A CLINICAL CONSIDERATION OF THE METHODS OF EQUALIZING LEG LENGTH *

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IN ALL ages and by all races, inequality of leg length has been regarded as a disgraceful and crippling affliction. The disability resulting from it varies and is directly proportional to the amount of difference in the length of the two limbs. An individual who is otherwise normal can generally compensate for a discrepancy of as much as one inch by tilting the pelvis and walking with one hip higher than the other. When the difference is greater than this, a lift should be inserted under the shoe or an excessive curvature of the spine will be produced and symptoms of strain and fatigue may result. For a discrepancy of two to three inches a cork insert under the shoe is fairly satisfactory. When the shortening exceeds four inches a metal patten must generally be used and in extreme instances a wooden prosthesis constructed after the manner of an artificial limb.

Inequality of leg length often produces a bad psychologic effect, as the raised shoe is conspicuous whether walking or sitting. Every boy or girl demands that something be done to rid him of what is considered to be a badge of ignominy. The cost is also an important factor when one considers the expense of specially built shoes during a lifetime. The elevation of the shoe is apt to increase the instability of the already crippled extremity. Its weight is also objectionable in the case of individuals with partially paralyzed muscles or disabilities of the joints.

TABLE I

COMMON CAUSES OF INEQUALITY OF LEG LENGTH

Conditions	Lengthening	Shortening
Poliomyelitis		–
Chronic bone infections	+	–
Tuberculosis of hip		–
Tuberculosis of knee	+	–
Epiphyseal injuries		–
Congenital dislocations		–
Tumors	+	–
Hemiatrophy		–
Hemihypertrophy	+	
Congenital anomalies	+	–
Malunited fractures		–

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Discrepancy in leg length may be due either to retardation of growth in the short extremity or to overgrowth of the long one. Sometimes the same pathologic condition may cause shortening in one individual and lengthening in another. The more common causes are listed in Table I.

Different ways of dealing with instances of unequal leg length by surgical methods have been devised. They approach the problem from different angles and may be classified as follows:

I. Changing the Rate of Growth:
  (1) Stimulation of growth in the shorter extremity.
    (a) Local stimulation of bone growth.
    (b) Lumbar sympathectomy.
  (2) Retardation of growth in the longer extremity.
    (a) Epiphyseal arrest.

II. Surgical Reconstruction:
  (1) Bone lengthening of the shorter extremity.
  (2) Bone shortening of the longer extremity.

Although considerable pressure is often brought to bear upon the surgeon to correct inequality of leg length, he should never permit sentimental reasons to overcome his surgical judgment. An elevated shoe often affords the best solution of the problem. Careful observation of a patient's gait with a raised shoe should always precede any decision as to operative treatment. In crippling conditions, shortening is often only one of several factors responsible for the disability or limp. Ankylosis or deformity of the hip, knee or foot, or muscle weakness may be more disabling factors than the shortening and should receive appropriate treatment. Equalization of leg length when such other factors are ignored is likely to prove disappointing.

I. CHANGING THE RATE OF GROWTH.— (1) *Stimulation of Growth in the Shorter Extremity:* The hereditary, physiologic, metabolic and pathologic factors determining bone growth are too varied and complicated to discuss in detail. The longitudinal growth of the long bones is unique, in that it occurs only near the ends at the epiphyseal cartilage disks. Other body structures, even the periosteum, enlarge by general interstitial growth. If the causative agents of achondroplasia and gigantism could be isolated and used locally, accurate control of epiphyseal growth might be possible. Generalized increase or decrease in the growth of bones depends upon various systemic factors, many of them unknown.

It has often been observed that decreased function and/or decreased circulation cause subnormal epiphyseal bone growth as well as atrophy of the entire part. Conversely, increased local circulation is often accompanied by increased growth. Numerous pathologic conditions are sometimes associated with increased length of the affected extremity (Table II). Temporary or permanent hyperemia is found in all of them. As it is not feasible to reproduce any of these pathologic conditions for the purpose of stimulating the growth in a short extremity, many attempts have been made to induce hyperemia by other means.

