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GRAPHIC REPRESENTATION OF HEALING TIME IN FRACTURES OF THE SHAFT OF THE TIBIA

By

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INTRODUCTION

The time required for union of a fracture of the shaft of the tibia is one criterion for judging the efficiency of treatment. In common with most authors *Ellis* (1958) chose 20 weeks as the upper limit for normal healing time. Delayed union and non-union are, however, difficult to define with regard to time.

Henderson (1926) stated that delayed or non-union was more common in open fractures and *Owen* (1932) pointed out that non-union was more frequent in fractures caused by direct violence. *Urist et al.* (1954) showed that healing time was related to the anatomical type of fracture. The purpose of this paper is to evaluate the influence on healing time of various factors such as anatomical type of fracture, etiology, infection and treatment.

MATERIAL

The material consisted of 492 consecutive fractures of the shaft of the tibia in adults treated in the Orthopaedic Department of the University of Lund at the Malmö General Hospital during the years 1949 through 1963. The cases were divided into a control series (311 fractures) in which no standardized treatment was given and a prospective series (181 fractures) where treatment was modified, as regards skin injuries, to prevent osteomyelitis. A detailed description of these cases has been published by *Edwards* (1965).

A. *Definitions.*

Transverse fractures: fractures in which the fracture line formed an angle between 45 and 90 degrees with the long axis of the shaft, and fractures in which one or more

intermediate fragments involved at least half of the bone diameter (comminuted fractures).

These fractures were generally the result of direct severe violence such as traffic accidents and crush injuries.

Longitudinal fractures: all other fractures, *i.e.* spiral and long oblique fractures.

These fractures were generally the result of indirect moderate violence such as falls at the ground level or from a height of less than 3 meters.

Displaced fractures: fractures with longitudinal or transverse displacement regardless of angulation.

Open fractures: fractures where a wound communicated with the fracture.

Osteomyelitis: bone infection with fistula formation.

METHODS

A. *Estimation of Healing Time.*

Healing time was defined as the interval from injury to clinical union of the fracture. Stability was evaluated every time the plaster was removed. Generally the healing time was equal to the period of plaster fixation. This method tends to overestimate the actual time for union. In the prospective series more attention was paid to healing time and the overestimate may be less.

TABLE 1

Displaced Closed Longitudinal Fractures (Method of Calculation).

Col. 1 Months	Col. 2 Number	Col. 3 Acc. no.	Col. 4 Corr. no.	Col. 5 %	Col. 6 Probit
1	1	164	163.5	99.09	7.36
2	35	129	128.5	77.9	5.77
3	63	66	65.5	39.7	4.74
4	42	24	23.5	14.2	3.93
5	17	7	6.5	3.9	3.24
6	4	3	2.5	1.5	2.83
7	2	1	0.5	0.3	2.25
12	1				
	165				

Column 1: Time in months following fracture.

Column 2: Number of fractures observed to be healed at corresponding time.

Column 3: The numbers are reversely accumulated to represent the number of fractures not yet healed at corresponding time.

Column 4: The accumulated numbers are corrected by —0.5 units according to the method of *Moore et al.* (1951).

Column 5: The accumulated corrected numbers are expressed as per cent of the total number of fractures derived from Column 2.

Column 6: Probits derived from a probit table are taken for the corresponding percentages.

B. *Analysis of Data.*

1. *Calculations:* Probit analysis was used to evaluate the healing time for various groups of fractures. The steps in the calculations are found in Table 1 as they were applied to the closed displaced longitudinal fractures.

The probits from Column 6 in Table 1 were plotted against time in months where time was made a logarithmic function. The best line was fitted by eye (Fig. 3). In the line fitting little attention was paid to the points representing the extreme periods as these points were based upon very few fractures. The times required for healing of 50 per cent and 95 per cent of the fractures were derived from the graphs and are listed in Table 2 and 3. These times correspond to probits 5.00 and 3.36 respectively.

TABLE 2

Healing Time for Different Types of Fractures (Control and Prospective Series).

