Treatment of congenital clubfoot and study of calf muscle histopathology

Li Zhao, Wei Lei, Long-Shun Xu and Yao-Tian Huang

Xi'an, China

Background: **Congenital clubfoot (talipes equinovarus) is a common condition in pediatric orthopedic surgery. However, there is still disagreement over the best surgical approaches and age indications.**

Methods: **Surgical treatment was carried out by early operation, achieving dynamic muscle balance in 926 congenital clubfeet of 644 patients who had been followed up for 6 months to 33 years, with reference to unsuccessful treatment because of failure to achieve dynamic muscle balance. Muscle biopsy specimens were taken from the calf muscles in patients with congenital clubfoot for histochemical studies.**

Results: **Excellent and good results were achieved in 90.9% of the involved feet. Histochemical studies of calf muscle biopsy specimens showed hypertrophy and predominance of type I fibres, grouping of fibre types, and loss of fibre direction in the posteromedial muscles, but no evidence of active denervation and degeneration in the involved calf muscles.**

Conclusions: **Our findings support the theory of muscle imbalance in the etiology of congenital clubfoot. It is advocated that surgical treatment of congenital clubfoot be carried out immediately after 6 months of age by an operation achieving dynamic muscle balance for the maintenance of satisfactory correction and the 3rd cuneiform be the most appropriate site for a new insertion of transferred tendon.**

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Key words: **congenital clubfoot; clinical follow-up; histopathology**

Author Affiliations: Department of Orthopedic Surgery, Xijing Hospital, the Fourth Military Medical University, Xi'an 710032 (Zhao L, Lei W and Huang YT); Department of Orthopedic Surgery, Tangdu Hospital, Xi'an 710038 (Xu LS), China

Corresponding Author: Li Zhao, MD, Department of Orthopedic Surgery, Xijing Hospital, the Fourth Military Medical University, Xi'an 710032, China (Tel: 86-29-83375284; Fax: 86-29-83244986; Email: zhaoli@fmmu.edu.cn)

Introduction

Congenital clubfoot (talipes equinovarus) is common in pediatric orthopedic practice, yet the etiology and pathoanatomy of this condition remain obscure despite numerous research. For all clubfoot deformities which do not respond to initial conservative treatment, surgery is indicated.[1-6] The aim of clubfoot treatment is to obtain a functional, pain-free, plantigrade foot, with good mobility, but without calluses and the use of modified shoes. It has been recognized that surgy should be performed after the failure of conservative treatment to prevent secondary bony changes in clubfoot. However, various surgical regimens have been introduced because of different understandings of the etiology and pathoanatomy of clubfoot.[7-12] There is still disagreement on the best surgical approaches for this deformity as well as the age at which the operation should be undertaken.

Clinical, electrophysiological and histopathological studies of calf muscles have shown that muscle imbalance is an etiological factor for congenital clubfoot.[13-16] Hence, dynamic muscle balance should be obtained for the correction of clubfoot and the alleviation of muscle imbalance. Nevertheless, this regimen has not been widely accepted in clinical practice because the procedure for muscle balance is undertaken only in patients with resistant or relapsed clubfoot.[1,11,17-19] In this paper, we describe our protocol for the treatment of 1373 congenital clubfeet of 970 patients at Xijing Hospital by early operation for dynamic muscle balance, with reference to the analysis of unsuccessful surgical treatment and the studies of calf muscle biopsies from clubfoot.

Methods

The protocol remained consistant in the treatment of congenital clubfoot at the PLA Institute of Orthopedics, Xijing Hospital, Xi'an during the period of 1957-1993. Because clubfoot includes equines and inversion and adduction of the forefoot assumedly owing to congenital muscle imbalance, which subsequently lead to pathological changes of the soft tissues, bones and joints, surgical attempt was made to correct all the components of the deformity and to establish dynamic muscle balance for the maintenance of the correction during the operation.

Treatment protocol

Before operation, accurate manipulation was required to correct adduction or inversion of the forefoot under the supervision of a consultant surgeon, or at least to make the foot more pliable. Equinus, however, was not corrected this way for fear of any damage to the arch of the foot.

Surgery was undertaken at 3 months of age when proper manipulation failed to correct clubfoot. The procedures were as follows.

Equinus versus dorsiflexion

Equinus was corrected by Achilles tendon lengthening through percutaneous tenotomy in a patient younger than 1.5 years or through White or Z-plasty in a patient older than 1.5 years, with or without severe equinus; but the posterior tibial neurovascular bundle was released. Posterior capsulotomy of the talocalcaneal and ankle joints and even lengthening of the posterior tibia, flexor hallucis longus and flexor digiti longus were indicated for more severe equinus. When equinus was not pronounced or had been corrected by preoperative manipulations, the anterior (or posterior) tibialis was transferred laterally for dynamic muscle balance, and percutaneous Achilles tenotomy or Achilles tendon lengthening was not performed as well.