TABLE II

PATHOLOGIC CONDITIONS ASSOCIATED WITH LENGTHENING OF AN EXTREMITY

(A) Congenital Conditions
- (1) Hemihypertrophy
- (2) Arteriovenous aneurysm
- (3) Recurring hemarthrosis in hemophilia

(B) Infections
- (1) Tuberculosis of knee (low grade)
- (2) Chronic osteomyelitis of femur or tibia
- (3) Chronic soft tissue infection
- (4) Syphilis
- (5) Femoral or iliac thrombosis
- (6) Elephantiasis

(C) Tumors
- (1) Giant cell tumor
- (2) Osteitis fibrosa cystica (diffuse unilateral type)
- (3) Neurofibromatosis (von Recklinghausen)
- (4) Hemangioma or lymphangioma
- (5) Large nevi

(D) Trauma
- (1) Fracture of femur
- (2) Removal of bone graft from tibia
- (3) Extensive periosteal stripping

Ollier,[46] in 1867, noted that irritation of the shaft of a bone produced acceleration in the rate of growth, and Kishikawa[40] found that ligation of the femoral vein, or injection of oil of turpentine into the marrow cavity, caused slight but definite increase in the growth rate. Meisenbach,[43] Bohlman[15] and others inserted numerous foreign materials into the region of the epiphyseal cartilage with the object of producing more rapid bone growth through local irritation. However, most of these substances caused retardation, and none of them accomplished the desired result. When the material inserted was definitely irritating or caustic there was often complete disappearance of the epiphyseal line. Brooks[18] found that small doses of roentgen ray (2 to 5 per cent S.E.D.) caused no stimulation. The most successful experiments were those of Wu and Miltner,[62] who produced an increase of 5 to 15 per cent in the growth rate of the extremities of young animals by extensive periosteal stripping.

Increased longitudinal growth following fracture of a growing bone has been noted clinically and experimentally. It cannot be considered compensatory as it commonly occurs even though there is no shortening due to the fracture. Ferguson[31] believed that the interruption of the metaphyseal blood supply with resulting hyperemia in the epiphyseal region was the cause of this increased growth rate. Based upon this assumption, stimulation of growth was attempted in a number of patients by drilling the cortex near the epiphysis and curetting across the marrow cavity. A gain of one-twelfth to one-eighth of an inch was reported three to five months after operation.

Wu and Miltner,[62] and Compere and Adams[27] were unable to produce, experimentally, any stimulation of bone growth by the method advocated by

Ferguson. Brockway,[19] Chandler,[23] and Compere and Adams observed definitely increased growth in normal tibiae from which a graft had been removed. The latter two, after an extensive experimental and clinical study, concluded that gross trauma involving a considerable portion of a long bone and requiring a lengthy period of repair was the inciting factor. In their opinion the increased growth rate was directly associated with the local hyperemia and continued only during the period of increased vascularity.

The problem of producing an increased blood supply over a prolonged period presents great difficulties. Lumbar sympathectomy apparently accomplishes this better than any local procedure yet devised. Although the experimental attempts to stimulate growth by lumbar sympathectomy in animals have been uniformly unsuccessful, in children it is known to produce a lasting hyperemia, and many of these patients show definite gain in the rate of growth on the operated side. Stewart[55] noted one-half of an inch lengthening in two out of six patients who had had unilateral sympathectomy for spastic hemiplegia. Harris and McDonald[36] reported increased growth of one-half to one inch in three patients upon whom unilateral sympathectomy had been performed for Hirschsprung's disease.

These authors examined 46 out of 100 patients with poliomyelitis, who had had unilateral lumbar sympathectomy to improve circulation and stimulate growth. They stated that there was always some increase in the growth rate. In 21 of these, the improved vascularity resulted in a decrease in the discrepancy between the two extremities. This decrease amounted to one inch in two instances, three-quarters of an inch in four, and in the other 15 it was one-half of an inch or less. In eight, the hyperemia was sufficient to prevent any further increase in discrepancy. In 17, the discrepancy between the two extremities increased, but less rapidly than before the operation. According to these authors there is a basic rate of growth which in normal legs is stimulated by normal muscle activity and a normal blood supply. Sympathectomy improves only the latter and is not very effective in a severely paralyzed extremity. There are probably other factors such as diminished weight bearing which influence the leg growth after paralysis. It is even possible that there is a direct control of growth by special cells in the central nervous system, and that these, as well as the anterior horn cells, are affected by the virus of poliomyelitis.