Type of fracture	No.	Months required for healing of 50% of the group	Months required for healing of 95% of the group
Displaced closed longitudinal ...	165	2.6	5
Not displaced transverse	32	2.1	4
Displaced closed transverse ...	156	3.4	10
D:o excluding osteomyelitis ...	150	3.4	9
Displaced open transverse	118	4.6	19
D:o excluding osteomyelitis ...	105	4.5	14
Fractures complicated by osteomyelitis	20	9.5	34

TABLE 3

Comparison between Control and Prospective Series of Displaced Open Transverse Fractures. Time, in Months, Required for Healing of 95 per Cent.

	Healing time, months	Healing time, months
	Including osteomyelitis	Excluding osteomyelitis
Control Series	20	14
Prospective Series	14	14

2. *Time as a geometric variable.* In Fig. 1 numbers of fractures observed to be healed plotted against the corresponding times produced a skewed curve. When a logarithmic time scale was used the resulting curve became symmetric (Fig. 2). If we conceive of the fracture groups as normally distributed around a central healing time, then the distribution of numbers of healed fractures on either side of the central healing time can be interpreted as follows:

Let $\bar{t}$ be the central healing time and t_s the standard deviation of the healing time, then in the logarithmic approach referred to in Fig. 2, an upper limit can be set to:

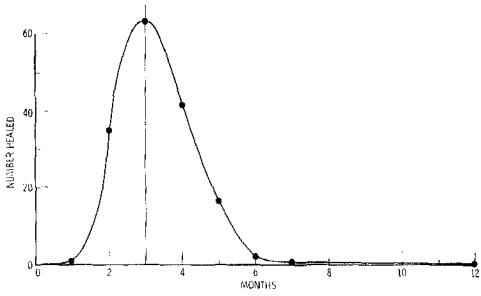

Fig. 1.

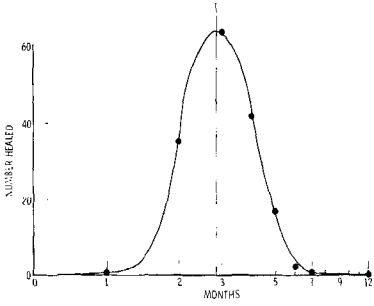

Fig. 2.

Fig. 1. Healing of closed displaced longitudinal fractures. Time as a linear function.
Fig. 2. Healing of closed displaced longitudinal fractures. Time as a logarithmic function.

$$\log \bar{t} + \log ts = \log (\bar{t} \cdot t_s)$$

and a lower limit to:

$$\log \bar{t} - \log t_s = \log (\bar{t} / t_s)$$

In the linear approach in Fig. 1 the abscissa represents the anti-logarithms of the quantities above or in terms of upper and lower limits:

$$\bar{t} \cdot t_s \text{ and } \bar{t} / t_s$$

and the value for central healing time is:

$$\bar{t} = \sqrt{\bar{t} \cdot t_s \cdot \bar{t} / t_s}$$

The central healing time is thus the geometrical average between the two limits.

The other groups of fractures also had this type of distribution and have been analyzed in a similar way. The data for all groups fit reasonably well a straight line when plotted with time as a logarithmic function of the probits (Fig. 3).

3. *The significance of the calculated healing time.* The regression lines (Fig. 3) show how the slope is flatter with longer healing times and how the 50 per cent (probit 5.00) and 95 per cent (probit 3.36) intercepts vary. A difference between two groups consisting of a decrease in a limited number of cases with a very long healing time will not influence the average healing time particularly but will change the distribution. In the graphs—compare displaced open transverse fractures including and excluding osteomyelitis in Fig. 3—this is reflected by a minor change in the 50 per cent value and an obvious change in the 95 per cent value. The central healing time is relatively constant while the regression line is changed to intercept with the 95 per cent level about 5 months earlier. Thus the 95 per cent value provides a measure for studying minor extreme subgroups in the group which clinically have not been rated separately. The same example illustrates how such a subgroup with common clinical criteria (osteomyelitis) can be separated from the main group resulting in a change in the 95 per cent healing time.