Adduction of the forefoot

Preoperatively, the forefoot was gently manipulated in the patient under the supervision of a consultant surgeon. Medial soft tissue release was not necessarily indicated for mild adduction of the forefoot in a younger patient, except for more severe and/or rigid adduction which needs medial capsulotomy for talonavicular, navicular-cuneiform and cuneiform-metatarsal joints. In an older patient with secondary bony changes, wedge resection of the cuboid along with medial soft tissue release was indicated.

Inversion versus eversion

Before operation, gentle manipulation was undertaken in the patient to correct inversion under the supervision of a consultant surgeon. In a younger patient with mild inversion, dynamic muscle balance was maintained after the correction by lateral transfer of the anterior (or posterior) tibialis once the inversion was corrected. In an older patient with rigid inversion, Achilles tendon lengthening combined with posterior soft tissue release and partial transection of the deltoid ligament was performed before the anterior (or posterior) tibialis was transferred laterally for dynamic muscle balance. The tendon was transferred laterally and re-inserted to the 3rd cuneiform. When the anterior tibialis muscle was poorly-developed or absent, the posterior tibialis was employed instead.

Internal torsion of the leg

No surgical procedure was required to correct the internal torsion of the leg because it was corrected by itself after clubfoot was corrected. Gait instruction, however, was helpful.

After operation, a long leg plaster cast was applied with the knee in 90° of flexion. The ankle was in 0-5° of dorsiflexion, and the forefoot in the position of mild abduction. The cast was replaced by a well-molded one while the stitches were removed 2 weeks after the operation. The cast was worn for 6 weeks before the wire, which was used for re-insertion of the transferred tendon, was removed, and the patient was allowed to make functional exercises. It was unnecessary to protect the foot with any splint or modified shoes.

Follow-up study

Following the protocol (Table 1), 970 patients, aged 3 months to 12 years, with 1373 congenital clubfeet were treated at the PLA Institute of Orthopaedics, Xijing Hospital from 1957 to 1993. In this group, 644 patients (503 males and 141 females) with 926 (67.4%) involved feet were followed up at an average of 5 years and 4 months (range, 6 months to 32 years and 8 months) after the operation. The left foot was involved in 164 patients, the right in 194, and both feet were involved in 286 patients. The patients were followed up regularly after the operation. The criteria for evaluating the results were similar to those of Laaveg and Ponseti.[18] Radiological assessment was carried out using anteroposterior and lateral radiographs.[20] Four hundred and ten feet (44.3%) were followed up for 1-5 years, and 407 (43.9%) for more than 5 years after the operation (Table 1).

Of the 970 patients with 1373 congenital clubfeet, 89 patients with 111 affected feet underwent reoperation for the relapse of the deformity or eversion. Sixty-six patients (58 males and 8 females) had the relapsed in 87 clubfeet after the first operation. In this group, 29 patients (38 affected feet) underwent primary surgery at Xijing Hospital and 37 patients (49 affected feet) at other hospitals. The age at primary surgery ranged from 2 months to 12 years with an average of 2 years and 4 months. The age at reoperation ranged from 10 months to 15 years with an average of 4 years and 1 month.

Table 1. Duration of follow-up

Duration (y)	No. of feet	Percentage (%)
0.5-1.0	109	11.8
0.5-2.0	102	11.0
0.5-5.0	308	33.3
0.5-10.0	332	35.8
0.5-20.0	50	5.4
0.5-33.0	25	2.7
Total	926	100.0

Twenty-three patients (14 males and 9 females) developed eversion in 24 feet after the first operation. In this group, 22 patients underwent primary surgery for 23 clubfeet at Xijing Hospital and one patient with one clubfoot at another hospital. The age at primary surgery ranged from 4 months to 6 years and 7 months with an average of 1 year and 8 months. The age at reoperation ranged from 9 months to 7 years and 10 months with an average of 5 years and 2 months. Eversion presented at 12 months on average (range, 1 month to 3 years) after primary surgery.

Histochemical studies of calf muscles

Seventy-one biopsy specimens were taken from the anterior tibialis, posterior tibialis, peronei and gastrocnemius of 13 patients with congenital clubfoot for histochemical studies (10 males and 3 females). Control biopsies were performed at the corresponding muscles in 5 patients younger than 4 years old without neuromuscular disease. Twenty-one biopsy specimens were taken from the anterior tibialis, 21 from the peronei, 12 from the posterior tibialis, and 9 from the gastrocnemius. The age of the patients at operation for clubfoot ranged from 4 months to 4 years with an average of 1 year and 4 months. Unilateral foot was involved in 8 patients and bilateral feet in 5.

