THE MECHANICS OF THE HIND FOOT IN CLUB FOOT
AS DEMONSTRATED RADIOGRAPHICALLY

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This investigation was undertaken to test a hypothesis that excision-arthrodesis of the ankle is preferable to wedge tarsectomy in the treatment of certain relapsed club feet. If the ankle joint is so damaged that its sagittal movement is less than that of the tarsal joints it would be preferable to sacrifice the ankle, thus preserving the rotatory movement of the tarsal joints in addition to their greater contribution to flexion and extension. Because necropsy material was not available, radiographic studies were used to determine the percentage of the total sagittal movement of the foot that occurred at the ankle joint.

METHOD AND MATERIALS

Radiographic studies were made of fifty-seven club feet in thirty-seven patients aged from four months to twenty years. The patients were chosen at random from clinics, and included all stages from the fully corrected to the highly resistant club foot. Seventeen normal feet were used as controls.

For each foot standard lateral radiographs were made. With the flexed knee, the lateral malleolus and the fifth metatarsal on the cassette, the third metatarsal head was grasped between thumb and forefinger, and radiographs were taken with the forefoot first pushed
plantarwards and then pushed dorsally as shown in Figure 1. No attempt was made to rotate the forefoot. Most of the radiographs were supervised by the author, the remainder by the same trained nurse.

Tracings were made of the tibia, talus, calcaneus and third metatarsal bone, and the tracings were superimposed as in Figure 2. The third metatarsal bone was chosen to represent the forefoot because, being central, it was unaffected by supination. The axis of the talus, of the sole and of the calcaneus were then drawn in. The axis of the tibia was added in order to measure the angles of equinus of the three foot constituents. The arcs traversed by the talus, the sole and the calcaneus could thus be measured. The angle between the axes of the talus and calcaneus (talo-calcaneal angle) could also be studied in dorsiflexion and in equinus, as in Figure 5.

![Figure 2](image)

**Fig. 2**

Superimposed tracings of a club foot in forced dorsiflexion and forced equinus, showing the components of the sagittal movement that are measured. The axis of the talus joins the mid-points of the head and body. The axis of the sole is a line joining the calcaneal tubercles and the head of the third metatarsal. The axis of the calcaneus is the line joining the calcaneal tubercles and the anterior plantar convexity of the calcaneus.

**FINDINGS**

**Arcs traversed by talus and sole**—Under one year of age the excursion of the talus in the normal ankle joint was found to average 76 degrees; over one year it averaged 60 degrees. The average values for club feet were 40 degrees under one year and 30 degrees over one year. The arc varied directly with the severity of the deformity as measured by equinus on the lateral radiographs. The number of manipulations given previously had no constant effect on the arc; in amenable feet the arc was increased by stretching of soft tissues, whereas in rigid feet the arc was diminished by bony distortion.

Figure 3 shows how the gliding action of the talus in the ankle mortise is progressively lost in severe grades of club foot, being replaced by a slight book-like opening and closing of the anterior part of the joint. As might be expected, this was most marked in cases of flat-topped talus consequent to treatment.
Subtraction of the talar arc from the sole arc gives the contribution of the tarsal joints. Table I shows that the ankle of the average club foot, regardless of flat-topped talus, contributes more than half the total sagittal movement of the foot. However, in a few isolated adults (Fig. 4), the contribution of the ankle was half or less, having apparently been reduced by osteoarthritis.

The normal gliding antero-posterior movement of the talus in the ankle joint is replaced by book-like opening in the front of the joint in severe club foot. The black and plain circles represent the same fixed point on the talus in each diagram.

The talo-calcaneal angle—The sole line in Figures 1 and 2 is a false index of correction: crossing the anterior end of the calcaneus, it demonstrates that a rocker-bottom foot has been created. The true index of correction is the calcaneal line, which in normal feet in forced dorsiflexion was found to vary between 40 degrees and 56 degrees above a right angle.

In this series the equinus of the calcaneus in club foot was always far worse than that of the talus and of the sole, and after manipulative treatment it was found to lag far behind the apparent clinical correction. In forced dorsiflexion the normal calcaneal line averaged 44 degrees above the horizontal; in the average club foot it was 2 degrees below the horizontal—that is 46 degrees of equinus.

The talo-calcaneal angle—This is the angle of intersection between the talar and calcaneal lines as shown in Figure 5. The following features of this angle emerged: 1) It varied between 35 degrees and 50 degrees in the normal foot. In club foot it was less than 35 degrees, and in newborn infants with club foot it might even be a negative quantity (Fig. 6). 2) In the normal foot the talo-calcaneal angle is increased by forced dorsiflexion as the plantar fascia pulls the mobile heel forwards and upwards. In the club foot the already small angle is often decreased still further by forced dorsiflexion; the calcaneus is held in equinus by the tight posterior tissues.

The talo-calcaneal angle in lateral radiographs with the foot in forced dorsiflexion is, therefore, a valuable guide to the amount of correction obtained. A figure of 35 degrees should theoretically be obtained, but in the present series this occurred only three times.
Comparison of the talo-calcaneal angle on lateral radiographs of a normal foot and a club foot. Note the low angle between the two bones in the club foot, and that this is lowest in dorsiflexion.