For further information on this method the reader is referred to *Moore et al.* (1951) and to *Hoffmann* (1963).

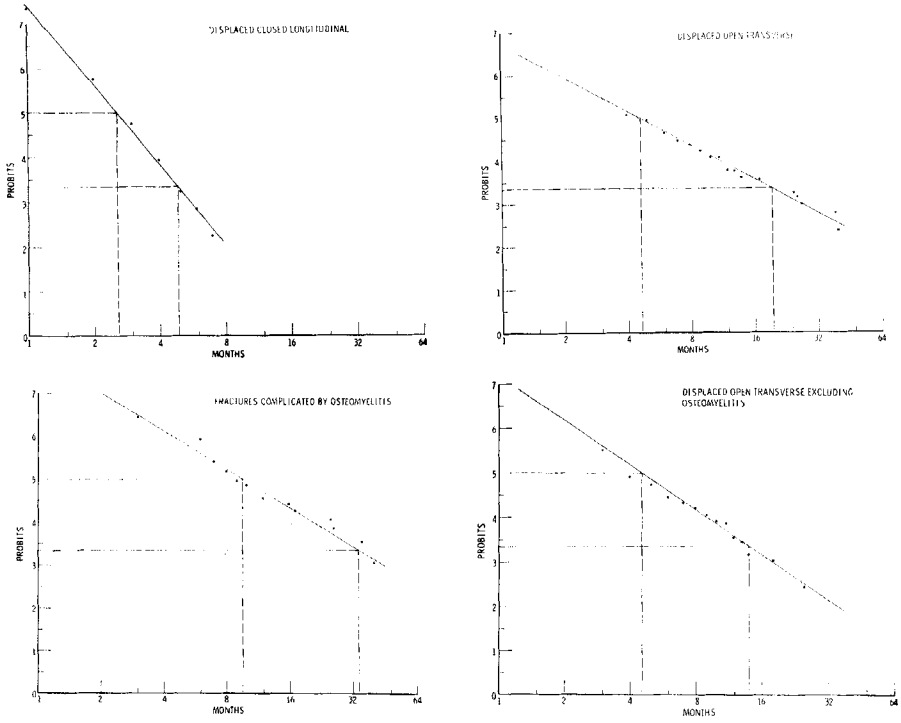

Fig. 3.

Examples of graphs used for derivations of healing times. Broken lines are the coordinates for the point of interception of the 50 per cent and 95 per cent levels.

RESULTS

The healing times for different types of fractures as derived from the type of graph shown in Fig. 3 have been listed in Table 2. Longitudinal and transverse fractures show large differences in healing time. There is also a difference between open and closed transverse fractures which is considerably reduced after removal of osteomyelitis cases from both groups. Only two out of 22 cases of osteomyelitis were subjected to amputation before clinical union had occurred. Therefore it was possible to estimate healing time in this group as well. Osteomyelitis can be shown to double the time for healing for 50 per cent as well as for 95 per cent of the cases compared to the time for healing of open transverse displaced fractures without ostemyelitis.

Undisplaced fractures even if transverse show the shortest healing times of all.

A comparison between control and prospective series showed a longer healing time of open transverse fractures in the former series (Table 3). A large difference in the incidence of osteomyelitis between these series was observed (*Edwards* 1965). Removing osteomyelitis cases from both series accounted for the difference observed in healing time.

DISCUSSION

Healing of 95 per cent of the group of closed longitudinal frectures required five months. *Ellis* (1958) referred to cases not healed at this time as delayed union. As shown above the anatomical type of fracture, skin injury, degree of displacement and infection influence the pattern of healing time. Therefore, closed longitudinal fractures are not a standard for normal healing time unless the composition of the material is considered. As union may be delayed by causes which are clinically apparent it seems reasonable that healing of a fracture should not be considered delayed until the 95 per cent time period for the type of fracture has elapsed.