Specimen preparations

The biopsy specimens sized $5 \times 3 \times 3$ mm^3, taken from the muscle belly 2-4 cm proximal to the musculotendinous junction, was attached to a wood block marking the orientation of muscle fibres, and preserved subsequently in liquid nitrogen (−196℃). The temperature of the specimen was restored to −20℃ in a cryo-microtome before cutting into 10 μm cross- and 25 μm longitudinal sections, stained for histochemical studies to identify the types of muscle fibres and neuro-muscular junction (NMJ).

Stainings and measurements

With the computer-assisted image processing-analyzing system at the PLA Institute of Orthopaedics, Xijing Hospital, the density of staining was quantitated by the value of grey degree.

Adenosine triphosphatase (ATPase) staining of muscle fibres was made according to Sarnat.[21] The morphology and distribution of muscle fibres were observed and recorded under a light microscope, and the images were stored in the microcomputer. The values of grey degree and equivalent diameter were obtained through the random measurements of 200 muscle fibres in each specimen, which was incubated at a pH of 4.4, 4.7 or 10.2 respectively and stained with ATPase. The types and subtypes of muscle fibres were identified and outlined according to the difference in grey degree and characteristic staining under different conditions. The ratio of each type or subtype of muscle fibres was thus calculated to all the types of muscle fibres.

Acridine orange staining of muscle fibres was performed according to Perl and Little.[22] Fluorescence microscope was employed to identify the denervated muscle fibres and the muscle fibres being re-innervated and showing vivid orange fluorescence. The normal muscle stained with acridine orange showed a little yellow-green fluorescence, which was uniform across all the viewing areas of each section.

NMJ acetycholinesterase (AchE) staining was made according to Kolle.[23] The morphology of NMJ was observed and recorded under a light microscope and the images were stored in the microcomputer. The values of grey degree of NMJ area and the background were obtained respectively. The mean value of grey degree at the NMJ area was obtained across all the viewing areas of each section. The mean value of background grey degree was obtained through the random measurements across ten viewing areas of each section. The mean value of grey degree of the background was substracted from that of NMJ area to obtain the real value of NMJ grey degree. The content of AchE was quantitated in the area of NMJ according to the real value of grey degree by AchE staining. The smaller the value of NMJ grey degree, the higher the content of AchE.

Statistical analysis

The result of treatment was graded with the sum of scoring points. Statistical significance was obtained by the chi-square test. The data of the histochemical study were analyzed using analysis of variance followed by Student's t test. A P value of less than 0.05 was considered statistically significant.

Results

Clinical outcome

In 926 feet of the 644 patients who underwent the operation for dynamic muscle balance and were followed up, 586 were rated as excellent, 256 as good, 55 as fair, and 29 as poor . The excellent and good results were

Table 2. Clinical outcome in correlation with main surgical procedures

Main procedures	No. of feet	Excellent	Good	Fair	Poor	Percentage (%) (Excellent & Good)
Transfer of ant. tibialis only	77	46	22	7	2	88.3
Percutaneous Achilles tenotomy + transfer of ant. tibialis	383	264	94	16	9	93.5
Percutaneous Achilles tenotomy + medial release + transfer of ant. tibialis	135	93	35	5	2	94.8
Achilles tendon lengthening + transfer of ant. tibialis	104	66	26	8	4	88.6
Achilles tendon lengthening + posteromedial release + transfer of ant. tibialis	201	109	73	18	10	86.7
Transfer of post. tibialis + other procedures	17	8	6	1	2	82.4
Total	926	586	256	55	29	90.9

Table 3. Clinical outcome in correlation with age at operation

Age at operation (y)	No. of feet	Excellent	Good	Fair	Poor	Percentage (%) (Excellent & Good)
-0.5	160	112	34	7	7	91.3
-1.5	366	249	97	15	5	94.5
-5.0	263	149	82	23	9	87.8
-10.0	124	71	37	9	7	87.1
-12.0	13	5	6	1	1	84.6
Total	926	586	256	55	29	90.9

