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Femoral shaft fracture in 265 children

Log-normal correlation with age of speed of healing

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After exclusion of delayed unions and pseudoarthroses in teenagers, the time required for union of 275 consecutive fractures of the femoral diaphysis in children followed a log-normal pattern with a constant 10 percent coefficient of variation and a geometric mean increasing uniformly by 0.7 weeks per year. Multiple injuries increased, and operative treatment reduced the geometric mean time for fracture healing.

Investigations on the speed of fracture union have almost exclusively been carried out on tibial fractures in adults (Watson-Jones 1943, Ellis 1958, Nicoll 1964, Edwards 1965, Hoaglund and Stater 1967, Allum and Mowbray 1979, Austin 1981, Hammer et al. 1984), and we could not find any study dealing with fracture healing in children.

Edwards and Nilsson (1965) found that the times of healing of tibial fractures in adults conformed to a log-normal pattern, whereas Austin (1977) advocated a reciprocal transformation of data. We assessed the pattern and variation with age of the healing times in a large series of fractures of the femoral shaft in children.

Patients and methods

During the period 1970–1981, 278 nonpathologic fractures of the femoral diaphysis in children were treated at the orthopedic departments at Esbjerg, Frederiksberg, and Sönderborg Hospitals in Denmark. Included were fractures between the lesser trochanter and the distal quarter of the femur. Because the radiographs and records of three patients were lost, 275 fractures in 265 children (197 boys, 68 girls) were studied. Twelve fractures were open. Multiple injuries, including other severe fractures, injuries to the trunk or head, were found in 57 patients.

The treatment was usually nonoperative, but the teenagers often had open reduction and internal fixation (Table 1). In only a few cases, internal fixation with the Rush pin was carried out after closed reduction. In 9 fractures, another reduction or internal fixation was performed after more than 2 weeks owing to a malposition. Four fractures were treated with internal fixation because of delayed healing. In 3 patients a new trauma before clinical union led to bending at the fracture site, and in another 2 patients radiographs revealed new fracture lines. Eight fractures healed with a distance between the bone ends of more than 1 cm. There were two deep infections.

The fractures were considered healed at the time of full unsupported weight bearing for babies and toddlers when all kinds of treatment or restrictions were discontinued. When weight bearing was not allowed or possible because of other injuries, the assessment was based on the radiographic appearance. Delayed union was defined as union occurring after more than 5 months and pseudoarthrosis as union following a second-

Table 1. Treatment of 275 femoral fractures in children

	Age (yr)		
	0–5	6–12	13–17
Traction	90	75	14
Plaster of Paris	4	2	0
Plate	0	8	14
Intramedullary nailing[a]	0	6	61
Screws	0	0	1

[a] Küntscher, AO, Street-Hansen, or Rush pins.

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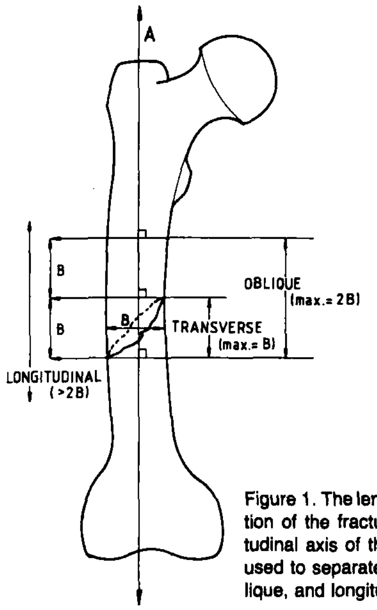

Figure 1. The length of the projection of the fracture on the longitudinal axis of the bone (A) was used to separate transverse, oblique, and longitudinal fractures.

ary operation carried out after more than 6 months. There were 14 cases of delayed union and 5 pseudoarthroses. The youngest patients with delayed union or pseudoarthrosis were 13 and 15 years of age, respectively. There was no case of refracture following final union.

The accidents were classified as high- or low-energy trauma according to Bauer et al. (1962). The fractures were classified as transverse, oblique, and longitudinal (Figure 1). Fractures with fragments of more than half the diameter of the shaft and segmental fractures were classified as comminuted.

Statistics

The preliminary assessment of the approximation of data to various patterns of distributions was accomplished by plotting the data in a probit diagram and using the chi-square test for goodness of fit. The geometric mean was used as an estimate of the mean time for union. Bartlett's test was used to compare variances and the *F*-test to assess means. Calculations of the increment of the mean time of union with age was accomplished by simple regression analysis after exclusion of delayed unions and pseudoarthroses. The multivariate regression analysis was used to assess the influence of side, sex, type of fracture, type of trauma, type of treatment, and multiple injuries (Table 2) complemented with the values of log H (H = time required for union in weeks). Because the ages of 0 and 1 year fell outside a rectilinear connection between age and log H, these ages were excluded from this part of the study. To avoid random factors with a potential for interference with fracture union, grade III open fractures (Gustilo and Anderson 1976), infected fractures, fractures with a gap > 1 cm, refractures, and cases of late rereduction were excluded as well.

