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FRACTURES OF THE FEMORAL SHAFT IN CHILDREN

The Overgrowth Phenomenon

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Femoral overgrowth following femoral shaft fracture in children less than 13 years old has been documented by orthoroentgenogram in 74 patients from the time of healing 3 months following fracture until skeletal maturity. The femoral overgrowth averaged 0.92 centimeters (range 0.4–2.7) and was found to be independent of age, level of fracture, or position of fracture at the time of healing. The overgrowth was a universal phenomenon. Ipsilateral tibial overgrowth averaging 0.29 centimeters (0.1–0.5) occurred in 82 per cent of the patients. In the first 18 months following fracture 78 per cent of the overgrowth occurred. There was a time limit to the overgrowth phenomenon in 91 per cent of all patients following which the discrepancy persisted without change. By 18 months following fracture, however, only 12 per cent of the patients had completed the overgrowth and by 3 years and 6 months following fracture 85 per cent had completed their overgrowth. In 9 per cent of the patients overgrowth continued throughout the remaining growth period although at a slower rate than in the first 18 months following fracture.

Key words: children's fractures; femoral shaft; overgrowth

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Fractures of the femoral shaft in children unite readily but there has been considerable interest in such aspects as angulation (Griffin et al. 1972, Viljanto et al. 1975), malrotation (Benum et al. 1979, Verbeek et al. 1976) and overgrowth of the fractured femur (Aitken 1940, Barfod & Christensen 1958/59, Blount 1955, Burdick & Siris 1923, Cole 1922, Conwell 1929, David 1924, Griffin et al. 1972, Hedberg 1944, Staheli 1967, Truesdell 1921, Viljanto et al. 1975). It is common practice to allow displaced fractures to heal in a somewhat shortened position (Tachdjian 1972) in children 12 years of age or younger. Certain questions concerning the overgrowth phenomenon have prompted a continuing assessment of children with fractured femurs whose lower extremity lengths have been documented by serial orthoroentgenograms in the Growth Study Unit of the Children's Hospital Medical Center, Boston. This report concerns itself specifically with the frequency of overgrowth, the period during which it occurs and its extent as related to sex, age at the time of fracture, position of healing and level of fracture.

PATIENTS AND METHODS

The patients studied had suffered isolated femoral shaft fractures when under 13 years of age. This study includes 116 patients whose lower extremity lengths were documented by orthoroentgenograms until skeletal maturity. As some of these patients were assessed initially 6 months or more following healing, the more detailed studies on the overgrowth phenomenon have been derived from 74 patients followed up using orthoroentgenograms from the time of fracture healing at 3 months to skeletal maturity. The patients studied were not drawn from a consecutive series. Because of the interest of our unit in lower extremity length discre-

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pancy problems, however, the patients were assessed prospectively because of femoral shaft fracture rather than on the basis of a noticed and specific clinical problem.

Fracture treatment: Those less than 3 years of age were treated initially in Bryant's traction followed by a one and a half hip spica. Those 3 years of age and older were treated initially by distal femoral Kirschner wire skeletal traction in either the "90–90" position or with a Thomas splint and Pearson knee piece (Griffin et al. 1972). When callus appeared radiologically and fracture site pain to palpation had disappeared the patient was transferred to a one and a half hip spica. The time of plaster application varied between 3 and 5 weeks post-fracture and the time of cast discontinuation varied from 10 to 12 weeks post-fracture. Tibial Kirschner wires were not used and no patients were treated by osteosynthesis.

Lower extremity length determinations: The lower extremity lengths were assessed by serial orthoroentgenograms (Green et al. 1946) taken at 6 month intervals for the first 18 months and then at annual intervals. The patients were followed until skeletal maturity. In 74 patients intensively reviewed the initial radiologic documentation was 3 months following fracture when the patient was readmitted to hospital for plaster removal and physical therapy. At this time the fracture was considered clinically and radiologically healed.

