

## THE DEVELOPMENT OF THE CALCANEAN FOOT DEFORMITY AFTER POLIOMYELITIS

By

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### INTRODUCTION

In the literature on the paralytic calcanean foot the consensus of opinion is that the principal cause of the deformity is paralysis of m. triceps, with a consequently reduced muscular pull upon the calcanean tubercle. On the other hand, opinions differ as to the mechanism involved in the development of the deformity and as to the disturbance of the muscle co-ordination in leg and foot which produces the deformity.

*Duchenne*, who published the first description of the calcanean foot in 1867, considered that the deformity consisted of a change in the mutual positions of the bones in the foot. The reduced tone of the paralyzed triceps, combined with the traction exerted on the foot by the muscles at the front of the leg, caused a lowering of the posterior part of the calcaneum, whilst flexor digitorum comm. and the peroneals caused the equinus posture of the fore-foot. In *Irwin's* opinion (1951), the position of the calcaneum changes as a result of the mechanical advantage of the plantar muscles in relation to the paralyzed triceps, and the change of position becomes fixed by contracture in the plantar fascia. The equinus posture of the fore-foot is the result of the traction of the posterior tibial and the peroneals, and if the anterior tibial is intact the excavation may be increased still more.

Contrasting with *Duchenne*, *Nicoladoni* (1881), *Hoffa* (1909) and *Pürckhauer* (1912) considered that the deformity was the result solely of a change in the shape of the calcaneum: during the growing period the posterior process of the calcaneum in the paralytic foot grows plantarly and anteriorly owing to the preponderance of the plantar muscles vis-a-vis the paralyzed triceps. *Abrahamsen* (1916) also be-

lieved the changes in the shape of the calcaneum to be the principal factor, though he added that in quite young individuals, whose ligaments are pliable to some extent, there is a possibility of a slight alteration of the position of the calcaneum in relation to the talus, as the joint cavity between these two bones can be made to open posteriorly. Abrahamsen then points out that this change in the position of the calcaneum will be aggravated if the foot is inverted, as the anterior extremity of the calcaneum will then be able to glide up on to the lateral aspect of the head of the talus.

*Wittek* (1902), *Wulpius* (1910), *Tubby* (1912) and *Steindler* (1921) also believed in a change in the shape of the calcaneum, but considered that the essential factor lay in an alteration of the attitude of the bone, both in relation to the talus and, together with the talus, in relation to the leg.

Presumably the lack of agreement on the nature of this deformity, and the absence of clarity as to its pathogenesis, may be ascribed to the fact that each of the published communications is based upon a relatively small series and that the various authors proceeded according to mutually different principles in their clinical observations and in their estimation of the roentgenological findings in the paralyzed feet.

It is not surprising that the so-called calcanean foot may appear in varying forms, having regard to the structure of the foot and also bearing in mind that a number of factors have an influence on the positions of the bones and, in the growing period, on their shape. By this is meant the disturbance of the muscular correlation in leg and foot, in the blood circulation and in the growth of the bone, as a result of the paralysis, depending upon its extent, degree and duration and upon the age at the onset of the disease, as well as upon the development of contracture in the plantar fascia and in the connective tissue around the paralyzed muscles.

This report is based on a series comprising 134 patients who had paralysis of the triceps: bilaterally in 33 and unilaterally in 101 patients, which means a total of 167 cases of triceps paralysis. In addition to this muscle, the majority of the 134 patients had paralysis of some of the other muscles of the leg and foot. For each patient, the clinical findings were compared with the changes in the shape and position of the calcaneum as demonstrated by X-ray examination under uniform conditions in every case.

The series consists exclusively of patients whose paralytic feet had only been given physical therapy prior to examination here; in other words, it does not include patients whose feet had previously been

operated on, for instance by tendon transplantation, osteoplastic operation or the like. Consequently, the series should be suitable for illustrating the nature of the calcanean foot deformity and its genesis.

#### SERIES AND METHOD OF EXAMINATION

The above mentioned 134 patients comprise all the cases of triceps paralysis which have been attended to at *The Infantile Paralysis Institute* in Copenhagen during the years 1945 to 1952 inclusive.

TABLE 1

*Distribution of patients according to year of onset of the disease.*

1885-1943	1944	1945	1946	1947	1948	1949	1950	1951
25	33	4	1	13	22	16	18	2

*Distribution of feet according to age at onset of the disease.*

$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3	4	5	6	7	8	9	10	11	12	13	>13 years
15	32		16	12	18	9	4	3	4	4	2	2	3	1	42

*Distribution of feet according to lapse of time between paralysis and X-ray examination.*

$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3	4	5	6	7	8	9	10	11	12	13	>13 years
10	14	6	24	20	9	10	22	14	8	5	5	2	1	3	14

Most of the patients had poliomyelitis in 1944 and the following years, but there are cases in which the disease began in 1885 (Table 1).

The series is somewhat heterogeneous as regards age at onset and duration of the paralysis (Table 1), a description which may also be applied to treatment; 90 of the feet came under immediate treatment, 39 received attention some time after the onset and 28 were not treated at all.

It has been impossible to get information as to when the patient first stood erect after the paralysis set in, or of the nature and duration of any bracing therapy.

The result of every clinical examination is recorded in a scheme for each case, as shown in Table 2.

The indication of the degree of paralysis involves some uncertainty, being dependent to some extent upon a subjective estimate.

*The X-ray examination* of the patients' feet was made with the patient lying on one side (Fig. 1) with the foot pressed firmly against a support (a wooden block), which was photographed together with the



*Fig. 1.*

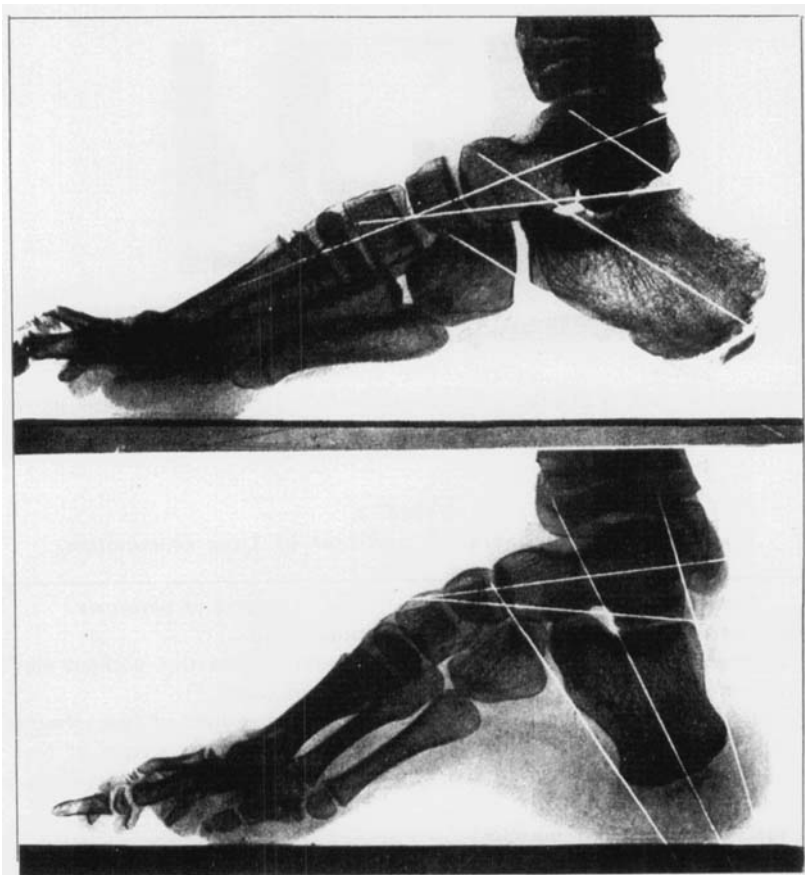
X-raying the foot in profile, with the ankle flexed rectangularly and pressed firmly against a wooden block.

TABLE 2

*Age: at onset, at beginning of treatment, at X-ray examination.*

<i>Localization of paralysis</i>		<i>Degree of paralysis</i>
Lower extremity: right/left		0: innervation
gastrocnemius		1: palpable contraction without movement of foot
soleus		2: movement, weight of foot eliminated
tib. post.		3: movement against weight of foot
tib. ant.		4: movement against slight resistance
peron. long.		5: normal
peron. brevis		
toe flexors (plantar muscles)		
toe extensors		
<i>Deformity, standing</i>	<i>Position of foot standing</i>	<i>Contracture</i>
excavatus cavus	neutral	in planta
equinus	valgus	in triceps
calcaneus	varus	elsewhere
planus		

profile of the foot (Fig. 2). In the radiographs the outline of the wooden block is seen as a base line (Fig. 2). *The position of the calcaneum* in the sagittal plane may now be expressed by the size of the angle which a plane (the plane of the articular surface) forms—through the superior surface of the calcaneum, from the posterior border of the articular facet, to the anterior extremity of the calcaneum,—with the block. The angle is given a positive value when the articular plane inclines anteriorly (normal foot) and a negative value if the anterior end of the calcaneum is elevated so much that the articular plane inclines posteriorly.



*Fig. 2.*

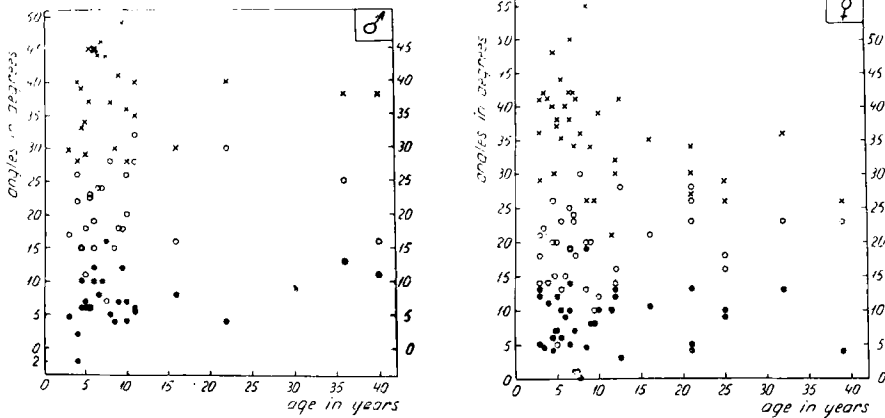
Group II, No. 7240 (Table 4, page 232).