A scattergram showing the talo-calcaneal angles in forced dorsiflexion of all the feet studied. Practically all the normal feet have an angle between 40 and 56 degrees whereas in the club feet it is always below 35 degrees. The lowest values in club feet were recorded in early infancy; there is a slight but definite rise with advancing years. Among fully corrected club feet the angle was nearly normal. (The four fully corrected feet do not represent the incidence of successful treatment because such feet were rarely seen at clinics and so escaped the series.)
DISCUSSION

This study demonstrated that in children of all ages with club foot the ankle usually contributed more to sagittal movement than did the tarsal joints (Table 1). It follows that the average neglected club foot in adolescents is best treated by wedge tarsectomy or triple arthrodesis. It is exceptional, as in Figure 4, that the ankle should contribute only half, or less, of the total range. In such a case Commerell (1963) suggested that wedge excision of the severely damaged ankle had more to offer than wedge tarsectomy, because it preserved the greater component of flexion-extension movement. Wedge excision of the ankle has the further advantages that medial rotation of the foot can also be corrected and that the very important rotatory movement of the subtaloid joint is preserved. After triple arthrodesis, rotatory movement gradually occurs in the ankle with the development of a ball-and-socket shaped joint, and osteoarthritis is a frequent result. These advantages may well outweigh those of wedge tarsectomy even in feet in which the ankle contributes more than half of the total sagittal movement of the sole.

In a suro-plantar radiograph (Fig. 7) the talus normally points medially in relation to the calcaneus at an angle of 20 to 40 degrees. This talo-calcaneal angle is diminished in club foot, and may approach zero. Attention was drawn to this mal-alignment by Wisbrun (1932) and confirmed by Kite (1935) and Kandel (1952). As inversion in the club foot is corrected the talar head no longer lies on top of the calcaneus, but projects medially, producing the normal talo-calcaneal angle. Only when this has happened can equinus be corrected.

It might be expected that after correction of the talo-calcaneal angle as seen in a suro-plantar radiograph, manipulative correction of the equinus would restore the angle between talus and calcaneus as seen in a lateral radiograph. The present series shows that this is not achieved in a high percentage of cases. A study of the radiographs published by Kite (1935) shows that in most of his feet graded as "corrected," correction has taken place largely at the mid-tarsal joint. That the feet are slightly rocker-bottomed is shown by the sole line passing through the calcaneo-cuboid joint instead of below it. The equinus of the calcaneus on the talus has been only partly corrected, both in Kite’s series and in the present series. Three possible explanations for this are offered: 1) Inversion may not have been corrected fully before starting on the equinus deformity. The anterior part of the calcaneus, still lying directly under the talar head, cannot be pushed upwards past it, as it must if the normal

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**TABLE 1**

**AVERAGE CONTRIBUTIONS TO SAGITTAL MOVEMENT MADE BY THE ANKLE AND THE TARSAL JOINTS IN NORMAL AND CLUB FEET**

<table>
<thead>
<tr>
<th></th>
<th>Talar arc</th>
<th>Sole arc</th>
<th>Percentage of range contributed by ankle</th>
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</thead>
<tbody>
<tr>
<td>Normal (17 feet)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talipes equino varus. Under 12 years (47 feet)</td>
<td>30</td>
<td>46</td>
<td>65</td>
</tr>
<tr>
<td>Talipes equino varus. Over 12 years (10 feet)</td>
<td>29</td>
<td>36</td>
<td>80</td>
</tr>
</tbody>
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**Fig. 7**

Tracings of suro-plantar radiographs of a normal foot and a club foot showing the dispositions of calcaneus and talus. In the club foot there is a decrease in the talo-calcaneal angle and a posterior shift of the calcaneus (after Davis and Hatt 1955).
relationship is to be achieved. 2) Upward pressure under the calcaneo-cuboid region is inefficient because it is too close to the ankle fulcrum, and pressure sustained in plaster is more likely to crush the talus than to correct the equinus of the heel. The longer leverage offered by pressure under the forefoot is forbidden for fear of producing a rocker-bottomed foot; and it is impossible to grip the heel efficiently to pull it down. Morita's (1962) method involving a pin through the calcaneus attached to a sole plate, has a strong theoretical appeal on these grounds. 3) Tight posterior and talo-calcaneal structures prevent the heel from being drawn forwards and upwards under the talus by the plantar fascia, as happens in the normal foot during forced dorsiflexion. Lengthening of the teno calcaneus and posterior capsulotomy are of little help.

The conclusion to be drawn is that, after full correction of the inversion deformity, attention must next be directed not at getting the forefoot up, but at getting the heel down. The heel, having been the key to correction of varus, remains the key to the correction of equinus. It cannot be efficiently gripped in plaster, so in the intractable club foot there may well be a place for transfixion of the calcaneus by a pin to obtain downward pressure by exerting counter-pressure against the leg. This method is now being subjected to clinical trial.

SUMMARY
1. Lateral radiographs of fifty-seven club feet and seventeen normal feet were taken in forced flexion and forced extension. On these, the arcs traversed by the talus, the sole and the calcaneus were measured, as was the talo-calcaneal angle.
2. It was found that the ankle in club feet usually contributed more than half of the total sagittal movement of the foot.
3. Occasional cases were encountered in which the ankle was so damaged that it contributed only half or less than half of this movement. In such cases wedge excision of the ankle joint is theoretically justified in preference to wedge tarsectomy.
4. The talo-calcaneal angle is much reduced in club foot, and this element of deformity is extremely resistant to manipulative treatment. The reasons for this and a possible method of treatment are discussed.

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REFERENCES