The following parameters were assessed: 1. Sex distribution (116 patients); 2. Age at the time of fracture (116); 3. Side of fracture (116); 4. Level of fracture (proximal, middle, or distal third), and the relationship of level of fracture to age and sex (116); 5. Amount of femoral overgrowth from the time of healing 3 months post-fracture until skeletal maturity (74 patients) and the amount of overgrowth as related to i) sex, ii) age at fracture, iii) position of healing (shortening, at length or distracted), and iv) level of fracture; 6. Period of time during which overgrowth occurred (74); 7. Tibial overgrowth from the time of femoral fracture healing to skeletal maturation (74); and 8. Epiphyseal arrests (in entire group).

RESULTS

1. *Sex distribution* – There were 90 males and 26 females, a ratio of 3.46/1.

2. *Age at which fracture occurred* – The age distribution at the time of fracture is shown in Table 1.

3. *Side of femoral fracture* – There was a slightly increased tendency for the left side to be fractured (56 per cent) (Table 2).

4. *Level of fracture* – In the entire group of 116 patients 63 per cent of the fractures occurred in the middle third of the femur, 28 per cent in the proximal third, and 9 per cent in the distal third. In the 74 patients studied in greater detail a similar distribution was seen with 66 per cent in the middle third, 27 per cent in the proximal third and 7 per cent in the distal third. The site of fracture was similar regardless of age or sex (Table 3).

5. *Extent of femoral overgrowth* – In the 74 patients with initial radiographs within 3 months of fracture, overgrowth of the fractured femur occurred universally. The average femoral overgrowth in all cases from the time of healing onwards was 0.92 centimeters. The extent of overgrowth was not dependent on sex, age at the time of fracture, the position of healing, or the level of fracture (Table 4).

6. *Temporal aspects of the overgrowth phenomenon* – Two patterns of overgrowth were

Table 2. Side of femoral fracture

	Male	Female	Total
Right	41 (46%)	10 (38%)	51 (44%)
Left	49 (54%)	16 (62%)	65 (56%)

Table 1. Age at time of fracture

Age (years)	0–1	1	2	3	4	5	6	7	8	9	10	11	12	
Male	3	2	3	10	5	13	14	13	8	10	5	1	3	= 90
Female	0	2	1	4	2	5	2	4	2	3	1	0	0	= 26
Total	3	4	4	14	7	18	16	17	10	13	6	1	3	= 116

Table 3. Level of femoral shaft fracture in 116 patients

Age (years)	0–1	2–5	6–8	9–12	Male	Female	Total
Proximal (M/F)	–	10/3	13/1	4/1	27 (30%)	5 (19%)	32 (28%)
Middle	3/2	19/9	20/4	13/3	55 (61%)	18 (69%)	73 (63%)
Distal	2/8	2/0	2/3	2/0	8 (9%)	3 (12%)	11 (9%)

Table 4. Extent of femoral overgrowth in 74 patients with fractured femoral shafts

	Centi-meters	Range
Femoral overgrowth		
Entire series (74)	0.92	(0.40–2.70)
Female	0.81	
Male	0.95	
Overgrowth in relation to age at fracture		
2–4	0.92	(0.50–1.30)
5–7	0.87	(0.50–2.70)
8–12	0.91	(0.60–1.30)
Overgrowth in relation to position of healing		
Short (28 Cases)	0.92	(0.60–2.70)
Equal (21 Cases)	0.85	(0.50–1.40)
Long (25 Cases)	0.94	(0.60–1.60)
Overgrowth at various levels of fracture		
Proximal third	0.91	(0.40–1.50)
Middle third	0.94	(1.50–2.70)
Distal third	0.95	(0.60–1.80)