Above: normal foot (left): calcanean articular plane angle  $6^{\circ}$ . Böhler angle  $43^{\circ}$ . Calcanean plantar surface angle  $33^{\circ}$ . Talus angle  $22^{\circ}$ .

Below: calcanean foot (right) with elevation of anterior end of calcaneum, atrophy of calcanean tubercle and antero-plantarly: calcanean articular plane angle  $-3^{\circ}$ . Böhler angle  $70^{\circ}$ . Calcanean plantar surface angle  $55 - 9 = 46^{\circ}$ . Talus angle  $8^{\circ}$ .

*Atrophy of the calcanean tubercle* is indicated by the size of the Böhler angle, one leg of which is the articular plane and the other is the plane through the superior border of the calcanean tubercle.

*Changes in the shape of the plantar part of the calcaneum* may be expressed by changes in the angle formed by a plane through the plantar surface of the calcaneum and the block, correction first being made for any elevation of the anterior extremity of the calcaneum.



Figs. 3 and 4.

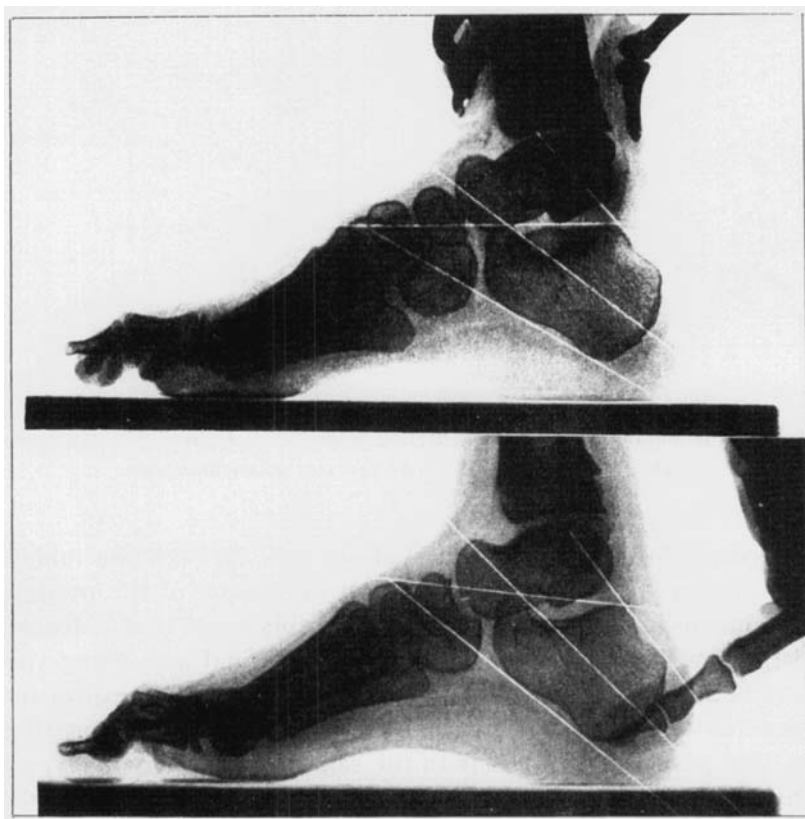
Calcanean articular plane angle ●. Böhler angle ×. Calcanean plantar surface angle ○ for 26 males and 37 females at various ages.

The angle formed by the longitudinal axis through the middle of the calcaneum with the block is also an expression of the position of the calcaneum in the sagittal plane; but as this angle is also dependent upon the shape of the calcaneum, the longitudinal axis being steeper if there is atrophy of the tubercle, it is not so exact an expression of the position of the calcaneum as the angle of the calcanean articular plane. The position of the talus in the sagittal plane may be expressed by the angle formed, by the longitudinal axis through the middle of the talus, with the block.

Figs. 3 and 4 show the individual variation of the calcanean articular plane angle, of the Böhler angle and the calcanean plantar surface angle for 26 normal males and 37 normal females. The figures show that there is no difference in the size of the angles of the two sexes and no difference at different ages.

Repeated X-ray examinations within a period of from 6 months to two years of 14 normal feet of children between  $3\frac{1}{2}$  and 10 years of age show furthermore that the shape and position of the calcaneum are practically unchanged.

In order to ascertain the mechanism governing the change in the position of the calcaneum in this deformity the mutual positions of calcaneum to talus were determined by a series of tests in which the feet of normal individuals and of polio patients with paralysis in leg and foot were examined by X-ray after inversion and eversion and after maximal dorsal and plantar flexion of the foot, with the following results:



*Fig. 5.*

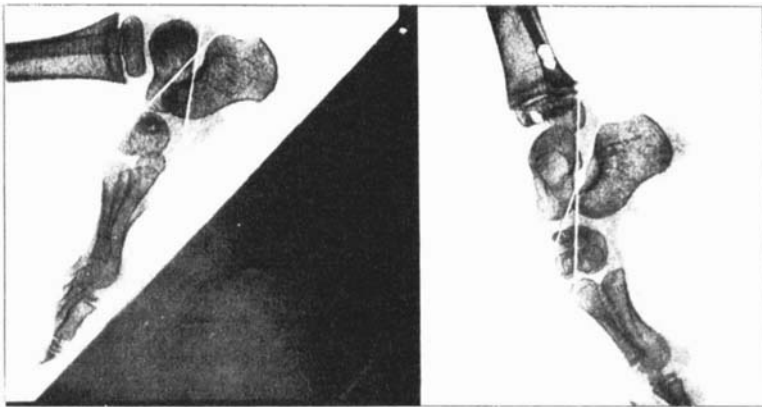
Group II, No. 5491 (Table 4, page 232).

**Above:** foot in neutral position calcaneal articular plane angle  $1^{\circ}$ .

**Below:** same foot in valgus position after inversion. Anterior extremity of calcaneum has glided up on the lateral aspect of the caput tali. Calcaneal articular plane angle  $-6^{\circ}$ .

*Inversion of the foot* (14 tests) revealed a number of cases in which the anterior extremity of the calcaneum glides up on the lateral aspect of the head of the talus with a consequent alteration of the calcaneal articular plane, varying between  $4$  and  $16^{\circ}$  (Fig. 5), the movement being greatest in feet with the valgus deformity. This displacement was not found in inversion tests with varus feet and normal feet in which the talus and calcaneum were fully developed. No change in the width of the talo-calcaneal joint cavity posteriorly could be observed in these tests.

Inversion and eversion of the foot showed practically no change in the position of the talus in relation to the leg.



*Fig. 6.*

Group II, No. 3958 (Table 4, page 232).

**Left:** Valgus foot, maximum dorsal flexion of angle, anterior extremity of calcaneum has glided up on lateral aspect of head of talus, the space between the bones narrowed posteriorly.

**Right:** Same foot, maximum plantar flexion, anterior extremity of calcaneum under head of the talus. Calcaneum has glided 2-3 mm. posteriorly and the space between the bones has widened a little posteriorly.

With the *maximum dorsal flexion* of the ankle (31 tests) there was a narrowing anteriorly of the space between calcaneum and talus in children up to the age of 8 (23 cases). In some cases the anterior extremity of the calcaneum glides a short distance up to the lateral aspect of the head of the talus, the movement being greatest in valgus feet (Fig. 6). The space between calcaneum and talus could not be induced to widen posteriorly when the foot was flexed dorsally; in fact, especially among young individuals, this space narrowed to the extent of 2-3 mm. when the foot was dorsally flexed to the maximum.

With *maximum plantar flexion* (23 cases) the anterior extremity of the calcaneum is displaced plantarly (Fig. 6) and the space between talus and calcaneum may widen anteriorly. In some cases there was also a displacement posteriorly of the calcaneum in relation to the talus, with a widening of the space between calcaneum and talus of 2-3 mm posteriorly.

The explanation of these conditions accompanying movement lies in the fact that with the maximum dorsal and plantar flexions the foot is first turned on the transversal axis of the talo-crural joint. When the talus reaches its extreme position the movement thereafter proceeds only as inversion and eversion in the talo-calcanean joint around an axis which inclines from the medial aspect of the collum

tali to the lateral aspect of the tuber calcanei. Hereby the anterior end of the calcaneum glides up on the lateral aspect of the head of the talus when the foot is flexed dorsally, and under it when flexed plantarily. Normally the displacement of the bones is very little; the movement will be greater when the muscles in the leg are paretic. The narrowing of the space posteriorly between talus and calcaneum when the foot is flexed dorsally to the maximum in young individuals, is due to the talus in this position being pressed down against the posterior articular facet of the calcaneum. Finally, the increase of the same cavity with maximum plantar flexion must be a result of the calcaneum being displaced posteriorly in relation to the talus.

