Kawasaki Med. J. Vol. 3: No. 3, 167-179, 1977

ROTATION DEFORMITY OF THE TIBIA DUE TO MECHANICAL PROPERTIES OF THE SUBTALAR JOINT AXIS IN CLUB FOOT

Akira SHIMAZU, Hideo MATSUDA, Yoshiki YAMANO and Kazuyuki NAKAJIMA

Department of Orthopedic Surgery,
Kawaski Medical School,
Kurashiki, 701-01, Japan

Mikio OKAJIMA

Department of Orthopedic Surgery,
Osaka City University Medical School

Accepted for Publication on Feb. 22, 1977

Abstract

The foot in the standing position usually makes combined motions of the three joint axes, i. e. the subtalar joint, the talocrural joint and the calcaneo-contact joint (between lateral margin of the foot and the floor). Correlation between the abnormalities of the directions of these axes and the elements of the deformity of the congenital club foot were studied.

From the fact that the abnormal inclination of the subtalar joint axis is likely to cause the abnormal rotating movement of the tibita, the relation formula concerned was obtained by the projection drawing:

The inversion is:

$$\angle\theta = \tan^{-1}\frac{\tan\beta}{\cos\alpha'}\times\sin\ (\alpha^\circ - n^\circ)$$

The eversion is:

$$\angle\theta = \tan^{-1}\ (\tan\beta\times\sin\ n^\circ + \tan\alpha\times\cos\ n^\circ)$$

The lateral rotation deformity of the tibia is influenced, not only by the residual adduction deformity, but also by the inversion deformity. The lateral rotatory position of the tibia is related to the flat-top talus, but it is difficult for the flat-top talus to appear in the pes equinus or decreased inclination angle of the subtalar joint axis on the sagittal plane.

INTRODUCTION

Follow-up studies of cases of congenital club foot revealed the fact that there were a number of patients whose foot deformities were almost

島津　晃，松田英雄，山野慶樹，中嶋一行，岡島幹雄

completely corrected in appearance, but still had the toe-in gait. On the lateral roentgengram of the foot, it was observed that the leg was externally rotated and the talus was flattened at the top. These facts were already pointed out by Ferguson, Wynne-Davies,[1] Swann.[2] The authors[3] also reported through the results of the follow-up study that there was considerable correlation between the outward rotation of the tibia and the flat-top talus.

The authors have observed the following, in all of the dissection specimens of the club foot; the adduction (inward flexion), the inner rotation, and the downward flexion deformity of the neck of the talus, and the mal-alignment of the tarsal bones. The toe-in gait found at the follow-up study was attributed to the residual deformity of the talus, but it was not always easy to detect this deformity solely from appearances. One of the reasons for this spurious appearance is that the foot consists of many tarsal bones which have these respective joints; and the deformities of these bones are concealed within the range of mobility of these joints. The mechanical properties of an interreaction between the subtalar joint and the talo-crural joint play a role of the universal joint, whereby making the plantigrade gait possible, even when the deformities of bones are left uncorrected. The purpose of the study is to analyze the club foot deformity, by viewing the locus of the motion of the joints having the abnormal joint axes in club foot. Our model experiments showed the fact that the toe-in gait was caused not only by the pes adductus but also by the residual inverted deformity of the subtalar joint.

1. Studies based on the foot model

As shown in Fig. 1, the authors made a model demonstrating the motion of the foot. The model has a total of three joint axes; namely, two joints corresponding to a talo-crural joint and a subtalar joint, and another a calcaneo-contact joint.[4] The last joint movement is concerned in the inversion or eversion at outer or inner margin of the foot. The normal subtalar joint axis is inclined 42° from the anterior upper to the posterior lower direction in the sagittal plane, and is inclined 16° from the anterior inner to the posterior outer direction in the horizontal plane. Because there are pathological positions of the ioint axis in the club foot, the axial positions of the three joints of the model are made changeable. By photographing this model from three directions—sagittally, perpendicularly and laterally—its motion locus is plotted. The outer marginal axis of the model is placed parallel to the sagittal axis.