Table 4. Clinical outcome in correlation with severity of clubfoot

Deformity severity	No. of feet	Excellent	Good	Fair	Poor	Percentage (%) (Excellent & Good)
Mild	210	145	48	12	5	91.9
Moderate	554	346	161	29	18	91.5
Severe	162	95	47	14	6	87.7
Total	926	586	256	55	29	90.9

obtained in 90.9% of the involved feet. The operation (Table 2) was performed particularly according to the severity of deformity and the pathological changes in each involvement. Equinus, inversion and adduction of the forefoot were corrected satisfactorily in above 90% of the involved feet. The clinical outcome was correlated with the age of a patient at operation (Table 3), and the preoperative severity of the deformity (Table 4). The operative result of mild and moderate clubfoot was better than that of severe clubfoot. The best outcome was achieved when the patient underwent the operation at the age of 6 months to 1.5 years; as a result, excellent and good results were seen in 94.5% of the involved feet. The outcome of surgical treatment at the age of younger than 6 months was not as good as that at the age of between 6 months and 1.5 years. Radiologically, marked deformation of the talar and navicular bones was observed after the primary surgery was undertaken at an age younger than 6 months. The possiblity of excellent and good surgical results was reduced gradually with the age older than 1.5 years. In this group, one involved foot developed a wound infection and 5 feet had skin necrosis at the incision postoperatively. No evidence of nerve or arterial injury was seen.

Causes for reoperation

Of the 970 patients with 1373 congenital clubfeet who underwent operation for dynamic muscle balance at Xijing Hospital, 51 had a relapsed or secondary deformity in 61 affected feet that needed reoperation. In addition, 38 patients with 50 affected feet had had an operation at other hospitals before they underwent the operation according to the protocol of Xijing Hospital. In total, 89 patients with 111 affected feet underwent reoperation for the relapsed clubfoot or eversion after the primary operation at Xijing Hospital.

The relapsed clubfoot was mainly due to the procedure for soft tissue release and the failure to establish dynamic muscle balance (Table 5). Thirty-eight feet of 32 patients who underwent reoperation for the relapsed deformity were followed up for 4 years and 11 months on average (range, 6 months to 12 years and 5 months). Excellent and good surgical results were achieved in 60.5% of the involved feet.

Eversion was mainly due to the inadequate procedures of tendon transfer and percutaneous Achilles tenotomy (Table 6). The site of the transferred tendon re-insertion was radiologically verified and documented in 46 involved feet at the time of follow-up. The occurrence of eversion was correlated with the site of tendon re-insertion and the surgical procedure of medial release (Table 7). Fourteen feet of the 13 patients who underwent reoperation for secondary eversion were followed up for 5 years and 5 months on average (range, 6 months to 11 years and 6 months). Excellent and good surgical results were achieved in 50% of the involved feet.

Table 5. Causes of relapsed clubfoot

Main causes	Xj hospital*	Other hospitals**	Total
Transferred tendon			
Poor development of muscle	8	1	9
Lower tension	9	4	13
Inadequate insertion (more to the proximal and medial of the dorsum of foot)	3	10	13
Detachment from insertion	15	2	17
Indirect route	1	–	1
Soft tissue release only	2	32	34
Total	38	49	87

*: number of the clubfeet treated in Xijing Hospital; **: number of the clubfeet treated in other Hospitals.

Table 6. Causes of secondary eversion

Main causes	Xj hospital*	Other hospitals**	Total
Transferred tendon			
Inadequate insertion (more to the lateral and distal of the dorsum of foot)	12	1	13
Over-tensioned and inserted more to the lateral and distal of the dorsum of foot	6	–	6
Over-tensioned	4	–	4
Percutaneous Achilles tenotomy more to the proximal of the tendon	1	–	1
Total	23	1	24

*: number of the clubfeet treated in Xijing hospital; **: number of the clubfeet treated in other hospitals.

Histochemical findings

The patients who underwent muscle biopsies were not infected or had nerve injury after the operation. Satisfactory results were achieved in all the patients with clubfoot, who were subjected to muscle biopsies.

Typing and subtyping of muscle fibres

The types and subtypes of muscle fibres were identified and categorized according to the grey degree and staining under different conditions of pH. The types of muscle fibres were incorporated with each other from the normal muscles of the anterior tibialis, posterior tibialis, peronei and gastrocnemius. The normal muscle consisted of the muscle fibres of type I (40%), type IIa (35%), type Iib (15%), and type Iic (5%), which were arranged in a perfect order. The muscle fibres of the same type had the similar diameters, which were different from each other by less than 12%. There was no evidence of grouping of the fibre types. The muscle fibres from the anterior tibialis and peroneal muscles of patients with clubfoot essentially had a normal appearance. There was no evidence of loss of fibre direction and grouping of fibre types. The ratio of type I to type II fibres from the anterior tibialis and peroneal muscles of patients with clubfoot was the same as that of the control ($P > 0.05$). The abnormality of muscle fibres was revealed in the muscles of the posterior tibialis and gastrocnemius from the patients with clubfoot, which were characterized by the hypertrophy and predominance of type I fibres, atrophy of type IIa fibres ($P < 0.01$) and loss of fibre direction. The muscle fibres of the same types had the diameters different from each other by more than 12%. No significant difference was observed in the mean values of fibre diameter between all the types of muscle fibres except for grouping of fibre types from the muscles of the posterior tibialis and gastrocnemius in some patients with clubfoot, indicating a change in histochemical typing of muscle fibres. The rate of muscle fibres of each type or subtype was calculated (Table 8).