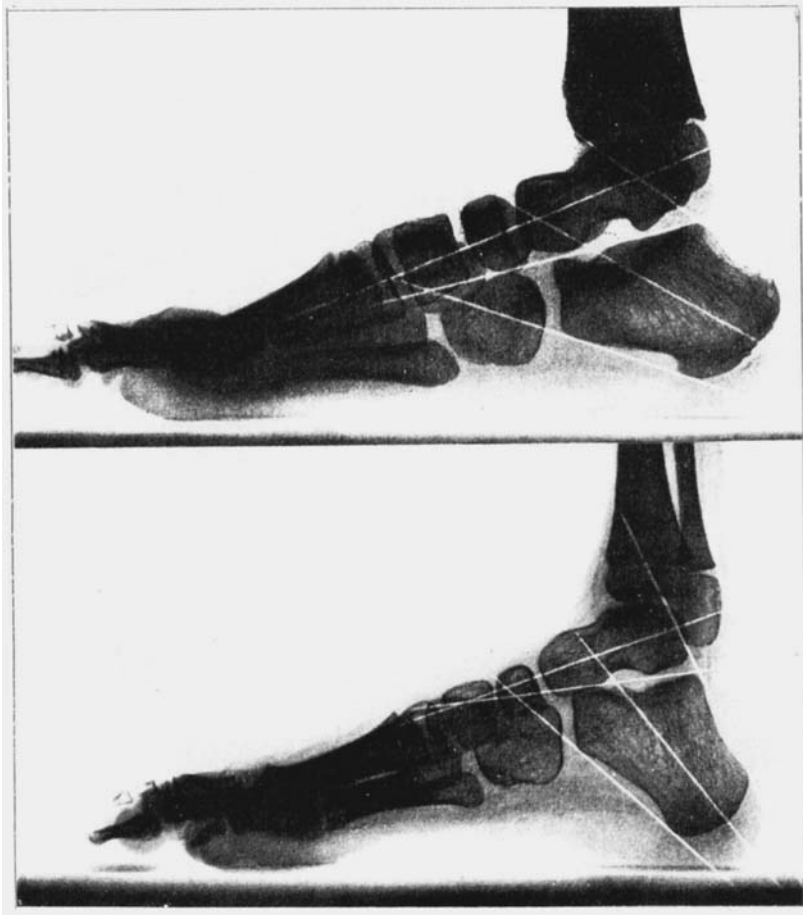
These tests show that there is no possibility of any angular movement in the sagittal plane between talus and calcaneum and the rearward movement between the two bones is so slight that it cannot explain the change observed in the attitude of the calcaneum in the paralytic calcanean foot. There is somewhat greater motility forward between calcaneum and talus in conjunction with inversion and eversion and the mobility increases with inversion if there is paralysis involving valgus deformity of the foot. It is therefore probable that in the paralytic calcanean foot a change in the position of the calcaneum may take place in the manner described without the talus being turned with it when the foot is simultaneously in valgus. If the attitude of the calcaneum undergoes a greater change, the talus must also change and it will be flexed dorsally.

#### EXAMINATION OF 167 PARALYTIC FEET

X-ray examination of the 167 feet in the series revealed a change in the shape of the calcaneum in 105 cases and a change in the position of the calcaneum in the sagittal plane in 52 cases.

*The change of form* in every case consisted of atrophy of the calcanean tubercle (Fig. 7), with an increase of the Böhler angle. In some cases there was also atrophy of the calcaneum antero-plantarly and, in a few cases, increased prominence plantarly of the posterior calcanean process (Fig. 7). Each of these two changes in form may be expressed by an increase of the angle made with the block by the plantar surface of the calcaneum.

*Change of the position of the calcaneum* in the sagittal plane consists of a turn of the calcaneum around a transversal axis. In most cases (48) the anterior extremity of the calcaneum is elevated (Fig. 2). In 4 cases (Table 3, group: plano-valgus feet) the anterior extremity



*Fig. 7.*

Group I D, No. 825 (Table 4, page 230).

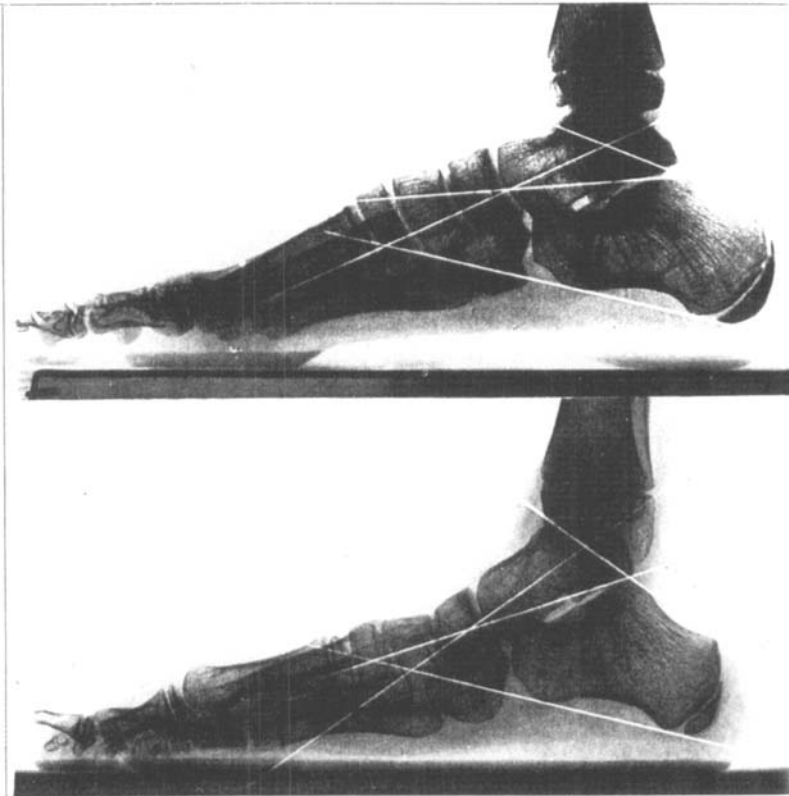
Above: normal foot (left), Böhler angle 50°.

Below: Calcaneal foot (right) with atrophy of calcaneal tubercle, Böhler angle 70°, antero-plantar atrophy and plantar prominence of posterior calcaneal process with increase of calcaneal plantar surface angle.

TABLE 3

*Os calcis in 167 feet with paralysis in triceps and other muscles of leg and foot.*

	A	7 neutral
	B	14 valgus
	C	7 plano-valgus
	D	36 varus
I Changes of form: 64 feet	41	14 neutral
		27 valgus
II Changes of form	4	
Elevation of anterior extremity		
III Elevation of anterior extremity		
No change of form	58	12 <13 years
IV No elevation of anterior extremity	46	>13 „



*Fig. 8.*

Group I C, No. 9232 (Table 4, page 228).

Above: normal foot (left), calcanean articular plane angle  $5^{\circ}$ . Böhler angle  $26^{\circ}$ . Talus angle  $25^{\circ}$ .

Below: plano-valgus foot (right), anterior end of calcaneum and head of talus turned plantarly; atrophy of calcanean tubercle. Calcanean articular plane angle  $18^{\circ}$ . Böhler angle  $52^{\circ}$ . Talus angle  $35^{\circ}$ .

of the calcaneum is turned plantarly, the median border of the foot is flattened and the head of the talus is also turned plantarly (Fig. 8).

In Table 3 the material is subdivided on the basis of changes in the shape and position of the calcaneum in the sagittal plane. Groups I and II are broken down to show the number of feet whose lateral balance is normal or altered as a consequence of paralysis in the other leg muscles. Group I C (plano-valgus feet) includes the four cases where the anterior extremity of the calcaneum is turned plantarly and in Group I D (varus feet) three cases in which there is slight elevation of the anterior extremity but where the change in the shape of the calcaneum is the dominating feature.

The various data for each case in Groups I, II and III are given in Table 4. Of Group IV, comprising feet with no change in the shape and position of the calcaneum, only the 12 cases where the disease occurred prior to the 13th year are included, but not the other 46 cases where the onset came after the 13th year.

In the following I have endeavoured to evaluate the significance of the various factors which, as already stated (page 221) may be assumed to contribute towards the change in the shape and position of the calcaneum as demonstrated by X-ray examination of the paralytic foot.

An estimation of this sort is made difficult by the circumstance that in most cases the various factors are present concurrently, but in differing degrees, the outcome being various combinations of changes in the shape and position of the calcaneum.

As a consequence, owing to the heterogeneity of the material and its somewhat limited size, it is difficult to decide whether the degree of the paralysis in the various muscles or its duration has made the greater contribution towards the development of the calcanean foot or whether early age at the onset of the disease, the occurrence of contracture, or the absence of treatment is chiefly responsible for the deformity.

#### CHANGES IN SHAPE OF CALCANEUM

*Atrophy of calcanean tubercle* (Fig. 7). Paralysis of the triceps must be regarded as the direct cause of atrophy of the calcanean tubercle on account of the reduced pull of the muscle on the bone, de-

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TABLE 4

For all cases in the Groups I, II and III, and for 12 cases in Group IV, where the disease occurred prior to the 13th year, the position of the calcaneum is indicated by the angle of the calcanean articular plane, and the shape of the calcaneum is expressed by the size of the Böhler angle and the angle of the plantar surface of the bone all in order of size. The corresponding values for the normal foot are given for comparison after a stroke. The letter b after a patient's number signifies bilateral calcanean foot.

Anterior plantar atrophy in the calcaneum is shown in the tables by \* before and above the value of the angle of the plantar surface of the bone; increased plantar prominence of the posterior calcanean process by \* behind that value.

The other columns indicate the occurrence of clinical calcanean foot and of contracture; equinus position is indicated by eq. The position of the foot under body weight is shown and also the localization and degree of the paralysis (in numerical values between 0 and 5), then the age at onset, duration of the paralysis, whether the foot has been treated or not, and finally the sex of the patient.