As shown in Table 3 no difference could be demonstrated between the control and prospective series of open transverse fractures after removal of osteomyelitis cases. In the prospective series 13 out of 46 cases of open transverse fractures without osteomyelitis underwent secondary treatment for slow union compared to 5 out of 58 cases in the control series. This treatment seems to have had a negligible effect on Healing time.

From comparison of the two series it is apparent that the best means of improving rate of fracture healing was the prevention of bone infection.

SUMMARY AND CONCLUSIONS

The healing time of a large series of fractures of the shaft of the tibia was studied by probit analysis.

1) The incidence of healing in the different groups of fractures can be regarded as normally distributed in relation to time as a geometric variable.

2) Fractures of different etiological and or anatomical types show large differences in healing time and an analysis of healing time must take this fact into account.

3) Fractures complicated by osteomyelitis are normally distributed in relation to a healing time which is exceedingly long.

4) Comparison between open transverse displaced fractures treated with and without particular attention to the skin injury show that the difference in healing time is due to a difference in the incidence of osteomyelitis.

5) Secondary surgery for cases considered to have slow union has no demonstrable effect on healing time in cases without osteomyelitis.

6) It is suggested that the limit for delayed union should be defined as the time when healing of 95 per cent of the corresponding group has occurred.

RESUME ET CONCLUSIONS

Le délai de guérison d'une large série de fractures du corps du tibia a été étudié par analyse de la probabilité.

1) L'incidence de guérison dans les différents groupes de fractures peut être considérée comme normalement répartie en relation avec le temps comme une variable géométrique.

2) Les fractures de type etiologique et/ou anatomique différent montrent de grandes différences dans les délais de guérison et une analyse du délai de guérison doit tenir compte de ce fait.

3) Les fractures compliquées d'ostéomyélite sont normalement réparties par rapport à un délai de guérison qui est extrêmement long.

4) Une comparaison entre les fractures déplacées transversalement, traitées avec ou sans attention particulière à la plaie de l'épiderme, montrent que la différence du délai de guérison est due à une différence dans l'incidence de l'ostéomyélite.

5) Une intervention chirurgicale secondaire dans les cas considérés comme ayant une soudure lente n'a pas d'effet manifeste sur le délai de guérison dans les cas sans ostéomyélite.

6) Il est suggéré que la limite d'une soudure retardée doit être déterminée comme le temps nécessaire à la guérison de 95 pour cent du groups correspondant.

ZUSAMMENFASSUNG UND SCHLUSSFOLGERUNGEN

Die Heilungsdauer einer grossen Reihenfolge von Tibiaschaftbrüchen wurde mittels Probitanalyse studiert.

1) Das Auftreten von Heilung bei den verschiedenen Gruppen von Brüche kann als normal verteilt in Beziehung zur Zeit als eine geometrische Variable angesehen werden.

2) Brüche verschiedener äthiologischer und/oder anatomischer

Typen zeigen weitgehende Verschiedenheiten der Heilungsdauer und eine Analyse der Heilungsdauer muss diese Tatsache in Betracht ziehen.

3) Durch Osteomyelitis komplizierte Brüche sind normalerweise verteilt hinsichtlich einer Heilungsdauer, die ausserordentlich lang ist.

4) Ein Vergleich zwischen offenen, verschobenen Querbrüchen, die mit und ohne besondere Beachtung der Hautbeschädigung behandelt wurden, zeigt, dass die Verschiedenheit in der Heilungsdauer mit der Verschiedenheit im Auftreten von Osteomyelitis zusammenhengt.

5) Sekundäre Chirurgie in Fällen mit verspäteter Heilungstendenz hat keinen nachweisbaren Effekt auf die Heilungsdauer in Fällen ohne Osteomyelitis.

6) Man schlägt vor, dass die Grenze für verspätete Heilungsdauer als die Zeit bezeichnet werden sollte, in der 95 Prozent einer entsprechenden Gruppe geheilt sind.

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