Although lumbar sympathectomy may produce a prolonged hyperemia and is well worth while for the relief of chilblain and pain associated with poor circulation, the increase in growth is too little and too inconstant to recommend it as a method of equalizing leg lengths.

At the Hospital for Ruptured and Crippled, a small number of paralytic cases have been treated with diathermy to the epiphyses about the knee of the shorter extremity. In several instances there has been no further increase in the discrepancy between the two legs. Even if these treatments could be given daily or twice daily for a period of years, one would hardly expect as much improvement as from lumbar sympathectomy. We must, therefore, conclude that attempts to stimulate epiphyseal growth have not been successful enough up to this time to warrant their clinical application.

(2) *Retardation of Growth in the Longer Extremity.*—Diminution or complete cessation of longitudinal growth occurs even more commonly than increased growth. The same abnormal conditions which cause stimulation frequently cause retardation, especially if the pathologic process actually involves the epiphyseal line. Any lesion associated with diminished circulation or gross trauma to the region of the growing cartilage disk is apt to produce partial or complete arrest of growth (Table III). Uneven growth with angular deformity is even more serious than uniform shortening.

TABLE III

PATHOLOGIC CONDITIONS ASSOCIATED WITH SHORTENING OF AN EXTREMITY

(A) Congenital Conditions
- (1) Unreduced congenital dislocation of hip
- (2) Congenital absence or partial absence of a long bone
- (3) Congenital hemiatrophy
- (4) Chondrodysplasia
- (5) Other congenital anomalies

(B) Infections
- (1) Poliomyelitis
- (2) Tuberculosis of hip or knee
- (3) Suppurative arthritis of hip, knee, or ankle
- (4) Osteomyelitis of femur or tibia

(C) Tumors
- (1) Osteitis fibrosa cystica (diffuse type)
- (2) Osteochondroma
- (3) Giant cell tumors
- (4) Other tumors

(D) Trauma
- (1) Slipping of upper femoral epiphysis
- (2) Other epiphyseal separations
- (3) Fractures involving epiphyseal cartilage disks
- (4) Operative trauma to epiphysis
- (5) Roentgenotherapy for conditions near the epiphyseal line
- (6) Malunited fractures

Although short extremities and growth deformities of the bones have been observed for years, Phemister[49] was the first intentionally to limit longitudinal bone growth by surgical means. He described a simple procedure which consisted of removing small bone grafts from each side of the lower end of the femur or the upper end of the tibia. These were taken largely from the diaphysis but extended just across the epiphyseal line. The epiphyseal cartilage plate was exposed by this removal and a large area of it curetted. The grafts were turned end-for-end and reinserted across the epiphyseal line. No postoperative support was required. Compere[25] stated that this operation had been performed in more than 100 cases at the University of Chicago Clinics, without complications.

Brooks[18] and others have shown that proliferation of the cartilage cells of the epiphyseal line can be delayed or even completely inhibited by exposure to roentgen rays. No attempt has been made to apply this method clinically, as serious damage to the adjacent articular structures is almost inevitable.

Many of the attempts to stimulate bone growth, contrary to expectations, produced retardation or even complete cessation, and it is possible that some method of epiphyseal arrest, even simpler than that of Phemister, may yet be evolved.

Although late deformities have not been reported, we have encountered three patients operated upon according to Phemister's technic who developed disalignment at the knee sufficient to require operative correction. In experimental animals, attempts to arrest growth by his and other methods frequently resulted in severe lateral deformity. In a series of 25 rabbits, we were able to produce uniform and complete arrest of growth only when a considerable part of each side of the cartilage disk was removed and the remaining cells in this area destroyed by electrical cauterization. (Fig. 1.) With this combined procedure complete cessation of growth occurred either with or without the cortical graft across the epiphyseal line.

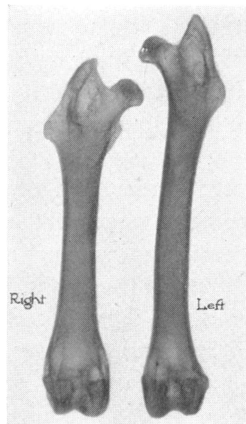

FIG. 1.—Rabbit bones after epiphyseal fusion on right, showing amount of shortening obtained.