TABLE

Number	Angle of calc-articular surface	Höhler-angle	Angle of calc-plantar surface	Clinical calcaneum foot	Contracture in planta	Contracture in calf	Contracture in peroneals	Contracture in tib. post.	Valgus
<b>I Change in Form of the calcaneum: 64 feet</b>									
<b>A Neutral feet: 7</b>									
5312/52	4	49/38	23		(+)				
658/51b	6	50	24		(+)				
2046/51	5	51/41	29	(+)	++ exc.	++			
1612/51	11	52/45	17						
4964/52	12	58/44	*15						
864/51	14	59/55	22		(+)				
10142/50	7	60/40	*26	+					
<b>B Valgus feet: 14</b>									
1433/51	2	37/28	22		(+)	+	+		+
1780/51b	9	49	25			+			+
2998/52b	0	52	27			eq.			++
2218/51	37	62/41	*25		(+)		(+)		+
11135/50b	11	62	27				+		++
901/51	14	65	20						++
3028/51	7	67	26		+		+		+
"	6	57	22		+	+	+		++
5592/52	4	67	*40	(+)	+				+
"	4	67	*40		++				(+)
2222/51	8	68/37	28						(+)
6127/52	5	69/41	*37*		++				+
994/51	18	71/46	*20*						+
2864/52	6	75/45	*39		(+)		(+)		+
<b>C Plano-valgus feet: 7</b>									
10869/50	20	42/40	10						+++
2223/51	8	43/39	19						+
2311/51	17	45/36	9			+			+
1780/51b	27	46	3						+
1682/51b	10	41	16			+			+
11135/50b	17	50	13			eq.			++
9232/52	18	52/26	14			+			++
<b>D Varus feet: 36</b>									
5550/52	11	37/30	10		+	eq.			
956/51	0	40	19			+			
1108/51	6	45/37	24		(+)	eq.			
5311/52	3	45/41	23		(+)	+		(+)	
10520/52	18	46/41	14						

TABLE 4

Varus	Gastrocnemius	Soleus	Tib. post.	Tib. ant.	Peron. longus	Peron. brevis	Toe flexors (plantar muscles)	Toe extensors	Age (year)	Duration (year)	treatment (year)	treatment (year)	Female, male
	3	3	4	5	4	4	4	4	6	1½		+	f
	0	0	0	0	0	0	0	0	6½	1		+	f
	4	4	4	4	5	5	5	5	3	9½	9	½	f
	2	1	0	0	1	1	1	3	3½	2½	2	½	m
	2	2	3	4	3	3	4	4	1	6	1	5	m
	3	3	2	1	4-5	4-5	3-4	4	8	½		+	f
	3	3	5	5	5	5	5	5	2	4		+	f
	3	3	0	0	4	4	3	4	1	10	±		m
	3	3	1	0	1-2	1-2	3	0	1	6½		+	m
	0	0	0	0	0	0	2 <sup>1</sup>	2	1	4		+	m
	1	1	0	0	1	1	2	0	2½	6	1	5	m
	0	0-1	0	0	0	0	3	1	⅔	5		+	f
	0	0-1	0	0	0	0	1 <sup>2</sup>	0	⅓	6	1	5	m
	2-3	2-3	0	1	3	3	4	4	5	4	2	2	f
	4	4	1	0	4-5	4-5	4	4	5	4	2	2	f
	3	3	1-2	1	5	4	2-4	3	1½	5	4	1	f
	3	3	2	1-2	3	3	3	1	1½	5	4	1	f
	0	0	0	0	0	0	0	0	1½	7		+	m
	3	2	1	1	3	3	0	2-3	2	6		+	f
	0	0	0	0	0	0	0	0	1½	6		+	m
	0	0	0	0	0	0	0	0	⅙	8		+	m
	3-4	3-4	1	0	4	4	4-5	4-5	1	3		+	f
	4	4	3	1-2	4	4	5	5	4	½		+	m
	4	3	1	0	1-2	3	3	3	1	6½	2	4½	f
	4	4	1-2	0	4	4	4	5	1	6½		+	m
	4	4	0	0	3	3	4	3	½	4	±		f
	4	4	1	0	4-5	4-5	5	5	⅔	5		+	f
	4	4	0	0	0	0	3-1	0	½	10	5	5	f
+	5	4	5	5	5	5	5	5	½	13	+		f
+	0	0	0	0	0	0	0	0	½	2	+		m
+	3	3	1	1	3	3	4	2	4	1		+	m
+	0	0	0	0	0	0	3-0	2-0	2½	2½		+	f
+	4-5	4	5	5	4-5	4	4-5	4-5	2½	3		+	f

<sup>1</sup> 4-5. toe. <sup>2</sup> 1. toe.

TABLE 4 (con)

Number	Angle of calc. articular surface	Böhler-angle	Angle of calc. plantar surface	Clinical calcanean foot	Contracture in planta	Contracture in calf	Contracture in peroneals	Contracture in tib. post.	Valgus
812/51	12	47/28	19		+	eq. +			
6170/52	22	48/21	0		+				
1071/51b	5	48	24		+				
2048/51	7	48/30	19						
2344/51	9	48/30	13		(+)	eq. +		+	
811/51	3	50/34	29*		+				
4727/52	3	50/41	23						
4767/52b	11	51	18		med. ++	(+)			
861/51	7	51/36	17		+				
657/51	17	51	9½			med. +			
1028/51	8	52/42	21						
11204/50	10	54/33	15	+	++				
1716/51	10	62/34	*27*	+	++			+	
5631/52b	8	66/45	32		+				
1112/51	12	65/29	19						
1111/51	10	66/45	26*						
1058/53	18	66/42	16		med. +				
656/51	7	67/42	25	+	+				
825/51	6	70/50	**40**		+				
1683/51	6	51	30	+	+				
„	3	47	16	+	+			+	
2221/51b	15	65	19		(+)	+		+	
5954/52b	13	62	26		+				
5905/52	5	54/38	29		+	eq. ++			
2925/51b	10	66	28	(+)	+				
„ b	12	67	24	(+)	+				
2453/50	9	65/39	21*	+	(+)			+	
1682/51b	22	65	1		+			+	
3628/51b	2	59	33		+			(+)	
1469/51b	10	70	*43**	+	++				
8883/52	19	69/24	21*		+	+			

BLE 4 (cont.)

varus	Gastrocnemius	Soleus	Tib. post.	Tib. ant.	Peron. longus	Peron. brevis	Toe flexors (plantar muscles)	Toe extensors	Age (year)	Duration (year)	- treatment (year)	+ treatment (year)	Female, male
+	4	4	2	0	1	1	3	1	7	7		+	f
lan.	4	4	1	1	2	2	4-2	1	1/3	11	5	6	f
+	2	2	1	1	1	1	3	3	8	1		+	m
+	1	1	0	0	0	0	2	0	1/2	2		+	m
+	3	3	2	0	0	0	4	0	2	2	7	+	m
+	3	3	0	0	0	0	3	0	2 1/2	2		+	m
+	1	1	0	0	1	1	4	0	3	2		+	f
+	0	0	0	0	0	0	2-3	0	5	2		+	f
+	0	0	0	0	0	0	0	0	1 1/2	1 1/2		+	f
+	0	0	0	0	0	0	1	0	1 1/4	7	+		f
+	1	1	0	0	1	1	4	0	1	7	5	2	m
- +	1	0-1	0	0	0	0	3	1	1	3 1/2	1	2 1/2	m
+	1	1	1	0	1	1	3-4	0-1 <sup>1</sup>	3	7	2	5	f
+	0	0	0	0	0	0	0	0	4 1/2	8	5	3	f
+	0	0	0	0	0	0	0	0	1/2	3		+	f
+	0	0	0	0	0	0	1	0	5	4		+	f
+	1	1	0	0	0	0	2-0	1	1/2	2 1/2		+	f
+) )	2	2	0	0	2	2	0	0	3 3/4	3		+	f
+) )	2	2	0	0	0	0	4	3	1/4	7	1	6	f
+	3	3	2	0	0	0	4	0	5	20	4	16	f
+	2	2	1	0	0	0	2	0	5	20	4	16	f
+	3	3	1	0	0	0	4	0	4	6 1/2	3	3 1/2	f
+	4-5	5	4	2	1	1	1	1-4	4	7	+		m
+	0	0	0	0	0	0	0	0	9	23	+		f
+	0	0	0	0	0	0	4	2	3	6		+	f
+	3	3	1	0	1	1	4	2	3	6		+	f
+	0-1	0	0	0	0	0	1-2	0	4	6	1	5	f
+	2	2	3	0	0	0	3	1	1/2	4	+		f
+	1	1	1	0-1	0	0	1	0	4	20	15	5	m
+	0	0	0	0	0	0	1	0	1	27	+		f
+	3	2	2	0	0	0	5-3	5-1	2	8	2	6	f

<sup>1</sup> 3. toe.

TABLE 4 (cont)

Number	Angle of calc. articular surface	Böhler-angle	Angle of calc. plantar surface	Clinical calcanean foot	Contracture in planta	Contracture in calf	Contracture in peroneals	Contracture in tib. post.	Valgus
<b>II Elevation of the anterior end of the calcaneum and form changes: 41 feet</b>									
1717/51	3/7	43/38	26		(+)				(+)
3001/52	3/12	47/37	21						
4767/52b	5	45	24		++				(+)
2224/52	5/12	49/44	27						
6128/52	6/12	57/41	**27	(+)	++		++		+++
4370/52	5/13	56/45	*20						+
11818/51	6/8	62/26	*26	+	++		++		
815/52	5	66/39	*37	+	+				
462/53	7/12	54/46	31	(+)	++				
2045/51	1/	50/41	34	+					+
5904/52	2/10	51/45	25						+
2309/51	3/6	55/29	(*)18	+			(+)		
4727/52	3/	59/44	30	+					+
1858/51	2/10	58/35	(*)24	+	(+)				
6410/52	2/8	59/50	30	(+)					+
1679/51	2/	60/46	*35	+	+		+		+
987/51	0/7	61/36	36	+	+		(+)		+
1459/53	0/8	44/33	*38		+	eq. +			++
3000/52b	0/13	49/33	43*	(+)					
658/51b	—½/	50	28						
902/51	—1/6	54/44	29		+				+
5594/52	—1/7	48/42	(*)32		+	+			(+)
5491/52	—1½/10	48/46	33	(+)	++				+
9268/52	—1/	52	34	(+)	+				
3723/51	—2½/8	39	32				++		++
3958/52	—4/	44/28	**29	+	+				+
5116/52b	4	55	*36*	++	++	(+)			+
"	—3	45	*44*	+	+				+
10142/52	—2/4	61/42	40	++	+				
2140/51	0/13	61/32	**45**	++	+		+		+
10521/52	—3/11	57/30	38*	++	+				+
2480/52	—3/7	60/30	**35	+	++				+
7240/52	—3/6	70/43	**55	++	++				
2221/51b	—4½	62	40	+	+		+		+
284/52	—4½/6	55/35	41	+	+		+		+
193/51	—6/2	50/28	*42	++	++		+		
3343/50	—7/11	53/40	*49	++	++				
5954/52b	—9	55	48	+	++				+
6015/52	—7/4	60/40	49*	++	++				+
5827/52	—10/	64/30	**62**	+	++				++
3628/51b	—21	64/	*59**	+	++		+		+

TABLE 4 (cont.)