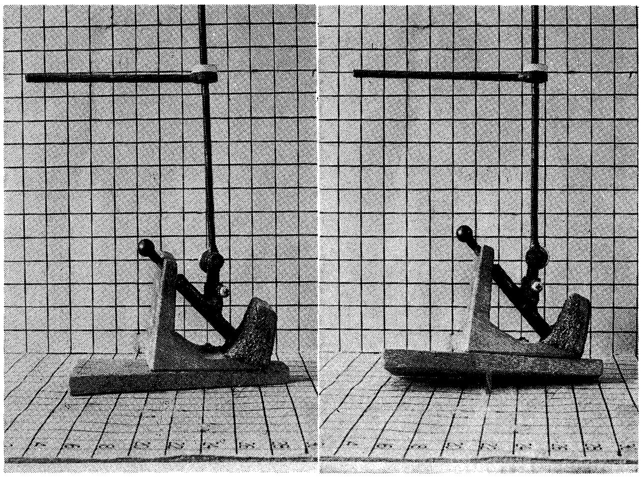


Fig. 1. Foot model

Projection of the subtalar joint axis in the inversion is shown as an elevation with outward shift in the frontal plane, therefore, the fanshape figure is drawn around the projected point of the outer marginal axis (i. e. calcaneo-contact joint axis). In the sagittal plane, the alteration of the inclination of the subtalar axis is shown in the up and down movement of the anterior part. Throughout this movement, the dorsal or plantar flexion occur in the talo-crural joint to hold the leg in the erect position. In the horizontal plane, the subtalar joint axis is projected as a triangular figure keeping an apex on the calcaneo-contact joint axis. The tibia changes its direction in accordance with the degree of movement in the subtalar joint axis, therefore, the rotation angle of the tibia can be estimated from the angle of this horizontal projection. However, at times, under the necessary condition of holding the tibia in upright position, the inversion becomes impossible, depending upon the combination of the stereocrossing angles of the three joint axes. As to the combination mentioned above, eighteen different types are shown in Table 1.

The types marked with × are the cases in which the upright position is impossible. Five types marked with ○ do not cause the rotation of the tibia. Eight types marked with ◎ will cause the inversion together with the outward rotation of the tibia. There are cases in which the rotation occurs, where one axis runs obliquely to another. This axis will well correspond to the subtalar joint axis in human beings. Under certain conditions, any ankle movement is a combination of multiple

Table I

The combination of the stereocrossing of the talo-crural (A), subtalar (B) and calcaneo-contact (C) joint axis

B in horizontal plane

	$B \parallel C$	$B \perp C$	$B \not+ C$
$A \parallel B$	○	×	×
$A \perp B$	○	○	◎
$A \not+ B$	○	◎	◎

B in non-horizontal plane

$B \parallel C$	$B \perp C$	$B \not+ C$
×	×	×
◎	○	◎
◎	◎	◎

$\parallel$: parallel
$\perp$: right angle crossing
$\not+$: slant crossing

× : no upright standing position
○ : no rotation of the tibia
◎ : rotation of the tibia

joint axes and the center of motion of these joints moves according to the change of the joint axes.

These are cases wherein the loci is plotted by the multiple axes, and the relation between inversion and the outer rotation of the tibia, and relation between inversion and the dorsal flexion of the talo-crural joint are not under a simple arithmetical relation. Accordingly, this relation formula was drawn from the stereodrawing.

