non-union	
			Number of fractures	Per cent
Manipulation and plaster .	15	30	4	13
Open reduction and plaster	6	12	—	—
Plating and plaster . . .	13	26	3	11
Plating without plaster . .	5	10	4	40
Total	39	78	11	14

TABLE XVI
FRACTURES OF BOTH BONES
GROUPS II AND III COMBINED: 102 CASES—204 FRACTURES

Method of Treatment	Number of cases	Number of fractures	Non-union	
			Number of fractures	Per cent
Manipulation and plaster .	45	90	7	7·7
Open reduction and plaster	11	22	1	4·5
Plating and plaster . . .	32	64	5	7·8
Plating without plaster . .	14	28	8	28·5
Total	102	204	21	10·2

As before, treatment has been analysed in relation to the factor of displacement (Tables XIII, XIV, XV and XVI).

These Tables show once again how the rate of non-union rises as the severity of initial displacement increases (4·5 per cent, 8 per cent, 14 per cent in the three groups).

The rate of non-union was the same after conservative treatment as for the patients treated by plating and plaster (7·7 and 7·8 per cent) but in cases treated by plating only it was nearly four times higher (28·5 per cent). In the group of cases with *severe* displacement treated in this way it went up to 40 per cent.

These figures are comparable with those of the whole series. Fractures of both bones are more severe than fractures of one bone, but the same rules of treatment can be applied to them.

TREATMENT OF NON-UNION

Predictability and prophylaxis—A high incidence of non-union can now be predicted when all the factors tending to produce it coincide in the same case. For example, in the present series there were eleven patients with fracture of both bones, comminuted, open and with severe displacement. Non-union occurred in four of these patients (36 per cent) and in five of the twenty-two fractures (23 per cent). Nine of these eleven patients had been treated by internal fixation, and in retrospect it would have been easy to supplement this at the time by iliac strip grafts as an insurance against non-union. In seven of the cases it would have been unnecessary but would have added nothing to the morbidity and probably would have accelerated the rate of union. In the remaining four cases, however, it might have saved the patient a second operation after six months and reduced the period of total incapacity by about eight months. It is considered that when the rate of non-union can reasonably be predicted to exceed 30 per cent such prophylactic measures are justifiable.

Treatment of established non-union—In this series there were thirty-three fractures in which bony union failed to occur. This affected twenty-nine patients, in four of whom both bones were involved. In three cases fibrous union was so firm as to be clinically indistinguishable from bony union, and function was perfect. In two other cases the distal fourth of the ulna was involved and resection was carried out in preference to grafting.

The remaining twenty-eight fractures were grafted by the technique described by Nicoll in 1956, and to these must be added eight cases referred from other hospitals but not included in the present series.

The theoretical basis of the graft—Nicoll's method is based on two fundamental principles: the superiority of cancellous grafts over cortical grafts, and the importance of absolute fixation. Union after grafting depends on two basic processes—first the invasion of the graft by primitive mesenchyme cells derived from the host tissues, and, second, the establishment of local biochemical conditions which stimulate these primitive mesenchyme cells to differentiate into osteoblasts. This biochemical environment is established early but does not persist indefinitely. If during this optimum period the area is impregnated with primitive mesenchyme cells, osteogenesis results, but if they arrive too late or in too few numbers, the stimulus may no longer be adequate and they will revert to fibroblasts. Siffert (1955) showed that this happens if there is undue movement between the host bone and the graft, or if there is delay in the complete impregnation of the graft and the graft bed with pre-osseous tissue. The superior osteogenetic properties of cancellous grafts have nothing to do with the survival of transplanted osteoblasts, which never occurs to an extent likely to make any significant contribution to union. It is due entirely to the architectural conditions in the graft itself, which favour rapid permeation and therefore the greatest likelihood that the invading cells will be present throughout the graft when the best environmental conditions become established.

The rapidity with which this permeation can occur in cancellous grafts is illustrated in Case 1. This concerned a boy of twelve in whom two previous cortical grafts had been carried out elsewhere and had failed. After the sclerotic ends had been squared and the lower end of the ulna had been resected, a gap of five centimetres had to be bridged. There had been infection and the tissues were very sclerotic. The distal fragment was so short that only one screw could be used. Yet, despite these unfavourable circumstances, union was achieved in nine weeks (Figs. 1 to 3).

The second fundamental principle is absolute fixation, and failure to secure this is the greatest single cause of failure in these operations. The most reliable method of fixation is plating, but really long plates must be used and internal fixation must be supplemented by external fixation in plaster as in the treatment of recent fractures, and for similar reasons. Case 2 is an example of failure of a cancellous insert graft in the ulna and a cortical onlay graft in the radius. In the ulna the insert has been used to bridge a gap of two and a half centimetres, and the subsequent failure was clearly associated with failure of fixation at the

FIG. 1

FIG. 2

FIG. 3

Case 1—Boy aged twelve. Figure 1—After two previous cortical grafts had failed. There was also a history of infection. Figure 2—After resection of sclerotic ends a gap of 5 centimetres was bridged by an autogenous cancellous insert. The lower end of the ulna was resected. Fixation by plating and plaster. Figure 3—The late result. Reformation of medullary canal after removal of plate. Union occurred in nine weeks.