Table 7. Occurrence of secondary eversion in correlation with site of tendon re-insertion and medial release procedure

Site of tendon insertion	Nil release*	Medial release*	Total
3rd cuneiform	– (26)	– (6)	– (32)
Cuboid	6 (8)	4 (6)	10 (14)
Total	6 (34)	4 (12)	10 (46)

*: number of the feet with secondary eversion.
Number in the parenthesis is the number of the clubfeet undergoing the procedure of tendon transfer to the corresponding site as indicated by the row caption.

Acridine orange fluorescence

Acridine orange staining revealed that the control muscles presented one uniform shade of light fluorescence of yellow-green colour under a fluorescence microscope. The control muscle fibres had the similar diameters and the arrangement in a perfect order, but the control muscles showed no fluorescence of orange-yellow colour, indicating no evidence of active denervation and degeneration in the calf muscles of patients with clubfoot.

AchE contents in the area of NMJ

The control NMJ was circular or elliptic in shape, with clear margin and enclosure of fine and yellow-brown granulated precipitate of cupric ferrohydride. No significant difference was observed morphologically in NMJ of the muscles between patients with clubfoot and con-

Table 8. The rates of fibre types and subtypes

Muscles	No. of specimens	Ratio (mean ± SD) (%)			
		I	IIa	IIb	IIc
Ant. tibialis	15	46.0 ±3.8	35.7 ±5.2	12.8 ±2.2	6.4 ±3.1
	6*	44.0 ±3.7	36.3 ±4.9	13.5 ±1.9	5.8 ±1.9
Peronei	15	41.8 ±3.9	37.5 ±6.0	13.5 ±2.6	6.4 ±2.7
	6*	42.3 ±3.5	35.8 ±3.7	15.0 ±0.9	6.5 ±1.0
Post. tibialis	9	54.6 ±6.8	28.4 ±5.6	12.4 ±2.7	4.6 ±3.2
	3*	45.0 ±2.0	34.2 ±2.9	14.0 ±3.0	6.7 ±2.9
Gastrocnemius	14	55.4 ±8.9	26.9 ±6.8	12.4 ±2.6	5.4 ±1.7
	3*	44.0 ±3.0	35.7 ±4.0	13.3 ±2.1	7.0 ±2.0

*: number of the control specimens.

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trols, nor in the real value of grey degree of NMJ ($P > 0.05$). There was no significant difference in the content of AchE in the area of NMJ of the muscles between patients with clubfoot and controls.