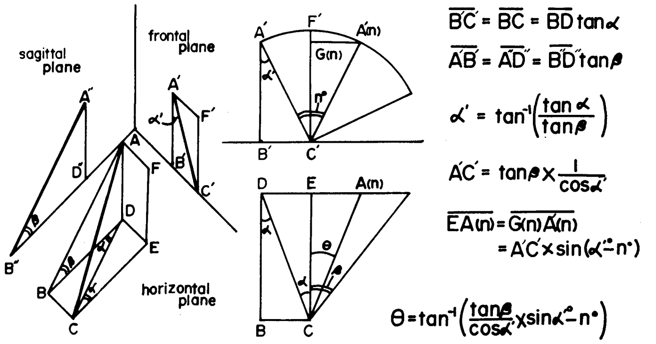
2. *Relation formulae of the motion loci derived from the projection drawings.*

The outer rotation of the tibia can be sought from the horizontal plane projection drawing of the subtalar joint axis in the inversion of the foot. Various different drawings can be made in proportion to the changes of the relative positions of the axes of the calcaneo-contact and subtalar joints, but the relation formulae obtained will be the same. Consequently, as shown in Fig. 2, the drawing in which the calcaneo-contact joint axis is set parallel to the sagittal axis, is adopted as the representative example.

$\alpha°$ indicates the projected inclination angle of the subtalar joint axis on the horizontal plane; $\beta°$ shows the projected inclination angle on the sagittal plane; and n° represents an arbitrary inversion angle. A segment of line AC, having $\alpha°$ from the sagittal and $\beta°$ from the horizontal planes, on the quadrilateral plane ▭ ABCF of a right-angled triangular prism having a $\beta°$ elevation angle, turns out to be the subtalar joint axis, on which the tibia stands upright.

Fig 2

motion loci of the subtalar joint axis in the inversion



The horizontal plane projection of this prism is ▭ DBCE; the frontal plane, projection is shown by ▭ A′B′C′F′; the sagittal plane projection is expressed by △A″B″D″; and $\overline{DC}$, $\overline{A'C'}$ and $\overline{A''B''}$ are respectively corresponding to the subtalar joint axes. The clockwise motion of △A′B′C′ of the frontal plane projection centering at C′ denotes the inversion movement; by the inversion movement, A′ will move around on the arc which makes $\overline{A'C'}$ as a radius; $\overline{B'C'}$ is equal to $\overline{BC}$; $\overline{A'B'}$ is equal to A″D″ on the sagittal plane; hence comes $\overline{B''D''} \times \tan\beta$. From this, $\overline{A'C'}$ can be obtained by the Pythagorean theorem or the trigometry, and by $\overline{A'C'} = \tan\beta \times \frac{1}{\cos\alpha'}$. In this case $\alpha' = \tan^{-1}\left(\frac{\tan\alpha}{\tan\beta}\right)$.

Now, in the inversion movement by n° the distance from A′(n) point to $\overline{F'C'}$, namely $\overline{G(n)A'(n)}$ becomes $\overline{A'C'} \times \sin(\alpha'-n)$, which agrees with $\overline{A(n)E}$ of the horizontal plane projection. At this point, if ∠ECA(n) is obtained, it will become the rotation angle of the subtalar joint axis and the lateral rotation of the tibia. The required relation formula of the angle θ is:

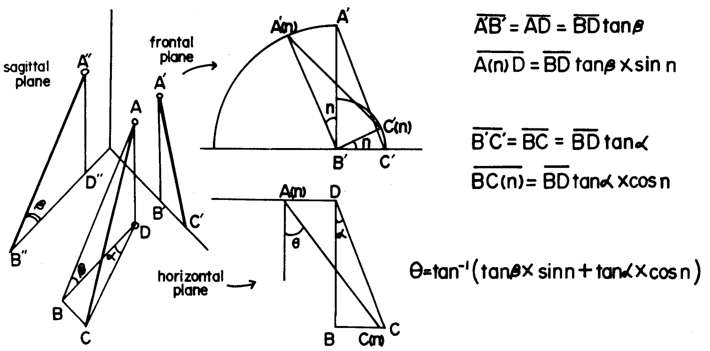
$$\angle\theta = \tan^{-1}\left\{\frac{\tan\beta}{\cos\alpha'} \times \sin(\alpha'^{\circ} - n^{\circ})\right\}$$