Results

The time required for union varied from 3 weeks to 2 years (Table 3) and followed a log-normal distribution; for the teenagers, however, only after exclusion of patients with delayed union and pseudoarthrosis (Figure 2). Dealing with years rather than the broad age groups in Figure 2 would increase the inclination (i.e. reduce the variation)

Table 2. Data subjected to multivariate regression analysis. Figures are number of fractures. Grade III open fractures, infected fractures, refractures, and fractures healed with more than 1 cm of lengthening have been excluded

		Age (yr)																
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Side	Left	8	14	9	5	10	6	9	3	7	3	7	3	11	7	11	8	121
	Right	12	7	9	7	10	8	8	5	3	2	6	2	5	7	7	8	106
Sex	Female	7	5	6	2	6	4	1	2	3	3	5		10	4	1	4	63
	Male	13	16	12	10	14	10	16	6	7	2	8	5	6	10	17	12	164
Type of trauma	Low-energy	19	11	6	6	10	4	9	3	2	1	4	1	5	1		1	83
	High-energy	1	10	12	6	10	10	8	5	8	4	9	4	11	13	18	15	144
Type of fracture	Transverse	3	11	11	3	9	8	9	4	7	3	6	4	10	10	10	9	117
	Oblique	2	3	3	2	2		4	3			2					1	22
	Longitudinal	15	7	4	4	5	2	3	1	1		1		1	2			46
	Comminuted				3	4	4	1		2	2	4	1	5	2	8	6	42
	Multiple injuries		1	3	1	4		6	2	2		6	1	2	5	6	5	44
Type of treatment	Closed	20	21	18	12	18	14	15	7	9	3	7	2	1			6	153
	Open					2		2	1	1	2	6	3	15	14	18	10	74
	Total																	227

Table 3. The variance of the times required for union in relation to age. The figures are numbers of fractures

Time required for union in weeks																			Cumulative percentage
104															1		2		100
52														1	2	4	1	3	99
26														1	1	1	1	1	96
20														1		1	4	2	94
19													1		1		1	1	
18															2	2	3	1	
17													1	2	2		2	2	
16										2		1	1	1	2	1			
15														1	1		2		
14											2		2			2	2	3	79
13							1		1	2		1	2	2	1	3	2		
12								2	4	2	2	1	1	1		2	2	2	70
11				1	1		2		3				3	1	2	2	2		
10						1	3	4	2	1	4	1	2						56
9			1	2	3	3	1	3	1	3	1	1	1		2	1		1	
8			1	3	2	6	5	2	5		1					1			40
7		1	2	7	7	3	8	3	2								2		
6		1	5	5	3	1													18
5	1	5	9	4	3														
4	2	2	3																4
3	2	4																	
Age (yr)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

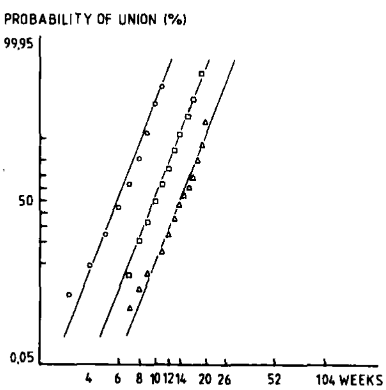

Figure 2

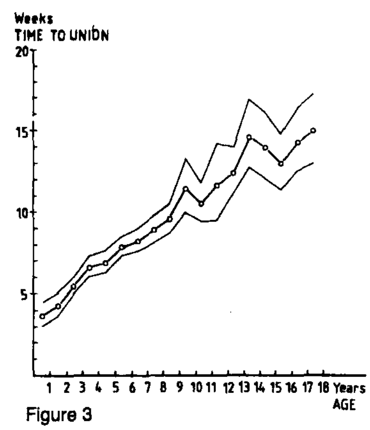

Figure 3

Figure 2. The times required for union in different age-groups plotted in a probit diagram with logarithmic scale 0 0–5, □ 6–12, Δ 13–17 years.

Figure 3. The increase of the mean times of union with increasing age. The unbroken lines represent the 2 SEM confidence limits. Delayed unions and pseudoarthroses have been excluded.

with only 15 percent. The coefficients of variation (SD/mean × 100 percent) were approximately 10 percent for all ages from 0 to 17 years, whereas the increment of the mean time of union was 0.7 weeks per year of age (Figure 3).

Side, sex, type of trauma, or type of fracture did not affect the mean time for healing, whereas multiple injury increased the time required for union with an average of 24 percent ($P < 0.001$), and operative treatment decreased the time on an average 12 percent ($P < 0.05$). The influence from the variables tested was much greater on the variance of the healing times; an increase was found after high-energy trauma, comminuted fracture, as well as multiple injuries and open treatment ($P < 0.05$).

Discussion

The observation that the distribution of fracture healing times follows a log-normal pattern (Edwards and Nilsson 1965) has not gained much attention. Published frequency distributions curves (Ellis 1958, Hammer et al. 1984) or cumulative percentage curves (Jensen et al. 1977, Allum and Mowbray 1979, Kristensen 1979, Austin 1981, Christensen et al. 1981, Harley et al. 1986) all indicate an asymmetrical distribution of the likelihood of union. The healing times of these series, as those of the teenagers in our study, tend to be too dispersed to conform to the log-normal pattern, some fitting better, although not very accurately, to the reciprocal-normal pattern proposed by Austin (1977).

There might be two explanations for the observation that delayed unions and pseudoarthroses in the teen-age group had to be excluded to provide an acceptable fit to the log-normal distribution. One is that the potential for healing in adult persons is less reliable than in children. Another is that the more liberal use of open treatment caused more complications.

As bone healing like growth is likely to be a log-normally distributed process, statistical parameters should be based on the logarithms rather than calculated directly from the times observed. The skewed shape of the log-normal distribution when plotted into diagrams with linear scales should be taken into consideration when estimating cases of slow healing. Such cases should not, as pointed out by Hammer et al. (1984), indiscriminately be regarded as therapeutic failures. The mean values of the log-normal distributions are fairly insensitive to an increment in the number of observations to the far right of the mean, as seen in series which tend to identify slow healers. Interpretation of differences of means between groups should thus be drawn guardedly, particularly when they occur simultaneously with differences of variances. Such differences may merely indicate trends towards segregation of series of observations less compatible with the log-normal presumption than any systemic effect exerted upon the basic fracture healing times.

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