seen. In the more common pattern overgrowth continued after fracture healing for a limited time period, then ceased with no change in discrepancy throughout the remainder of skeletal growth. This is referred to as the plateau pattern or plateau phenomenon. Much less frequently, overgrowth continued until skeletal maturity although at a much slower rate after the first 18 months following fracture. In the group of 74 patients with early and continuing documentation of lengths 91 per cent (67/74) showed temporally limited overgrowth (plateau pattern) while 9 per cent (7/74) continued overgrowth with time. In the entire group of 116 patients, 93 per cent (108/116) demonstrated the plateau phenomenon while 7 per cent (8/116) persisted in overgrowth. In the 74 completely studied patients, 64 per cent of the documented femoral overgrowth occurred within 9 months of healing (1 year post-fracture) and 78 per cent occurred within 15 months of healing (1 year 6 months post-fracture). Figure 1 illustrates the time following fracture when overgrowth ceased and a discrepancy plateau was reached. By 1 year 6 months post-fracture overgrowth was complete in only 12 per cent; by 2 years it was complete in 45 per cent; by 2 years 6 months in 65 per cent; by 3 years in 77 per cent; by 3 years 6 months in 85 per cent and by 5 years 9 months in 91 per cent. Table 5 indicates the results in those whose overgrowth continued without demonstrating the plateau phenomenon. Premature epiphyseal closure on the fractured side with a late change in discrepancy did not occur.

7. *Tibial overgrowth* – The tibia on the side of the fractured femur increased in length from the time of femoral fracture healing such that at skeletal maturity 82 per cent of patients had slightly longer ipsilateral tibias. In 13 per cent tibial length was equal and in only 5 per cent was the tibia on the contralateral, non-fractured side longer. The average tibial discrepancy was 0.29

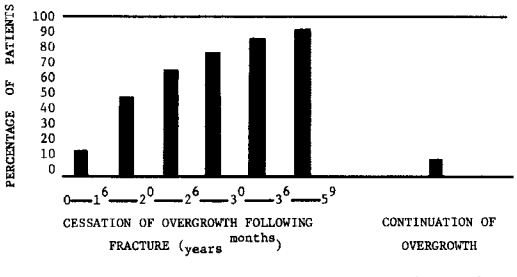

Figure 1. The time following fracture when femoral overgrowth reached its maximum.

Table 5. Patients where overgrowth of fractured femur continued throughout period of skeletal growth

Patient#*	Overgrowth (centimeters)	Percentage of overgrowth 18 months post-fracture	Years post-fracture with overgrowth still occurring	Possible contributing factors
1.	1.8	56	7	none identified
2.	2.0	30	7	↑ anterior bowing
3.	1.5	50	7	none identified
4.	2.3	30	9	none identified
5.	1.6	–	10	none identified
6.	2.7	33	8	myositis ossificans
7.	1.9	37	9	↑ anterior bowing
	average 1.98	average 39	average 8.1	

* Patient 8 was seen initially 3 years 7 months following fracture. Overgrowth on the fractured side persisted 9 years post-fracture. Medial bowing at fracture site was marked.

centimeters longer on the ipsilateral side (range 0.1 to 0.5).

8. *Epiphyseal arrest* – In the group of 116 patients, 28 underwent epiphyseal arrest. The average preoperative discrepancy was 2.39 centimeters (range 1.7 to 3.4). The discrepancies occurred as a combined result of overgrowth and healing in anatomical or slightly distracted position. The average discrepancy post-epiphyseal arrest at skeletal maturation was 0.66 centimeters (range 0–1.5) with 86 per cent of those operated showing a discrepancy of less than 1.0 centimeter. Five of the 28 patients requiring epiphyseal arrest had continued to increase their discrepancy with time due to continuing stimulation on the fractured side.

DISCUSSION

The sex, age, side, and level of fracture in the present series correspond well with other large series (Barfod & Christensen 1958/1959, Bloch 1922, Burdick & Siris 1923, Clark 1926, Cole 1922, Conwell 1929, Dameron & Thompson 1959, David 1924, Hedberg 1944, Staheli 1967, Viljanto et al. 1975). Males invariably predominate over females; the fractures occur almost equally on the left and right sides although most studies demonstrate a slight left-sided predominance; and the middle third of the femoral shaft is always the commonest level of fracture reported, varying from 60 to 78 per cent, with the proximal third the second commonest area of involvement and the distal third the least frequent level of involvement. The similarity of the patient profile in this series to that in all other series is important as it establishes that the orthoroentgenogram studies were performed in a group of patients whose fractures reflect the common pattern. In addition, the data presented indicate that the profile in the 74 patients in which the overgrowth measurements were most detailed is the same as the profile in the entire group of 116 patients. That the overgrowth findings represent the actual situation is further indicated by the fact that the 74 completely documented patients with fractured femurs were studied prospectively solely on the basis of femoral shaft fracture rather than on the basis of other clinical criteria.