Also, the changes of $\angle\beta$ of the sagittal plane projection, which are caused by the inversion, can be obtained in the similar manner, as mentioned above. The relation formula for this is:

$$\angle\beta(n) = \tan^{-1}\left\{\frac{\tan\beta}{\cos\alpha'} \times \sin(\alpha'^{\circ} - n^{\circ})\right\}$$

With regard to the eversion, it is the motion centering at $\overline{BD}$ in the horizontal plane, and the motion centering at B′ in the frontal plane as shown in Fig. 3. A′(n) point would plot an arc which has $\overline{A'B'}$ as its

Fig 3
motion loci of the subtalar joint axis in the eversion



radius, and C′(n) point may plot an arc which has $\overline{B'C'}$ as its radius.

In the eversion by n°, the distance from A′(n) point to $\overline{A'B'}$, and the distance from C′(n) point to $\overline{A'B'}$ can be obtained respectively by:

$\overline{A(n)D} = \overline{BD}\ \tan\beta^\circ \quad \times \sin n^\circ$

$\overline{BC(n)} = \overline{BD}\ \tan\alpha^\circ \quad \times \cos n^\circ$

$\tan^{-1}$ which is the sum of both formulae mentioned above becomes the rotation angle of the subtalar joint axis and the medial rotation angle of the tibia. Therefore, the required relation formula of angle θ is shown in the following.

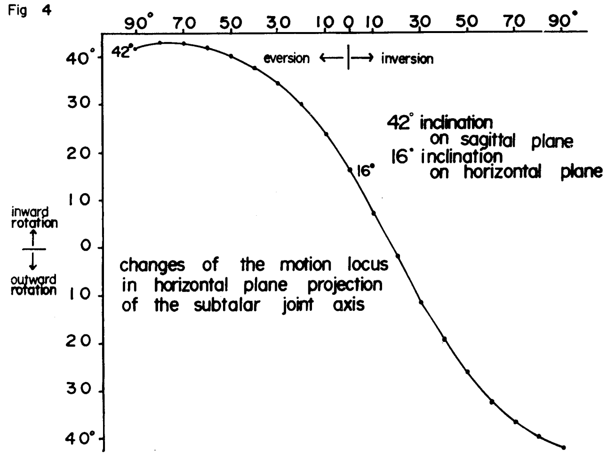
$$\angle\theta = \tan^{-1}(\tan\beta \times \sin n^\circ + \tan\alpha \times \cos n^\circ)$$

3. *Changes of the motion locus plotted by the deviation of the subtalar joint axis.*

In the upright position of a normal foot the locus of the subtalar joint axis in inversion or in eversion shows lateral rotation or medial rotation of the tibia respectively in the horizontal plane projection as shown in Fig. 4. When these rotational changes are checked at each 10° of inversion or eversion, the greatest degree of the rotation angle is 9.4° which is measured in the range from 10° of eversion to 20° of inversion. From 50° of inversion to 10° of eversion the values are still as high as over 7°. In the sagittal plane projection, it indicates a gentle uphill curve with apex at 20° of inversion, but its difference is about 1°. When inversion exceeds 30°, the curve is reversed and flattens.

As a result, the talo-crural joint will be slightly dorsiflexed at the beginning of inversion and then, the plantal flexion will take place.