Neutral	Gastrocnemius	Soleus	Tib. post.	Tib. ant.	Peron. longus	Peron. brevis	Toe flexors (plantar muscles)	Toe extensors	Age (year)	Duration (year)	- treatment (year)	+ treatment (year)	Female, male
	2	2	0	0	2	2	4	3	3	1½		+	f
+	3	3	1	1	3-4	3-4	3	4	2	2¼		+	f
	4	4	3-4	1	4	4	4-5	5	5	2		+	f
+	3	3	3-4	3	4	4	3	4	8	½		+	m
	1-2	1-2	0	0	4	2	0	1	1	4		+	f
	1	1	0	0	3	3	0	3	2	3		+	f
+	1	1	4	5	5	5	3	5	2	7	2	5	f
+	4	3-4	4-5	4-5	4	4-5	4-5	5	1	5		+	f
+	3	3	5	5	5	5	5	5	½	3½		+	m
	1-2	1-2	2	4	3-4	3-4	4-5	3	2	1½		+	f
	2	2	0	0	4	4	2-3 <sup>1</sup>	3	5	1		+	m
+	2	3	4-5	5	5	5	5	4	1	1	+		m
	2-3	2-3	4	4	5	5	5	5	4	2½		+	f
+	2	2	4	3	3-4	3-4	4	4	2	2½		+	f
	1-2	1-2	2	1	4	4	4	3	4	2¾		+	m
	3	3	1	1	3-4	3-4	4	3	2½	2½		+	m
	0	0	0	0	0	0	2-3	0	4	5½	2	3½	m
	4	4	2	1	5	5	2	5-3	1	9½	8	1½	m
+	1	2	3	4	3-4	4	0	4-2	9	18	+		m
+	3	3	4-5	4-5	5	5	5	5	6½	1		+	f
	2	1	0-1	0	2	3	3	3	4	2		+	f
	4	3	1	1	3	4	4	4	2	6	1	5	f
	3	3	2	1	5	5	5	4-5	5	1¾	+		m
+	1	2	4	2-3	5	5	4 <sup>2</sup>	3	1½	1½	+		m
	3	3	1	1	5	5	4-5	3	1/12	6		+	m
	0	0	0	0	4	4	1	1	1	3		+	m
	1	2	2-3	0	3	2	4	4	½	14	11	3	m
	0	0	0	0	0	1	1	1-3	½	14	11	3	m
+	3	2	5	5	5	5	5	5	7½	5	2	3	m
	2-3	2-3	1	3	4	4	2-3	4	3	9	4	5	f
	0	0	2	4	4	4	5	4	7	11	+		f
	2	2	1	0	3	3	3	0	1	3	+		f
+	2	3	4	4	2	3	5	2	1½	9½	+		m
	2	2	0	0	3	4	5	1	4	6½	3	3½	f
	3	3	0	0	3	3	5	4	4	8		+	m
+	3	3	3-4	4	5	5	5	4	4	8	+		f
+	3	3	2	2	5	5	4	5	6	10	+		f
	3	3	1-2	0	5	5	3	5-4	4	7	+		m
	0	0	2	1	5	5	3	3-4	9	13	+		m
	0	0	0	0	0	0	4 <sup>3</sup>	1	1	67	+		m
	2	2	1	1	5	5	5	4	4	20	15	5	m

<sup>1</sup> 5. toe. <sup>2</sup> 2. toe. <sup>3</sup> 4.-5. toe.

TABLE 4 (cont.)

Number	Angle of calc. articular surface	Böhler-angle	Angle of calc. plantar surface	Clinical calcaneum foot	Contracture in planta	Contracture in calf	Contracture in peroneals	Contracture in tibia. post	Valgus
<b>III Isolated elevation of anterior end of the calcaneum: 4 feet</b>									
6179/52b	7/10	32	32		+	eq. ++			
6444/52	6/13	30	34		+				
1262/51	7/11	34			+				
5751/52	4/9	43	27						
<b>IV No change in form or position of os calcis: 58 (only the 12 cases below 13 years are reported in the table)</b>									
2998/52b	11	25	4						plan. +
5268/52	3	35	22		+	eq. ++			
1558/51	10	41/48	16			eq. +	+		plan. +
1859/51	7	39	27		++	+			
1434/51	4	40	21			+			+
1155/21	15	42	11						plan. +
948/51	10/10	49/49	16						plan. +
5631/52b	22	46	11			eq. +			plan. +
1071/51b	4	43	24		+				
5751/52	9	46	24						
3000/52b	12	33	23						
1146/53	12	37	18		+	+			

pending on the degree of paralysis. This atrophy is least, or is absent, in the 26 cases where the paralysis of the triceps is least pronounced, i.e. with paralysis values higher than 3 (one case in I A, one in I B, seven in I C, five in I D, three in II and eight in IV, Table 4), and most pronounced among the 21 cases where the triceps paralysis is total or almost total (one case in I A, six in I B, eleven in I D, three in II, Table 4).

*Antero-plantar atrophy of calcaneum* (Fig. 2) has its highest frequency in Group II, where there is also elevation of the anterior extremity of the bone (twenty cases in II, one in I A, six in I B, three in I D, Table 4). This would suggest that one of the causes of this change is less weight on the anterior extremity of the calcaneum owing to the changed and more vertical position of the bone.

*Increased plantar prominence of the posterior process of the calcan-*

TABLE 4 (cont.)

Varus	Gastrocnemius	Soleus	Tib. post.	Tib. ant.	Peron. longus	Peron. brevis	Toe flexors (plantar muscles)	Toe extensors	Age (year)	Duration (year)	- treatment (year)	+ treatment (year)	Female, male
	3	3	1	1	5	5	4	5	31	5		+	f
	1-2	3	1	1	2	2	4-2	1-2	10 <sup>1</sup> / <sub>2</sub>	2		+	f
	2	2	1	1	3	0	0	0	12	8		+	f
	2	2	0	0	4	4	0	2	13	8	±		f
	4	4	3	0	5	5	5	4	1	4		+	m
	4	4	4	1	4-5	4	4-5	4	1	8		+	f
	4	4	0	0	3-4	3-4	3	3	1	3		+	f
	4	4	3-4	5	5	5	4	4	2	40	38	2	f
	5	2	2	2	3-4	3-4	4	4	3	1 <sup>1</sup> / <sub>2</sub>		+	f
	4	3	1	0	1	2	3	2	3	1 <sup>1</sup> / <sub>2</sub>		+	m
	3	3	0	0	3	3	5	4	3 <sup>1</sup> / <sub>2</sub>	1 <sup>1</sup> / <sub>2</sub>		+	f
	2	2	2	0	0	0	4	0	4 <sup>1</sup> / <sub>2</sub>	8	5	3	f
	4	4	3	2	5	5	5	5	8	1		+	m
	0	0	0	0	0	0	0	0	10 <sup>1</sup> / <sub>2</sub>	2		+	f
	4	4	5	5	5	5	5	5	9	18	+		m
+	4	4	4	0	1	1	0	5	1	10	+		m

*eum* (Fig. 7 and 9) occurs in two cases in I B, seven in I D and eight in II, Table 4. The cause of this change of shape must lie in the reduced pull of the triceps on the tubercle, whereby the plantar musculature gains a mechanical advantage.

*Patient's age at onset and duration of paralysis.* No change in the shape of the calcaneum was found except where the onset of the disease came before the tenth year, and the series indicates that the maximum age at which changes in the shape of the calcaneum occur is ten years. There are several examples to show that atrophy of the calcanean tubercle cannot be demonstrated until six to twelve months after paralysis occurs. Furthermore a number of cases followed up to two years with X-ray examinations show that the progression is slow.

The most pronounced degrees of atrophy of the calcanean tubercle were found among the 21 patients with total or almost total paralysis of the triceps, where the onset had been early in life and where the

paralysis had been of long duration. Antero-plantar atrophy and increased plantar prominence of the posterior process of the calcaneum cannot be demonstrated until the paralysis has lasted several years.

The slighter degrees of shape modification can only be discovered by X-ray examination. In the more pronounced degrees of atrophy, flattening of the tubercle, perhaps combined with plantar prominence of the posterior process of the calcaneum, will appear clinically as a calcanean foot deformity (12 cases in Group I, Table 3), but with no change in the position of the calcaneum in the sagittal plane (Fig. 11).

TABLE 5

*Distribution and degree of paralysis in leg and foot muscles, as well as contracture and clinical calcanean foot in 36 feet with change in form of the calcaneum and 41 feet with change in position and in form of the calcaneum.*

I. Change of form		II. Change of form and position			
36 varus feet		14 neutral		27 valgus feet	
Index of paralysis		Index of paralysis			
0-3	>3	0-3	>3	0-3	>3
31	5	13	1	25	2
21	15	5	9	11	16
33	3	3	11	26	1
34	2	5	9	24	3
34	2	1	13	10	17
34	2	3	11	16	11
23	preponderance of toe flexors (plantar muscles)			33	
1	„	„	peroneals	35	
5	„	„	toe extensors	33	
28	contract. in planta			30	
8	„	„	calf		3
8	„	„	tib. post.		
	„	„	peroneals	3	8
9	clinical calcanean foot		11		19

#### POSITIONAL CHANGE OF CALCANEUM

Elevation of the anterior extremity of the calcaneum, combined with change in the shape of the bone, was found in 41 cases (Group II in Table 3). In 4 cases the positional change was isolated (Group III, Table 3). In these four cases the paralysis had come after the 10th year of the patients, after which, as already stated, no change in form

could be expected in the bone. Furthermore, in Group I D, where change of shape of the calcaneum dominates, there were 3 cases in which the anterior extremity of the bone was elevated (Table 4, Nos. 5311, 811 and 825). Finally, in Group I C (Table 4, Nos. 10869, 2311, 1780 and 9232) there were four cases where the anterior extremity was turned plantarly.

The elevation of the anterior extremity of the calcaneum varies between one and a few degrees and a change in the position of the bone so considerable that the plane of the articular surface inclines posteriorly. In such cases the change of position may be as much as  $25^{\circ}$  compared with the normal foot.

Among the 41 cases in Group II (Table 3) with elevation of the anterior extremity of the calcaneum, the lateral balance is good in 14 and the foot is in the neutral position. In the other 27 cases the foot is in the valgus position.