Overgrowth was a universal phenomenon occurring in each of the 74 patients. This finding is similar to those who studied large numbers of patients by radiologic measurements: Hedberg (1944), who demonstrated overgrowth in 86 per cent (38/44); Aitken (1940), who documented overgrowth in all fractured femur patients but one (64/65) and Viljanto et al. (1975) who documented overgrowth in 50 out of 51 patients over 2 years of age. The average documented femoral overgrowth in this series was 0.92 centimeters which compares well with Viljanto et al.

(1975), 1.07 centimeters; Aitken (1940) 1 centimeter from position on discharge and Hedberg (1944), 0.9 centimeters. The same average amount of overgrowth occurred regardless of the age at fracture when the patient group was divided into the age brackets 2 to 4 years, 5 to 7 years, and 8 to 12 years. Hedberg (1944) and Staheli (1967) noted slightly greater overgrowth in those 4 to 8 years of age and 2 to 8 years of age, respectively, but Viljanto et al. (1975) found no statistically significant difference in average overgrowth in those less than 3 years old, 3 to 9 years old and more than 9 years old. Overgrowth also occurred regardless of whether the fracture had been allowed to heal in a shortened position, at length, or in a lengthened, distracted position. This is an important finding as regards the cause of overgrowth and is in agreement with Staheli (1967) and Viljanto et al. (1975). Overgrowth did not appear to be influenced by whether the fracture was in the proximal, middle, or distal third. Because of the large size of this series and the accurate method of assessment using frequent orthoroentgenograms, these data appeared to reflect the actual situation more closely than studies which rely on clinical measurements or less accurate radiologic measurements. Truesdell (1921), in one of the earliest documentations of the overgrowth phenomenon, noted that overgrowth occurred whether the fracture was in the upper, middle, or lower third of the femur. Similar overgrowth regardless of level disagrees somewhat with the opinion of Staheli (1967) who felt that proximal fractures demonstrated more overgrowth but is consistent with the work of Viljanto et al. (1975).

The overgrowth phenomenon was appreciated well over a century ago by Ollier (1867) and received ample documentation early in this century (Burdick & Siris 1923, Cole 1922, David 1924). Increased blood supply to the healing bone was felt by Ollier (1867), Levander (1929), and Bisgard (1939) to be the primary cause of the overgrowth. Although there was early disagreement as to the cause of the phenomenon with some attributing it either to "young bone yielding to pull" as the shortening corrected itself (Cole 1922) or to a law of compensatory overgrowth (David 1924), most investigators now feel that the overgrowth is a physiologic process (Blount 1955) associated with the increased vascularity of the involved bone owing to healing. The increased vascularity extends to the epiphyseal plate regions where the overgrowth stimulus occurs. This now appears amply confirmed especially with the demonstration that overgrowth occurs regardless of the position of fracture healing and that it occurs in all patients thus indicating that it is an obligatory phenomenon rather than one called into play only to compensate for shortening. In addition it has been demonstrated to occur with humeral (Hedstrom 1969) and tibial (Greiff & Bergmann 1980) fractures. Kellernova et al. (1970) demonstrated increased vascularity to the entire limb following experimental tibial fracture. The tibial overgrowth documented here also provides evidence for à total limb response. Increased length of the ipsilateral tibia averaging 3 mm in 82 per cent of the patients with only 5 per cent showing a longer contralateral tibia is taken as presumptive evidence of overgrowth in association with femoral fracture. Tibial overgrowth was not noted by Staheli (1967) but was commented on by Greville & Ivins (1957).