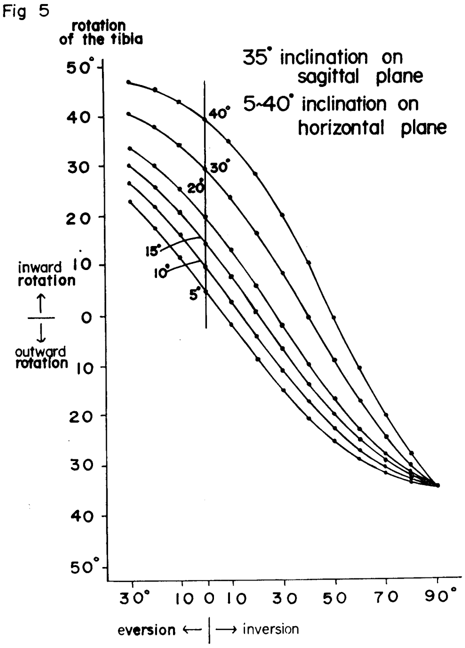
Fig 4



As a club foot, an assumption was made, in which the subtalar joint axis on the horizontal plane projection was set from 0°$\sim$55° and on the sagittal plane projection from 30°$\sim$55°. Then, under the respective combinations, the loci were plotted in various inversions.

Fig. 5 and 6 show the cases having the sagittal plane inclination

Fig 5



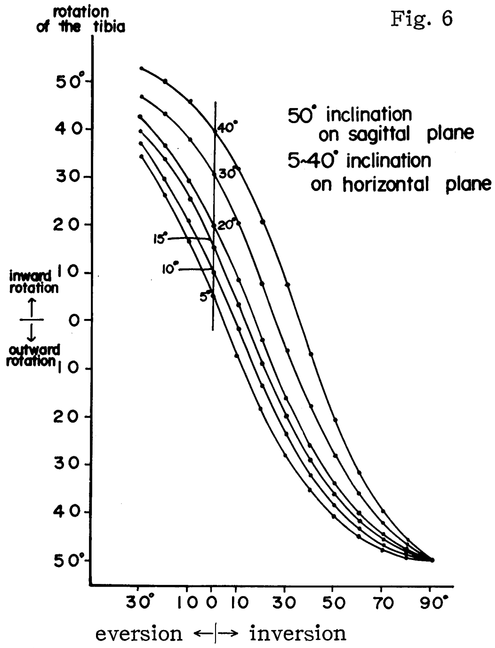


Fig. 6

angle of 35° and 50°. In these cases, they plot nearly the same curves as that of a case for the normal inclination of 42°, but when the horizontal plane inclination angle is 0°, no rotations of the tibia are observed. Namely, the more the horizontal plane inclination angle is increased, or the greater the adduction deformity, the greater the rotation of the tibia becomes.

Tables 2 and 3 show the degree of lateral rotation of the subtalar

TABLE 2.

Outward rotation of the subtalar joint axis in inversion 20°

incl. on h.-plane / incl. on s.-plane	5°	10°	15°	20°	30°	40°
30°	11.5	11.8	12	11.8	11	9.3
35°	13.5	14.2	14.3	14.2	13.2	11.2
40°	14.5	17	17	16.8	15.7	13.3
42°	17.7	18.1	18.2	18.1	16.8	14.3
45°	19.5	20	20.1	20	18.7	16
50°	23	23.7	23.8	23.7	22.2	19.2

TABLE 3.

Outward rotation of the subtalar joint axis in inversion 40°

incl. on h.-plane / incl. on s.-plane	5°	10°	15°	20°	30°	40°
30°	21.8	23.3	24.5	25.3	26	24.8
35°	26	27.5	28.7	29.7	30.5	29
40°	26.7	32	33.5	34.5	35.5	34.2
42°	32.1	33.9	35.5	36.7	37.7	36.3
45°	35	37	38.7	40	41.3	40
50°	40	42.3	43.8	46	47.8	47

TABLE 4.

Changes of the motion locus in sagittal plane projection of the subtalar joint axis