For both these sub-groups we find that when the elevation of the anterior extremity of the calcaneum is slight, the space anteriorly between talus and calcaneum is narrowed and that the calcaneum alone has changed position. In those cases in the valgus group where the elevation is more pronounced, the anterior extremity is raised up on the lateral side of the head of the talus but without change in the position of the latter bone (Fig. 13). In the still more pronounced changes in the calcaneum's position in both sub-groups the talus has also shifted, being turned dorsally as compared with the normal foot (Fig. 12). These observations agree with the tests already referred to (page 222), in which the motility of calcaneum and talus was studied in conjunction with flexion and inversion of the foot, and in which it was shown in particular that the valgus position increases the possibility of elevation of the anterior extremity of the calcaneum.

The various causes of the change in the position of the calcaneum are illustrated if we compare the clinical findings for the 36 varus feet in Group I D (Table 3), where change of form is the dominant feature, with the 41 cases in Group II comprising 14 neutral and 27 valgus feet, where there are changes in both the shape and the position of the calcaneum.

In Table 5 the cases in Groups I and II are separated according to whether the paralysis is pronounced (paralysis value 0-3) or slight (paralysis value  $>3$ ) in the various muscles. Next, the table shows the number of cases where the paralysis in the triceps is more pronounced than in the plantar musculature, in the peroneals and in the toe extensors (this is expressed in the table by the preponderance of the muscles named). The occurrence of contracture in the plantar and in

the various muscle groups is also shown, and finally the number of clinically observed calcanean foot deformities in Groups I and II.

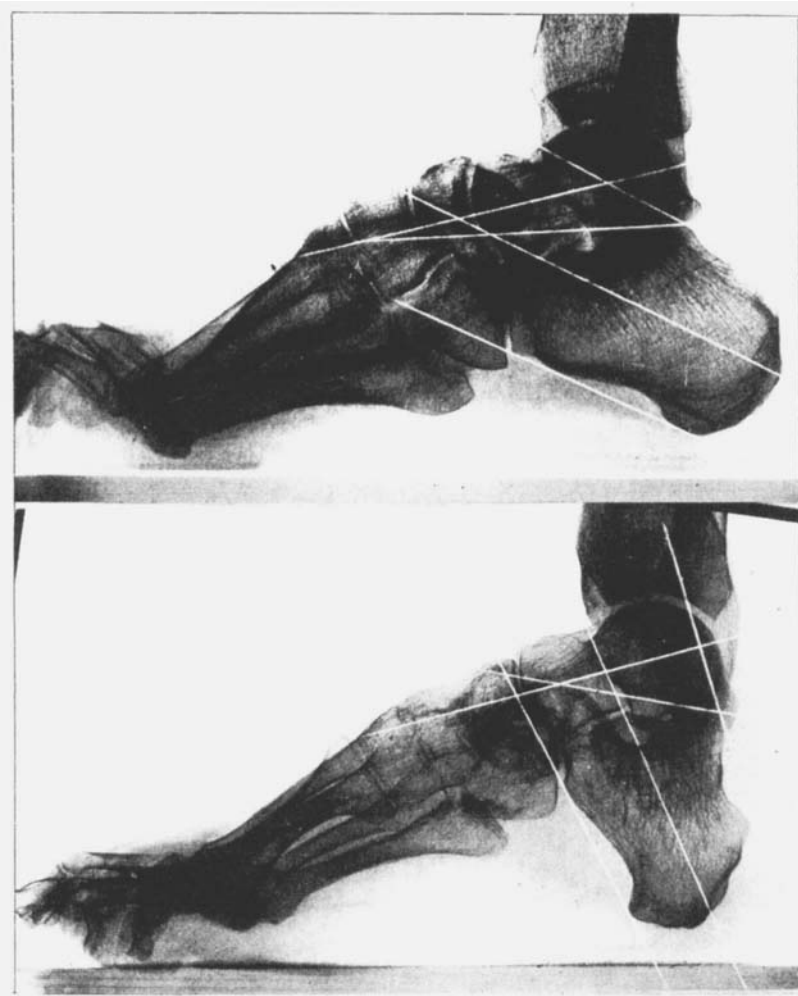
The table shows that the paralysis is pronounced in all the muscles of the leg, but slight in the plantar muscles in 15 cases in Group I. An explanation of the varus position is that the paralysis is less pronounced in the triceps and the posterior tibial than in the peroneals, and that there is contracture in triceps, posterior tibial and medially in the planta.

In Group II the paralysis is less pronounced in the various muscles, and in the 14 feet in the neutral position the lateral balance is preserved. The valgus position in the 27 feet is due to preponderance of the peroneals over the posterior and anterior tibials in 25 cases, contracture in the peroneals in one case, and in one patient the valgus position can be explained by preserved contraction in the plantar musculature to the fourth and fifth toes.

*Triceps paralysis and its degree.* The reduced traction on the calcanean tubercle accompanying paralysis in the triceps must be the precondition of the elevation of the anterior extremity of the calcaneum in the patients in Group II.

In the majority of cases the triceps paralysis is pronounced (paralysis value 0-3) and only in three cases is it slight ( $>3$ ). Among the other 23 cases in the series where the paralysis is slight ( $>3$ ) there is no elevation of the anterior extremity of the calcaneum, and in fact in 4 cases it is turned plantarly. It would thus seem that the anterior extremity of the bone only becomes elevated when the paralysis in the triceps attains to a certain degree (0-3).

*Paralysis in plantar musculature in relation to triceps paralysis.* Triceps paralysis occurs with the same frequency and degree in Groups I and II. Further, triceps paralysis is more pronounced than plantar paralysis (preponderance of the latter) in 23 and 33 cases in Groups I and II; finally, contracture in the planta occurs with the same frequency in the two groups (28 and 30 cases). According to earlier opinion, this combination of mechanical advantage in the plantar muscles and contracture in the planta would explain the change of the position of the calcaneum in Group II, and it might furthermore be expected that the positional change would also be found in Group I, comprising the varus feet of the series. As it happens, in most of the cases in Group I there is no positional change of the calcaneum, the explanation of which may be that the varus position of the foot hampers the elevation of the anterior extremity of the calcaneum, because it has glided in under the head of the talus. In these feet, where in most cases there is pronounced paralysis in all



*Fig. 9.*

Group II, No. 5827 (Table 4, page 232).

Above: normal foot (right).

Below: calcaneo-valgus foot (left). Anterior extremity of calcaneum elevated up on lateral aspect of head of talus. Considerable atrophy of calcanean tubercle, antero-plantar atrophy and plantar prominence of posterior calcanean process. Calcanean articular plane angle  $-10^{\circ}$ . Böhler angle  $64^{\circ}$ . Plantar surface angle  $64^{\circ}$ .

the leg muscles, the preponderance of the plantar musculature over the paralyzed triceps is insufficient alone to induce the elevation of the anterior extremity of the calcaneum. Three of the varus feet (Group I, Table 4, 5311, 811 and 825) with total paralysis of the posterior and anterior tibials and of the peroneals form an exception, the anterior extremity being slightly elevated in them all. In these

cases the cause may perhaps be that the paralysis had an early onset and that contracture in the planta caused the foot to shrink.

In Group II, the valgus position will promote the elevation of the calcaneum and its anterior end. Among the 27 valgus feet are two examples (Group II, Table 4, 987 and 5827) of how partially intact muscular contraction in the planta, coupled with contracture in the plantar fascia and with total paralysis of the crural muscles of long duration and without treatment, brought about a distinct change in the position of the calcaneum, and in one of them (5827, Fig. 9) led to the development of a typical calcaneo-valgus foot.

*Paralysis in the peroneals, posterior and anterior tibials and the toe extensors.* In the other 25 cases in the valgus group the peroneals, by turning the foot into the valgus position, and by the lifting action of the peroneus longus tendon on the anterior extremity of the calcaneum, help to elevate the latter. On comparing the degree of paralysis of the peroneals and the triceps in Groups I and II, we find that in the peroneals the paralysis is less pronounced than in the triceps in 35 cases in Group II, but in only one case in Group I. These figures illustrate the significance of the peroneals in the elevation of the anterior calcaneum extremity in Group II.

For the 14 neutral feet in Group II, where the lateral balance is preserved, the positional change of the calcaneum is brought about by the plantar muscles in conjunction with the posterior and anterior tibials and with the peroneals. Finally, there are eight cases in which the elevation of the anterior calcaneum extremity must be due chiefly to the posterior and anterior tibials as well as the peroneals and possibly the toe extensors, the paralysis in the triceps being less pronounced than in the plantar musculature in 4 cases and equal in the two muscle groups in 4 cases.

A comparison of the paralysis values for the toe extensors and for the triceps shows that it is more pronounced in the triceps than in the extensors in 33 cases in Group II, but only in 5 cases in Group I. This would suggest that the toe extensors also could make a contribution to the development of the calcanean foot.

*Contracture in the plantar fascia* in 28 cases in Group I, and in 30 cases in Group II, can scarcely be the sole explanation in most instances of the change in the position of the calcaneum (but see Table 4, No. I D, 5311, 811 and 825). The primary factor in the elevation of the anterior extremity of the bone must be the retained muscular contraction in the peroneals and in the posterior and anterior tibials, combined with the plantar musculature and perhaps the toe extensors. In Group II there are 11 examples of the calcaneum having

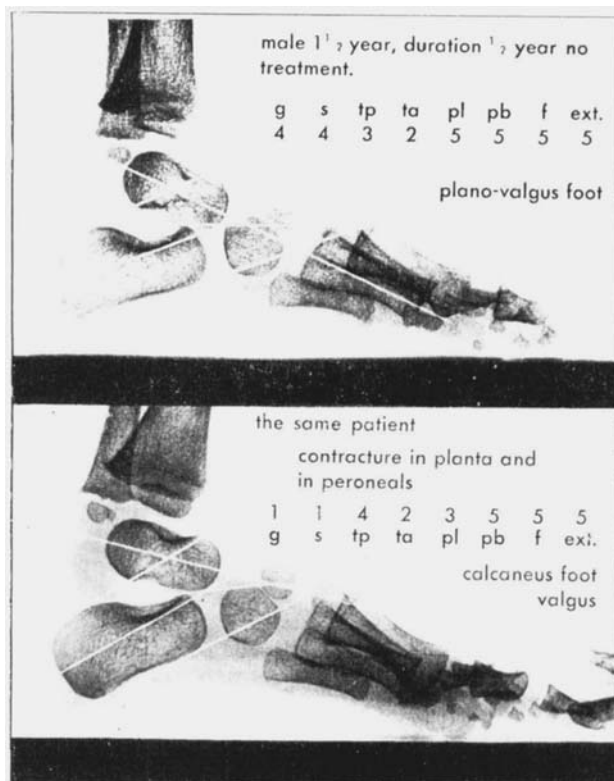


Fig. 10.