The frequent length assessments and the accuracy of the orthoroentgenographic method have allowed for more detailed study of the temporal aspect of overgrowth than has previously been reported. The impression that most of the overgrowth occurs within the first year of fracture and that it is virtually complete by 18 months (Burdick & Siris 1923, David 1924, Blount 1955) is valid but it is demonstrated that the overgrowth phenomenon can persist for 3 or 4 years and, more importantly, that in from 7 to 9 per cent of patients it continues for the remaining period of skeletal growth. Prolongation of overgrowth beyond 18 months or 2 years has been alluded to by Hedstrom (1969) and Viljanto et al. (1975) on the basis of remodeling which can continue for that period of time. These two findings are important in following children with femoral fractures especially if they have been allowed to heal at length or with some distraction.

In the eight patients (Table 5), whose overgrowth continued, assessment following fracture demonstrated overgrowth averaging

1.98 centimeters in contrast to the entire group which averaged 0.92 centimeters. The overgrowth 18 months following fracture was only 39 per cent in comparison to the overall group where 78 per cent of overgrowth had occurred by that time. Overgrowth was continuing 8 years post-fracture in these patients. Five of the eight had a discrepancy sufficiently large to require epiphyseal arrest. In four of the eight patients no unusual factor could be identified which might have contributed to the continuing overgrowth but in four of the patients hyperemic stimuli may well have persisted owing to excessive angulation which prolonged the remodeling phase and to myositis ossificans which also is associated with an increased blood supply.

During the early weeks of fracture healing there is slight motion at the fracture site and it is neither feasible nor necessary to perform accurate orthoroentgenographic length measurements. One virtually never has accurate radiographic documentation of the lengths prior to fracture; Barfod & Christensen (1958/59) in a clinical study of 431 normal children found 8 per cent with unequal length of the lower limbs although only 0.7 per cent had a 1 centimeter or more difference. These limitations in all clinical studies have been discussed in detail (Hedstrom 1969). Both Hedstrom (1969) and Bisgard (1939) attempted to assess overgrowth from the time of fracture in experimental animals. It is unknown, however, whether the vascular response begins simultaneously throughout the whole extent of the femur or whether it spreads from the fracture site towards the epiphyses. If the former mechanism occurs then overgrowth would probably be somewhat greater as it would begin earlier; if the latter, overgrowth may well represent primarily a post-consolidation phenomenon. It is my feeling that the latter is the case and that radiologic measurements begun at the time of healing reflect the total overgrowth accurately.

Recommendations for treatment and subsequent assessment of patients with a fractured femoral shaft as regards ultimate lower extremity length equality.

1. All displaced shaft fractures of the femur in children from 2 to 11 years of age should be positioned initially and allowed to heal with 1.5 centimeters of shortening in the expectation that overgrowth of the fractured femur and to a lesser extent of the ipsilateral tibia will correct the shortening and leave both limbs virtually equal in length. It appears that consideration need not be made based on the level of fracture.

2. Accurate measurement of the extremity lengths should be made as soon as the fracture has healed with the expectation that an additional 1.0 centimeter of overgrowth of the fractured femur will occur regardless of the position of healing.

3. Most of this overgrowth (78 per cent) will occur in the first 1½ years following fracture and by 3½ years following fracture the large majority of patients (85 per cent) will have reached the maximal extent of their discrepancy which will then persist unchanged throughout the remaining growth period.

4. From 7–9 per cent of patients may continue to increase their discrepancy throughout the remaining growth period although at a slower rate than seen shortly after fracture. Although it has not been possible to rigidly define which patients will continue to overgrow it should be suspected in those situations which favor continuing increased vascularity such as myositis ossificans and considerable angular deformity which requires a prolonged remodeling phase.

5. If epiphyseal arrest is necessary, timing by the Green-Anderson method and arrest using the Phemister technique (Tachdjian 1972) have proven to be highly effective.

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