Discussion

Muscle imbalance in etiology of congenital clubfoot

A number of studies on the muscles of the leg and foot in congenital clubfoot in terms of embryology, anatomical-physiology, electrophysiology and clinicopathology have suggested that congenital clubfoot is due to muscle imbalance.[13-16] Flinchum[24] found that the peroneal muscle was approximately one half the size of the normal side and the resistance to correction coming from the anterior tibialis in dissection of a premature cadaver. However, whether it is a primary or secondary defect is not clear. A histochemical study on the abductor hallucis, gastrocnemius and peroneal muscles of clubfoot in 60 patients younger than 5 years found hypertrophy and predominance of type I fibres as well as grouping of the fibre types, indicating muscle re-innervation, particularly in the gastrocnemius.[14] These changes were more prominent with the increasing age of a patient.[25] Electron-microscopic changes in the muscles also suggested that clubfoot might have a neurological basis.[14] Minor changes in innervation caused an increase in muscle fibrosis, leading to shortening of the posteromedial muscles.[14,26] To test whether the above changes were caused by preoperative stretching and immobilization, the extrinsic muscles of the foot were sudied in young baboons, in which one leg was splinted in a position of calcaneovalgus for 8, 17 and 25 weeks, respectively. The results showed no histochemical or electron-microscopic abnormalities in the posteromedial or peroneal muscles of either the splinted or control legs.[27] In the histochemical study of the anterior tibialis, posterior tibialis, gastrocnemius and peroneal muscles, which were responsible for the motion of ankle joint, we found hypertrophy and predominance of type I fibres, and grouping of fibre types in the posterior tibialis and gastrocnemius. But no abnormal muscle fibres were observed by stainings of Acridine orange and NMJ AchE. Presumbly, the pathological changes in hypertrophy and predominance of type I fibres and grouping of fibre types were due to the muscle re-innervation which happened to achieve a functional and structural integrity in the muscles denervated during the early developmental phase of intrauterine existence. The type I fibre as a fatigue-tolerant fibre of slow contractibility is rich in chondriosome, sarcoplasmic oxidase and blood supply. The posterior tibialis and gastrocnemius, predominated by type I fibres may predispose the motion of plantar flexion and inversion to a stronger activity. The minor difference in muscle biomechanics, which is due to the histochemical changes in the muscle and has a sustained effect, is supposed to lead to a muscle imbalance of inversion versus eversion as well as plantar flexion versus dorsal flexion. An embryo-pathoanatomical study on the development of foot during intrauterine existence demonstrated that the foot presents a condition of clubfoot within 9 weeks of fetus and develops to a normal foot gradually beyond 11 weeks.[28] Sustained existence of muscle imbalance, which is caused by the histochemical changes in the muscles during the early developmental phase of intrauterine existence, therefore deters the foot from developing in a normal process, and eventually leads to the occurrence of equinus, inversion and adduction of the forefoot.

Garceau and Manning[17] successfully treated relapsed clubfoot by lateral transfer of the anterior tibialis, suggesting that lateral transfer of the anterior tibialis contributes to the correction of clubfoot. However, the procedure for dynamic muscle balance was undertaken for the treatment of relapsed or resistant clubfoot and the site of tendon re-insertion varied.[1,11,17-19] Muscle imbalance was considered the main cause of congenital clubfoot and progressive soft tissue contracture, and bony deformities were secondary to muscle imbalance. Lu et al[9] recommended early operation for dynamic muscle balance. Clubfoot was surgically corrected before the tendon of the anterior (or posterior) tibialis was transferred laterally to the dorsum of foot for a sustained correction. Gentle manipulation was indicated to correct the deformity or at least to make the foot pliable before the procedure was undertaken at 3 months of age. Satisfactory results were obtained in most patients. During the period of 1957-1993, 1373 congenital clubfeet of 970 patients were treated this way at Xijing Hospital.[9] Postoperatively, 926 feet of 644 patients were followed up for 5 years and 4 months on average. Excellent and good results were obtained in 90.9% of the involved feet. Radiological examination showed less skeletal changes of the involved feet. Clinical analysis also showed that relapsed clubfoot and secondary eversion were mainly due to the failure to establish dynamic muscle balance for a sustained correction. The follow-up results and histochemical findings supported the hypothesis that muscle imbalance is an etiological factor for congenital clubfoot.

Recommended protocol for treatment of congenital clubfoot

It is essential to correct clubfoot by complete soft tissue release and even osteotomy before dynamic muscle balance is established. It has been generally agreed that the younger the patient at operation, the smaller the disturbance of foot development while the less severe clubfoot, the better outcome of treatment. Because secondary pathological changes are minimal in a younger patient, the deformity is more readily corrected. However, there are considerable difficulties in localizing the anatomical structure of a small foot rather than plaster cast nursing postoperatively. Yet it has not been well described as to the proper age for early operation and the site of tendon re-insertion for the establishment of dynamic muscle balance. In this study, the age of patients for early operation ranged from 6 months to 1.5 years. This finding is consistent with the age of 1 or 2 years reported by Turco.[1] It is suggested that the operation for dynamic muscle balance should be performed at 6 months or later. The same result could be achieved below 6 months, provided the procedure had been performed very carefully. Hence, excellent and good results were achieved in 86.0% of the involved feet, which underwent an operation full of difficulties. A prerequisite for a better outcome is to correct equinus, inversion and adduction of the forefoot before the establishment of dynamic muscle balance. We noted that the treatment of 77 clubfeet, with mild equinus and failed to undergo percutaneous Achilles tenotomy or Achilles tendon lengthening was not as successful in correction of equinus as in correction of the remaining clubfeet, which underwent percutaneous Achilles tenotomy or Achilles tendon lengthening. This indicates that equinus, as one of the main components of clubfoot, should be corrected surgically. Secondary eversion occurred more likely in the foot which underwent medial capsulotomy of mid-tarsal joints than in the foot which failed to undergo medial capsulotomy of mid-tarsal joints. Hence, the adduction of the forefoot should not be over-corrected. Inversion was corrected and maintained by lateral transfer of the anterior (or posterior) tibialis to establish dynamic muscle balance. The causes of secondary eversion were identified in 24 involved feet of 23 patients. Secondary eversion in one involved foot was due to the improper site, close to the proximal end of the Achilles tendon, at which percutaneous Achilles tenotomy was performed. Secondary eversion in 23 remaining involved feet was due to the inadequate insertion close to the lateral and distal of the dorsum of the foot, and/or over-tension of the transferred tendon. The best outcome was achieved in a group of clubfeet, which had the anterior (or posterior) tibialis transferred to the 3rd cuneiform.