FIG. 4

FIG. 5

FIG. 6

Case 2. Figure 4—Non-union due to failure of fixation after cancellous insert graft of ulna and cortical onlay graft of radius. Figure 5—Cancellous onlay graft of radius with adequate fixation. Non-union of ulna ignored. Figure 6—Union established in four months.

upper end of the plate. In the radius the fixation was too short to be effective and there was non-union with increasing deformity (Fig. 4). With a cancellous onlay graft and better fixation, union occurred in four months (Figs. 5 and 6). The ununited ulna was ignored because at this level it causes no significant loss of function.

Nicoll's technique has proved most appropriate in the forearm. In the great majority of cases one of the bones is either intact or already united. The fractured ends of the other bone, after freshening, cannot be approximated without shortening the intact bone. Moreover, a gap already existed in one-third of the cases in the present series, even before sclerosed bone was resected. Case 3 shows such a gap of four centimetres after two cortical grafts had failed. There had also been some infection and a sequestrectomy. After a cancellous insert graft and rigid fixation by plating and plaster, union was firm at the upper end in three months but required six months at the lower, more sclerotic end (Figs. 7 and 8). After a year the plate was removed and the cortices and medullary canal then reformed in response to Wolff's law (Fig. 9).

FIG. 7

FIG. 8

FIG. 9

Case 3. Figure 7—Two years after gunshot wound. Two cortical grafts had already failed. Figure 8—Four months after insert graft, plating and plaster. Union at the proximal end has been rapid. At the distal end union is tenuous. Plaster discarded. Union became firm throughout in another two months. Figure 9—Late result. Union firm throughout. Reformation of medullary canal and cortices after removal of plate.

Many cases presented especially difficult problems. All of those referred from other sources had had one or more previous grafting operations by more conventional techniques. In five cases there had been two or more previous attempts, and in one case five attempts. In four cases there had been infection and there was considerable bone and soft-tissue sclerosis. These are difficult conditions which provide a basis for critical comparison with other methods. Success was achieved in each case at the first attempt by the technique advocated by Nicoll. *Union after grafting*—In twenty-seven cases union occurred within four months (75 per cent); in seven, in more than four months (19.5 per cent); and there were two failures. The method was therefore successful in 94.5 per cent of the cases in the forearm. It has been used altogether in fifty cases, with only two failures.

In the series published by Bertelsen, Birn, Christensen, Glistrup, Gregersen and Jørgensen in 1955, the incidence of failure in eighty-three cases of non-union in the forearm, treated by different grafting methods, was 24 per cent, which compares with 18 per cent for non-union of the femur, 12 per cent for the humerus and 4 per cent for the tibia. These figures show that non-union in the forearm bones still presents one of the more difficult technical problems of grafting.

Nicoll's graft was performed on twenty-four patients in the present series. Twenty-three recovered full mobility and the remaining patient had a limitation of rotation only. Mobility was therefore no more of a problem after grafting than after primary treatment.

SUMMARY AND CONCLUSIONS

1. The age of the patient has no influence on the incidence of non-union in fractures of the forearm in adults.
2. The degree of displacement of the fracture is an important factor in non-union, and is related to the violence of the injury.
3. Fractures of one bone unite better than fractures of both bones, and this is due to the stabilising effect of the intact bone.
4. Open and comminuted fractures have a much higher incidence of non-union.
5. The lowest incidence of non-union, allowances being made for other significant factors, was in cases treated conservatively; and after that in cases treated by plating followed by immobilisation in plaster.
6. Plating without subsequent immobilisation in plaster is a method to be abandoned, but there is some advantage in waiting for ten days, until post-operative oedema has been absorbed, before applying the plaster.
7. In cases in which several factors predisposing to non-union are present in the same patient, it seems justifiable to supplement plating by cancellous onlay strips as a primary procedure.
8. In cases of non-union the cancellous insert graft described by Nicoll succeeded in 94.5 per cent of the cases, many of which were exceptionally difficult problems. In 75 per cent union occurred within four months of grafting.
9. The restoration of mobility, either after union of the fracture or after grafting operations, was never a serious problem in the present series.

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REFERENCES

- BERTELSEN, A., BIRN, O., CHRISTENSEN, I., GLISTRUP, E., GREGERSEN, P. L., and JØRGENSEN, J. B. (1955): Treatment of Pseudarthrosis of the Long Bones in Denmark. *Danish Medical Bulletin*, **2**, 1.
- NICOLL, E. A. (1956): The Treatment of Gaps in Long Bones by Cancellous Insert Grafts. *Journal of Bone and Joint Surgery*, **38-B**, 70.
- NICOLL, E. A. (1961): *Personal communication*.
- SIFFERT, R. S. (1955): Experimental Bone Transplants. *Journal of Bone and Joint Surgery*, **37-A**, 742.
- WATSON-JONES, Sir R. (1955): *Fractures and Joint Injuries*. Fourth edition. Edinburgh and London: E. & S. Livingstone Ltd.