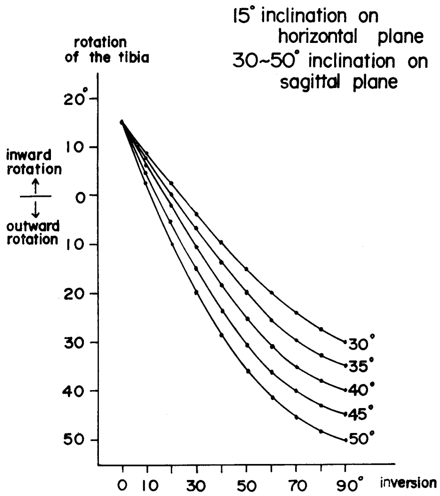
incl. on h.-plane / incl. on s.-plane	10°	15°	20°	30°	40°
35°	0.8 −2.0	1.4 0.3	2.0 2.6	3.3 7.2	4.9 12.1
42°	0.5 −3.2	1.0 −1.2	1.5 0.7	2.6 4.7	3.9 8.9
50°	0.3 −4.3	0.5 −2.7	1.0 −1.1	1.9 2.1	2.9 5.4

(in inversion 10° and 40°)

joint axis, i.e. the tibia in 20° and 40° of inversion. At 20° of inversion, the lateral rotation is greatest at the horizontal plane inclination angle of 15°, while at 40° of inversion, the value is largest at the horizontal plane inclination angle at 30°. Namely, this fact shows that the adduction deformity has its influence on the lateral rotation of the tibia and furthermore, if the varus deformity, especially the greater one, is added, the lateral rotation of the tibia will become even greater.

On the other hand, when the sagittal plane inclination angle is large, the lateral rotation of the tibia will become increased. This relation is shown more clearly in Fig. 7. The case with the pes cavus will be in-

Fig 7



fluenced more by the inversion deformity, but in the pes equinus, the same influence to the rotation of the tibia will become less.

In the second place, when changes of the inclination angle on the sagittal plane projection are examined, it becomes evident that the larger the horizontal plane inclination angle becomes, viz. the more noticeable the inversion deformity becomes, and the more the inclination angles are increased. As a result. the dorsal flexion in the talo-crural joint is required. It became evident also that the less the sagittal plane inclination angle becomes, the greater the change of the sagittal plane projection angle by the rotation would become (pes equinus), and the larger the inclination angle is, the less change would result (pes cavus), because they are in inverse relations.

4. Discussion

Through the analysis of the clinical cases as well as the dissections, the authors observed the lateral rotation of the tibia in the residual club foot deformity, and we have already published the data on the relation between the lateral rotation of the tibia and the flat-top talus, in which it was clarified that the laterally projected image of the trochlea would decrease its roundness or its height by the lateral rotation of the tibia or by the abduction and inversion of the talus; regarding the radius of the trochlea, 2 cm radius in lateral projection became 4 cm by 10° of abduction of the foot, 4.5 cm by 20°, 5.3 cm by 30° and more than 6 cm by 40°.[3)]

This lateral rotation of the tibia is derived from the combined rotational movement of the subtalar and calcaneo-contact joints. It was clarified quantitatively in this paper that greater lateral rotation was produced in the club foot case where the subtalar joint axis was more adducted and held in the residual varus than the normal.

When the elements of deformity of the club foot are analysed from the aspect of the deviation of the joint axis:

1. The varus deformity of the heel is an inversion deformity of the subtalar joint, and it accompanies the plantal flexion of the talo-crural joint. In the upright position, the foot is inverted on the calcaneo-contact joint, therefore inclination of the subtalar joint axis on the sagittal projection is increased and the dorsal flexion of the talo-crural joint occurs in a certain range of inversion.
2. The adduction deformity in the forefoot is a medial deviation of the subtalar joint axis in the horizontal plane.
3. The pes equinus is a plantal flexion deformity in the talo-crural joint, and it accompanies a decrease of the inclination angle of the subtalar joint axis in the sagittal plane.
4. The pes cavus is produced in some by the iatrogenic factors, and the case is found when the forefoot is everted leaving the inversion of the hind foot as it is. In such a case, the increase of the inclination of the subtalar joint axis takes place.
5. The rocker foot deformity is designated as the marked decrease of inclination, and the lateral deviation of the subtalar joint axis.
6. The mechanism of the development of the flat-top talus is generally understood by mistake as follows: Namely, the flatness is caused by the forcible manipulation of the pes equinus, whereby the upper surface of the trochlea is compressed.