Prevention of relapsed clubfoot and secondary eversion

The deformity of clubfoot relapsed after soft tissue release.[29,30] Taking Turco's approach for an example, reoperation was required in 33.3% of the involved feet.[31] Turco[1] found that the relapsed clubfoot was mainly due to the incomplete soft tissue release during an operation and short-time immobilisation after the operation. Hence, complete soft tissue release should be advocated to correct clubfoot in addition to the use of K-wire internal fixation for a sustained correction, plaster cast for at least 3 months, and splint for a long period after the removal of the plaster cast. These advices are given to prevent relapsed clubfoot, which occurrs after only soft tissue release. It was found in 39.1% of the involved feet which required a reoperation at Xijing Hospital. Relapsed clubfoot in the 34 involved feet which underwent Turco's posteromedial release was due to the failure of K-wire internal fixation during the operation, only 6-week immobilisation by plaster cast, and no splint prescribed after the removal of the plaster cast as well as the failure to undertake a procedure for dynamic muscle balance for a sustained correction. In this group, clubfoot relapsed because the correction could not be maintained. In most involved feet which underwent Turco's posteromedial release in other hospitals and relapsed, satisfactory result was achieved after an operation for deformity correction before dynamic muscle balance was established by lateral transfer of the anterior (or posterior) tibialis.

Our treatment of 1373 congenital clubfeet showed that satisfactory results can be achieved in most involved feet after early operation for the correction of equinus, inversion and adduction of the forefoot before dynamic muscle balance is established for a sustained correction. In our study, equinus was corrected by percutaneous Achilles tenotomy in a patient of below 1.5 years, and by Achilles tendon lengthening in a patient older than 1.5 years. If the correction was not satisfactory, posterior capsulotomy of ankle and talocalcaneal joints was indicated, even along with lengthening of the posterior tibialis, flexor hallucis longus and flexor digiti longus tendons if necessary. The anterior tibialis was transferred laterally to achieve dynamic muscle balance of invertors and evertors for the correction of inversion, as well as of dorsiflexors and plantar flexors for the correction of equinus. The tendon of the posterior tibialis was employed instead in case the anterior tibialis was poorly-developed or absent. In an older patient with moderate or severe deformity, deltoid ligament was partially transected in order to fully correct inversion of the hindfoot while Achilles tendon lengthening and posterior release were performed. In a younger patient with mild adduction of the forefoot, medial release was not required. Medial capsulotomy of talonavicular, navicular-cuneiform and cuneiform-metatarsal joints was indicated in case adduction of the forefoot was evident. Medial release was routinely performed through the incision which was used to expose the insertion of the anterior tibialis. In the minority of older patients with severe adduction of the forefoot and secondary bony changes, wedge resection of the cuboid was required while medial release was performed. K-wire internal fixation was not employed during the operation. Plaster cast was worn only for 6 weeks. Functional exercises were started soon after the removal of plaster cast. The patient had no need to wear any splint or modified shoes. Hence, less financial and psychological commitments were required to the patient and family. Furthermore, dynamic muscle balance was assumed to keep a sustained correction.

Technically, relapsed clubfoot was due to the improper procedures that failed to strictly follow the outlined protocol, because of the tendon transferred and re-inserted to the proximal and medial dorsum of the foot, the tendon transferred through an indirect route, and the transferred tendon loosened. Relapsed clubfoot was due to the improper procedures in 31.1% of the involved feet, which required reoperation at Xijing Hospital. In a patient, relapsed clubfoot was corrected essentially by primary operation, but dynamic muscle balance failed to achieve. The correction of clubfoot was not sustained because the transferred tendon failed to exert a full effect and the power of plantar flexors and invertors was still stronger than that of dorsal flexors and evertors. Conversely, analysis of the causes of relapsed clubfoot suggested that the 3rd cuneiform should be the most appropriate site for a new insertion of the transferred tendon.