At the Hospital for the Ruptured and Crippled, during the past four years, 34 operations for the retardation of growth have been performed upon 30 patients, with no infections and no postoperative deformities or other complications. The essential points of the technic are (Fig. 2):

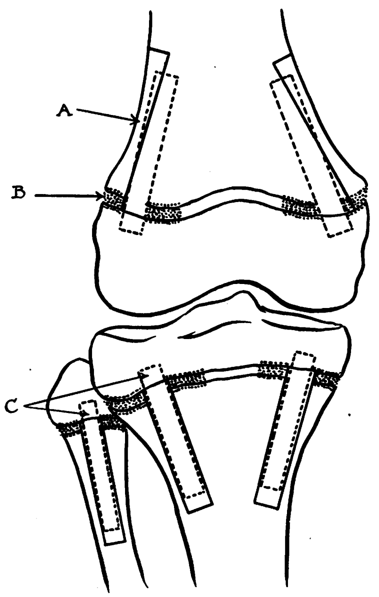

FIG. 2.—Diagram of operative technic for epiphysiodesis. (A) Bone removed for graft. (B) Area of epiphyseal cartilage curetted and cauterized. (C) Replacement of graft, with cartilage removed, across epiphyseal line.

(1) The medial and lateral sides of the lower end of the femur or upper end of the tibia and fibula are exposed through separate incisions.

(2) Bone grafts, about 1x4 cm. in size, are removed from the diaphysis. These extend as far as, but not across, the epiphyseal cartilage plate.

(3) A large area from both the medial and lateral aspects of the cartilage disk is removed with a chisel or curet.

(4) The curetted area is cauterized with the diathermy cautery.

(5) The grafts are replaced, countersunk beneath the cortex of the diaphysis, and driven across the epiphyseal line into the cancellous bone of the epiphysis.

More difficult than the actual technical procedure is the decision as to when the operation should be performed and which epiphyses should be fused. Digby,[30] in 1916, determined the proportional growth at the various epiphyseal lines and his estimations have been confirmed by subsequent clinical observations. Complicated methods for determining the optimum age for operation have been propounded, based upon the average height, leg length, and growth rate at various ages. The authors feel that each patient must be considered individually and decision made upon the basis of previous rate of growth and expected growth in the extremities as well as age, height and leg lengths. Measurements of the patient's family are also of definite assistance. With these considerations in view, and the fact that practically all adults are between five and six feet in height, with a leg length of 30 to 38 inches, it is possible to arrive, with a fair degree of accuracy, at a figure which will represent the expected length of the longer extremity at maturity. Subtracting the present leg length from this figure gives the expected amount of growth in this leg if no treatment is undertaken. As attempts to estimate the growth in the femur and tibia separately only make the problem more complicated, the figures of Digby have been adjusted to apply to total leg length. For all practical purposes the figures shown in Table IV are sufficiently accurate.

TABLE IV

APPROXIMATE PROPORTIONAL GROWTH AT THE EPIPHYSES OF THE LOWER EXTREMITY

Upper femoral epiphysis	15%
Lower femoral epiphysis	35%
Upper tibial epiphysis	30%
Lower tibial epiphysis	20%

The expected discrepancy can be estimated if records of the leg lengths over a period of years are available. If the discrepancy has not been increasing with growth, the present discrepancy equals the expected discrepancy. If the rate of growth in the longer leg has been greater than in the shorter extremity, the discrepancy will continue to increase proportionately.

If the expected discrepancy is divided by the expected growth in the longer extremity, the proportion of growth which should be eliminated is obtained, thus $\frac{\text{expected discrepancy}}{\text{expected growth}}$ = per cent of growth to be eliminated, for example—(1) If this proportion is less than 25 per cent, operative treatment should be delayed; (2) if it is between 25 and 60 per cent, growth should be arrested at the upper femoral or upper tibial and fibular epiphyses; (3) if it is more than 60 per cent, all the epiphyses at the knee should be fused; (4) if it is more than 70 per cent, complete equalization of leg length by this means cannot be obtained.

If the patient is under ten years of age the arrest of growth at a single epiphysis is preferred and is often sufficient. If the patient grows less than was anticipated and some discrepancy persists, another epiphysis can be fused a year or two later. If only a moderate retardation of growth seems indicated the decision as to whether the operation should be performed above or below the knee depends upon whether the shortening in the opposite extremity is greater in the thigh or lower leg.