What is called " Nutcracker treatment of club foot " was conceived.[8] However, if the pes equinus is corrected leaving hind-foot varus and forefoot adduction as they are, the lateral deviation of the talus and the lateral rotation of the tibia easily take place, resulting in apparent flattening of the trochlea. On the other hand, if the pes equinus is uncorrected, roentgenographic change of the dome of the trochlea will be minimal because of the lower inclination of the subtalar joint axis even if the varus and adduction deformities are still present. After all, their appearances depend on the variety of the joint axis, viz. on the correction of the pes equinus. From the fact that there are little sclerosis and necrotic changes of the trochlea on roentgenogram, it is difficult to consider that the pressure is responsible for the deformity. However, the examination regarding the case in which the heel is not in contact with the floor and its weight bearing portion shifts to the metatarsal head, will be left for the future studies.

Up to the present, many authors have pointed out the lateral rotation of the tibia in the club foot, but review of the literature revealed no biomechanical and quantitative analysis of the correlation among the lateral rotation of the tibia, the varus and the adduction deformity. This might be due to the fact that the scholars did not pay attention to the medial deviation (adduction) and the internal rotation of the neck of the talus which were already present in the club foot in the fetal period. Instead, they regarded the contracture of the soft tissues and the abnormal alignment of the tarsal bones seriously. Accordingly, they have not taken the abnormal joint axis into their considerations, as far as there was an apparent improvement of the deformity. Swann[2] and others performed a medial rotation osteotomy of the tibia for the laterotorsio tibiae secondary to the forcible manipulation against a contracted tibialis posterior tendon.[9] Tendon lengthening of the tibialis posterior has an important role in the early treatment, but when there is a bony deformity of the talus, it is inadequate to cure the foot deformity by this procedure alone. All of them are lacking the considerations to the abnormal joint axis. The foot is composed of the multiple joints and its motion simulates to an universal joint motion. Being concealed within this universal joint movement of the foot, it is difficult to measure correctly the subtalar joint motion indipendently and to point out the abnormal direction of the axis. Perhaps, with this very difficulty, it was delayed to analyze the lateral rotation of the tibia in asociation with the inversion in the upright position.

The toe-in gait in the club foot is an expression of the lateral rotation of the tibia in the dynamic condition of locomotion, which is also related to the abnormal positioning of the subtalar joint axis.

REFERENCES

1) Wynne-Davies, R.: Talipes equinovarus, a review of 84 cases after completion of treatment. J. Bone & Joint Surg., 46-B: 464-476, 1964
2) Swann, M. G., Lloid-Roberts, G. C. and Catterall, A.: The anatomy of uncorrected club foot. A study of rotation deformity. J. Bone & Joint Surg., 51-B: 263-269, 1969
3) Shimazu, A. et al.: The residual deformity of the congenital club foot. Iryo, 26: 778-785, 1972 (Japanese)
4) Rose, G. K.: Correction of the pronated foot. J. Bone & Joint Surg., 44-B: 642-647, 1962
5) Hicks, J. H.: The mechanics of the foot. J. Anat. London, 87: 345-357, 1953
6) Shimazu, A. et al.: The pathological anatomy of the congenital club foot. Seikeigeka, 24: 803-810, 1973 (Japanese)
7) Irani, R. and Sherman, M. S.: The pathological anatomy of club foot. J. Bone & Joint Surg., 45-A: 45-52, 1963
8) Keim, H. A. and Ritchie, G. W.: "Nutcracker" treatment of club foot. J. A. M. A., 189: 613-615, 1964
9) Lloid-Roberts. G. C., Swann, M. and Catterall, A.: Medial rotational osteotomy for severe residual deformity in club foot. A preliminary report on a new method of treatment, J. Bone & Joint Strg., 56-B: 37-43, 1974
10) Susuda, K. et al.: Toe in gait of congenital club foot. Clin. Orthop. Surg., 9: 720-724, 1974 (Jpanese)