Relapsed clubfoot was also due to the slipping of plaster cast and/or detachment of the transferred tendon from the new insertion because of rupture of the wire. This cause was identified in 19.5% of the involved feet which reoperated on at Xijing Hospital. Therefore, much care of plaster cast should be taken to prevent relapsed clubfoot postoperatively. At the same time, 9 relapsed clubfeet (10.3%) were due to failed dynamic muscle balance and/or poorly-developed transferred anterior (or posterior) tibialis. During the first operation, the anterior tibialis was poorly-developed or fibrosed. In this case, dynamic muscle balance failed to achieve because the transferred tendon only exerted an effect of lifting the foot, eventually resulting in relapsed clubfoot. In a patient with poorly-developed anterior tibiallis but well-developed posterior tibialis, the posterior tibialis was transferred laterally for dynamic muscle balance. The very uncommon condition of clubfoot with poor development of the anterior and posterior tibialis awaits further study.

After operation, the patient with clubfoot was followed up at regular intervals for early recognition and treatment of relapsed clubfoot, which otherwise was very difficult to deal with because of atrophy, contracture of calf muscle or even fibrosis and secondary bony changes. At Xijing Hospital, the relapsed clubfoot was reoperated on at the time interval of one year and 9 months on average after the primary operation. Excellent and good results were achieved in 60.5% of the 38 involved feet after reoperation for relapsed clubfoot and were followed up for an average of 4 years and 11 months. It is suggested that better outcome can be achieved provided reoperation is undertaken early.

Operation for secondary eversion was unsuccessful for dynamic muscle balance. A total of 24 feet with secondary eversion in 23 patients were reoperated on at Xijing Hospital. Secondary eversion was due to the inadequate insertion of the transferred tendon to the distal and lateral dorsum of the foot and/or the over-tension of the transferred tendon. These causes were identified in 23 involved feet (95.3%) of 22 patients who were reoperated upon for secondary eversion. Ankle joint is known to have a slanting articular surface. Accordingly, eversion occurs while the foot is dorsiflexed, in turn, inversion is accompanied by a strong plantar flexion of the foot. If the tendon is transferred laterally and re-inserted more adequately to the distal and lateral dorsum of the foot and/or the transferred tendon is overly tensioned, the power of the dorsiflexors and evertors is stronger than that of the plantar flexors and invertors, a new muscle imbalance therefore takes place. In some patients who were operated upon for clubfoot and followed up postoperatively, the power of the peroneal muscle was one of the evertors and graded as 0-II by physical examination preoperatively restored gradually after clubfoot was corrected. This was assumed to lead to or make the muscle imbalance worsened, and eventually secondary eversion presented. In one involved foot, secondary eversion with raised toes was due to the improper site for percutaneous Achilles tenotomy because it was located to the proximal end of the Achilles tendon. Healing and development of the Achilles tendon was deterred once Achilles tenotomy was performed at the improper site close to the proximal end of the Achilles tendon. Thus the power of the plantar flexors was significantly weakened and a new muscle imbalance took place, and even secondary eversion with raised toes presented. It is advised that the transferred tendon should not be inserted to the lateral part of the cuboid or even the base of the 5th metatarsal bone, but the transferred tendon should be preferably inserted to the 3rd cuneiform. Our radiological and biomechanical studies (unpublished) showed evidence to support this protocol of treatment, which is a safe and effective means by which dynamic muscle balance can be achieved.

After operation, the patient was followed up at regular intervals for early recognition and treatment of secondary eversion. It is recommended that secondary eversion be corrected completely through soft tissue release before the tendon is transferred medially and reinserted to the 1st or 2nd cuneiform. In a patient with secondary eversion, raised toes, and loosened Achilles tendon, a procedure should be performed to tighten the Achilles tendon. In our group, excellent and good results were achieved in 50% of the 16 involved feet which underwent reoperation and were followed up for 5 years and 5 months on average. The operation was performed at Xijing Hospital at the interval of 3 years and 6 months on average after the primary operation. A better outcome could be achieved in case secondary eversion was recognized and treated at early stage. During the reoperation for secondary eversion in the 2 involved feet 2 years after the primary operation, the cuneiform was dislocated dorsally by the strong lifting of the re-inserted tendon of the anterior tibialis. The result of treatment was thus affected.

In conclusion, our clinicopathological findings support the theory of muscle imbalance in the etiology of congenital clubfoot, which is also confirmed after early operation for dynamic muscle balance to maintain a correction. The surgical treatment of congenital clubfoot should be carried out after 6 months of age as early as possible, in addition to the correction of clubfoot before the establishment of dynamic muscle balance with the 3rd cuneiform as the most appropriate site for a new insertion of the transferred tendon.

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Original article

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