M. Age 1½ years at onset, duration 6 months, contracture in planta. No treatment.

changed its position although there was no contracture in the planta. There is contracture in all these cases in the material where the positional change is most pronounced, and it is an important factor in the fixation of the altered position by preventing the reposition of the bones of the foot when it is put under weight.

Contracture medially in the planta, together with contracture in the posterior tibial and in the calf, contributes to the varus position in Group I, whereas contracture in the peroneals has a bearing on the valgus position in Group II.

*Contracture in the calf* causes the equinus position of the foot in 6 cases of Group I, and among these six the atrophy of the calcanean tubercle is least pronounced. Contracture in the calf is also present in Group I C combined with slight tubercle atrophy, and among the 12 cases of Group IV where there is no change in the shape and position of the calcaneum. Thus it looks as if contracture in the calf may

counteract atrophy of the calcanean tubercle and perhaps also elevation of the anterior extremity of the calcaneum.

*Patient's age at onset, and duration of paralysis.* The age limit for changes in the position of the calcaneum seems to be the 13th year, there being only one case in the series (Table 4, Group III no. 1262) with elevation of the anterior extremity of the calcaneum where the disease occurred after that age—a woman who was 31 years old at onset.

There are several examples to show that the change in the position of the calcaneum may begin during the first four to six months. Fig. 10 is of such a case. This was a boy of 18 months at the onset, and six months later incipient calcanean foot was found, with elevation of the anterior extremity of the calcaneum, but no change in the shape of the bone. There is contracture in the planta and the case was not given physical treatment.

Among patients of the same age group, it is found that the change in the position of the calcaneum is greatest when the paralysis has been present for a long time. On the basis of 24 cases followed up with several X-ray examinations over a period of up to two years, it would seem that the change develops most within the first two years after onset of the disease, and in 16 cases, where there had been paralysis in the leg and foot for more than three years, progression had ceased within an observation period of up to two years.

It is probable that the earlier the paralysis begins, the more pronounced will the positional change become, but this point cannot be elucidated by the material.

Besides the two groups I and II employed in the discussion of the possible causes of the changes in the shape and position of the calcaneum, the material comprises a number of other cases, where there is a change in the shape of the calcaneum but no elevation of its anterior end (Table 4, Groups I A, B and C). In I A the lateral balance of the foot is retained, in I B the foot is in valgus and in I C in plano-valgus, these positional changes conforming to the paralysis combinations. Finally, Group IV contains 12 cases in which the calcaneum is normal, whereas the patients' ages would have led one to expect a change in the shape or the position of the bone.

In most of these cases the fact that there is merely a change in the shape of the calcaneum, or that shape and position are normal, may possibly be explained by the disease having occurred late in life, by slight paralysis of *m. triceps* or by total paralysis of all muscles in leg and foot, by the absence of contracture in the planta or by contracture in the calf.

## CONCLUSION

When poliomyelitis occurs before the age of 10-13 and causes paralysis in the triceps and in one or more of the other muscles of the leg and foot, the shape or position of the calcaneum will usually alter. The more pronounced degrees of these changes appear clinically in the picture of the paralytic calcanean foot.

In the opinion of some authors, this deformity is exclusively a result of a change in the position of the calcaneum, while others hold that it is exclusively or mainly due to a change in the shape of that bone.

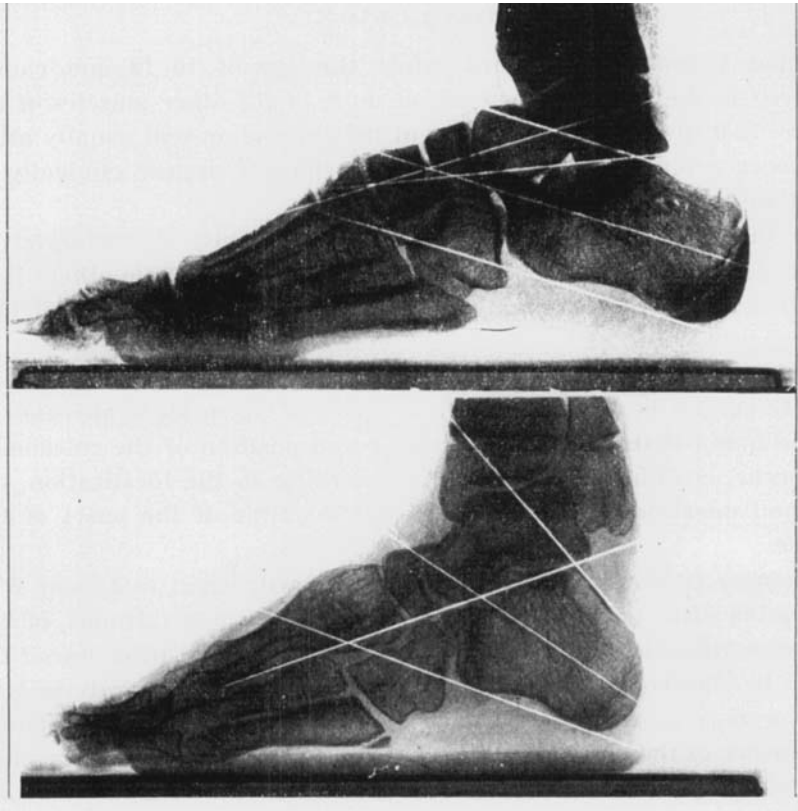
This sharp division in the interpretation of the nature of the deformity cannot be maintained. In a series of adequate dimensions it will be found that change in the shape and position of the calcaneum will occur, combined or separately, according to the localization, degree and duration of the paralysis and the time of the onset of the disease.

*Changes in the shape of the calcaneum* will begin to appear 6 to 12 months after paralysis has begun, in the form of atrophy of the calcanean tubercle, and this atrophy will be the more pronounced the earlier in childhood the disease occurs, the longer the paralysis lasts and the more paralytic is the triceps. Later on there may be plantar prominence of the posterior process of the calcaneum, and antero-plantar atrophy may also set in, especially if the calcaneum has also changed in position.

The isolated morphological change occurs among cases with pronounced paralysis in all the muscles of the leg. It is frequently combined with the varus position of the foot, on account of the paralysis in the peroneals, which leads to preponderance of the posterior and anterior tibials. In the pronounced degrees the deformity is manifested clinically as a *calcaneo-varus foot* (Fig. 11).

In most of the cases with this type there is no elevation of the anterior extremity of the calcaneum, which might be due to the muscular pull of the highly paralytic muscles of leg and planta being insufficient, even when supported by contracture in the planta, to elevate the anterior extremity of the calcaneum because, owing to the varus position of the foot, that extremity is now under the head of the talus, which counteracts elevation.

*Change in the position of the calcaneum* is manifested by elevation of its anterior extremity and may begin to occur within the first 6 months after the onset of the disease. The change of position is conditioned by fairly pronounced paralysis in the triceps and by the



*Fig. 11.*

Group I D, No. 8883 (Table 4, page 230).

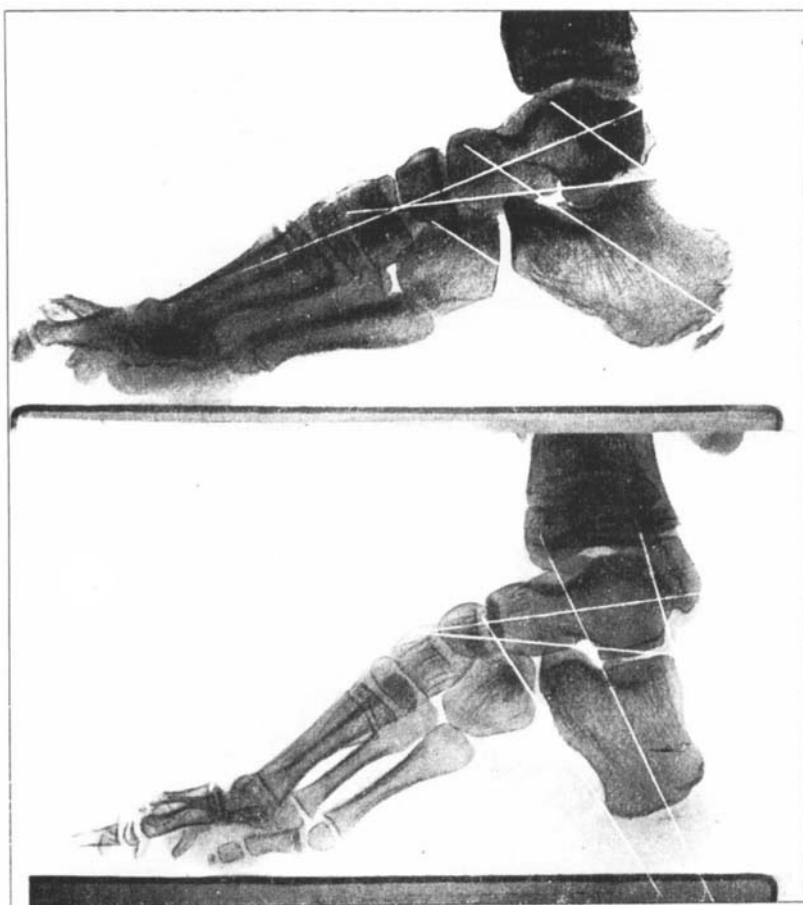
Above: normal foot (right): Böhler angle 24°.

Below: Calcaneo-varus foot (left) with pronounced tubercle atrophy and slight plantar prominence of posterior calcanean process. Böhler angle 69°.

exertion of a lifting action by the other leg muscles on the anterior extremity of the calcaneum, and by the traction of the plantar muscles on the posterior process of the calcaneum. Contracture in the planta is an important contributory factor, because it counteracts reposition of the foot bones under body weight. The change of position will be the more pronounced the longer the paralysis has lasted, and undoubtedly also the earlier the disease sets in.

An important factor in the development of this positional change is the valgus position of the hind-foot, which will permit the anterior part of the calcaneum to glide up on the lateral aspect of the head of the talus, with no positional change of the talus itself.

In pronounced degrees of positional changes, usually combined



*Fig. 12.*

Group II, No. 7240 (Table 4, page 232).

Above: normal foot (left), calcanean articular plane angle  $6^{\circ}$ . Böhler angle  $43^{\circ}$ . Talus angle  $22^{\circ}$ .

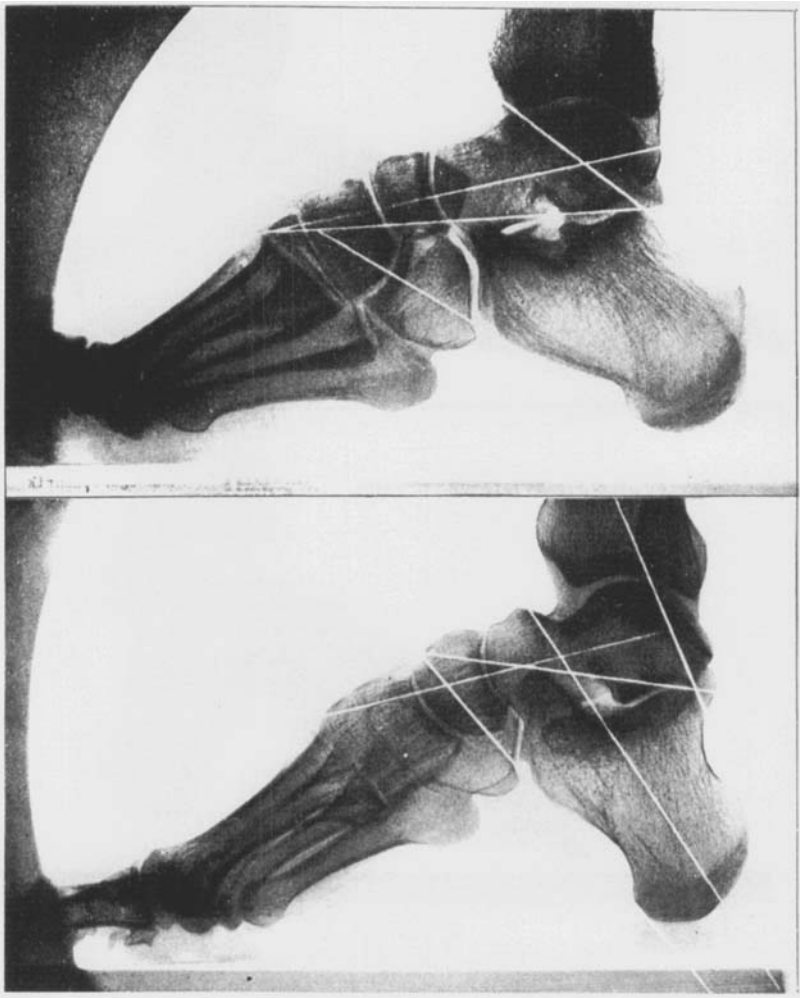
Below: neutral calcanean foot (right) with elevation of anterior extremity of calcaneum, atrophy of calcanean tubercle and antero-plantar atrophy.

Calcanean articular plane angle  $-3^{\circ}$ . Böhler angle  $70^{\circ}$ . Talus angle  $8^{\circ}$  (talus flexed dorsally).

with a change of the shape of the calcaneum, the deformity of the foot will be manifested in two types.

*The paralytic, neutral calcanean foot* (Fig. 12) develops when the triceps is paralytic although the other muscles of leg and planta are intact or partly so, and when the lateral balance of the foot is good.

The positional change of the calcaneum is due to the elevating action on the arch caused by the peroneals and by the posterior and



*Fig. 13.*

Group II, No. 6015 (Table 4, page 232).

Above: Normal foot (left). Calcanean articular plane angle  $4^{\circ}$ . Böhler angle  $40^{\circ}$ . Calcanean plantar surface angle  $30^{\circ}$ . Talus angle  $13^{\circ}$ .

Below: Calcaneo-valgus foot (right), anterior extremity of calcaneum elevated up on lateral aspect of head of talus. Atrophy of calcanean tubercle and plantar prominence of posterior calcanean process. No change in talus position.

Calcanean articular plane angle  $-7^{\circ}$ . Böhler angle  $60^{\circ}$ . Calcanean plantar surface angle  $49^{\circ} - 11^{\circ} = 38^{\circ}$ . Talus angle  $14^{\circ}$ .

anterior tibials combined with the traction of the plantar muscles on the posterior process of the calcaneum. In severe degrees the talus is flexed dorsally.

In the *paralytic calcaneo-valgus foot* (Fig. 13), which has the

highest numerical frequency in the series, the anterior extremity of the calcaneum is elevated on to the lateral aspect of the head of the talus, and it is only in the most aggravated degrees that the talus changes its position too. This form occurs when the triceps and the posterior and anterior fibials are paralytic, but the peroneals and the muscles in the planta are wholly or partly intact. In a few cases in the series it occurs too when there is total paralysis of the crural muscles and only the plantar muscles to the lateral toes are intact (Fig. 9).

*Prognostics.* The very close connection shown between the various combinations of paralysis and the development of the different types of the calcanean foot indicates that the course can be prognosticated early. Other factors of importance to prognosis are the time of the onset of the disease and the development of contractures, especially in the planta.

*Treatment* seems to be of importance to the course of the disease, as the most pronounced degrees of the deformity were found among the cases that had not been treated, and the lowest degrees of calcaneum changes among the treated feet.

With physical therapy, in which the foot is kept soft and the muscle function is exercised, it is scarcely possible to avoid atrophy of the calcanean tubercle. It is probable that change in the position of the calcaneum can be counteracted if the development of fixating contractures in the planta is countered immediately at the beginning of the paralysis, if necessary by manipulation of the foot under narcosis. Conversely it would seem that contracture in the calf may counteract atrophy of the calcanean tubercle and perhaps also elevation of the anterior extremity of the calcaneum.

In the brace treatment, much importance has earlier been attached to avoiding the varus deformity. Bearing the present series in mind there seems to be no doubt that the valgus position should also be avoided, and that the correct bracing position must be with the foot in the neutral position.

Early operative treatment is indicated when physical treatment and bracing prove to be insufficient for keeping the foot in the normal position. In operative treatment, transplantation of peroneal tendons should be of advantage in order to counteract a change in the position of the calcaneum, if the peroneals are intact.

The author wishes to express his most sincere thanks to Dr. Svend Clemmesen, for his stimulating advice and valuable help during the investigations.

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## SUMMARY

As the result of X-ray examinations under uniform conditions involving 167 feet of patients with paralysis of m. triceps and in most cases of one or more muscles of the lower leg and foot, the author shows that the deformity in the paralytic calcanean foot is caused by a change—either combined or separate—in the shape and position of the calcaneum.

The change consists of atrophy of tuber calcanei, the plantar prominence of proc. post. calcanei and atrophy antero-plantarly of the calcaneum. The change of position appears in the form of an elevation of the anterior end of the calcaneum, sometimes combined with the posterior part of the foot in the valgus position, and in the pronounced cases is accompanied by dorsal flexion of the talus.

The authors then explains the connection between the change of form and position of the calcaneum and the localization of the paralysis in the muscles of the leg and foot, the degree and duration of the paralysis, age of the patient at the onset of the disease and the occurrence of contractures, and finally the connection between the varus and valgus positions and the development of the paralytic calcanean foot.

## RESUME

Le résultat d'un examen aux rayons X pratiqué dans des conditions analogues, de 167 pieds de malades souffrant de paralysie du triceps et dans la plupart des cas d'un ou de plusieurs muscles du bas de la jambe ou du pied, les auteurs montrent que la déformité dans le pied calcanéen paralytique est causée par une modification — combinée ou associée — de la forme et de la position du calcanéum.

Cette modification consiste en une atrophie de la tubérosité calcanéenne, la prominence plantaire proc-post calcanei et l'atrophie antéro-plantaire du calcanéum. La modification de la position apparaît sous forme d'une élévation de la partie antérieure du pied dans la position valgus, et est accompagnée dans les cas marqués d'une flexion dorsale de l'astragale.

L'auteur explique le rapport entre le changement de forme et de position du calcanéum et la localisation de la paralysie dans les muscles de la jambe et du pied, le degré et la durée de la paralysie, l'âge du malade au moment où la maladie se manifeste et l'apparition de contractures et enfin la relation entre la position varus et valgus et le développement du pied calcanéen paralytique.

## ZUSAMMENFASSUNG

Die unter gleichen Bedingungen vorgenommene Röntgenuntersuchung von 167 Füßen von Patienten mit Lähmung des m. triceps und, in der Mehrzahl der Fälle, auch eines oder mehrerer Muskeln des Unterschenkels und Fusses ergab, dass die Deformität bei paralytischem des calcaneus durch eine Veränderung-entweder kombiniert oder isoliert – in der Form und Stellung des Calcaneus hervorgerufen wird.

Die Veränderung besteht in einer Atrophie des Tuberculi calcanei, der plantaren Prominenz des Proc. post. calcanei und einer antero-plantaren Atrophie des Calcaneus. Die Stellungsveränderung macht sich in einer Aufrichtung des vorderen Teiles des Fusses in Valgusstellung geltend und ist in ausgesprochenen Fällen von Dorsalflexion des Talus begleitet.

Der Verfasser erklärt fernerhin den Zusammenhang zwischen der Veränderung in der Form und Stellung des Calcaneus und der Lokalisation, dem Grade und der Dauer der Lähmung in den Muskeln des Unterschenkels und Fusses, den Alter des Patientens am Beginn der Erkrankung und dem Auftreten von Kontrakturen, und schliesslich den Zusammenhang zwischen Valgus und Varusstellung und der Entwicklung des Lähmungs-Hakenfusses.

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