It is impossible to report end-results in these cases until growth is complete, 14 patients, however, averaging 12½ years at the time of operation, have been observed from one to four years later. Seven of these showed a lessening in discrepancy of one to one and three-quarters inches. In three, the decrease was one-half to one inch. In two, the difference between the two legs remained the same, while in two, the discrepancy increased slightly despite the operation. Epiphyseal-diaphyseal fusion was accomplished in all cases, and even in those where no equalization of leg length was obtained a rapidly progressive discrepancy was arrested.

ILLUSTRATIVE CASE REPORTS

Case 1.—F. B., male, age 14. *Diagnosis:* Poliomyelitis in 1924, at the age of one year; resulting in a severe paralysis and marked shortening of the left leg.

Preoperative Measurements

Date	Age	R. Leg	L. Leg	Difference
3-6-29	5 yrs.	22 ins.	20¾ ins.	−1¼ ins.
12-5-34	10 yrs.	29¼ ins.	26¼ ins.	−3 ins.
2-5-35	11 yrs.	30 ins.	27 ins.	−3 ins.
3-8-37	13 yrs.	34¼ ins.	31¼ ins.	−3 ins.

Although the patient had already reached the age of 13, he was still growing rapidly, and as his family were also tall; the normal leg without treatment would probably grow three inches or even four inches more. If the present discrepancy of three inches is divided by the expected growth it is found that 75 to 100 per cent of this growth should be eliminated. On March 10, 1937, growth was arrested at the epiphyses of the lower end of the right femur and the upper end of the right tibia and fibula.

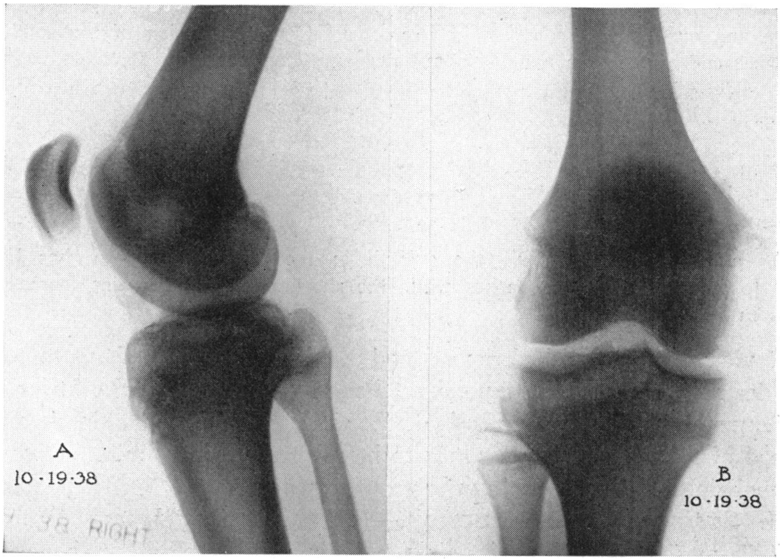

Fig. 3.—Case F. B. Views of knee 19 months after operative arrest of growth at the lower end of femur and upper end of tibia and fibula. During this period, the discrepancy in length decreased two and one-half inches.

Postoperative Measurements

Date	Age	R. Leg	L. Leg	Difference
9-15-37	13 yrs.	34¾ ins.	31½ ins.	−3¼ ins.
3-15-38	14 yrs.	34½ ins.	32½ ins.	−2 ins.
10-18-38	14 yrs.	35½ ins.	34½ ins.	−1 in.

After operation, the shorter leg grew three and one-quarter inches, while the longer one grew only one and one-quarter inches; showing that growth in the normal leg had been reduced at least 60 per cent.

Case 2.—J. M., female, age 12. *Diagnosis:* Poliomyelitis in 1927, at the age of one year; resulting in an extensive paralysis of the left leg.

Preoperative Measurements

Date	Age	R. Leg	L. Leg	Difference
9- 1-27	1 yr.	13⅜ ins.	13⅜ ins.	None
9-25-31	5 yrs.	20½ ins.	19 ins.	−1½ ins.
10-25-34	8 yrs.	27¼ ins.	25¼ ins.	−2 ins.
5-19-36	10 yrs.	28½ ins.	26½ ins.	−2 ins.

The patient's family were all rather short and although the patient was only age 10, she was well developed. It was evident that the normal leg without treatment would not grow more than six inches more. Dividing the discrepancy of two inches by the expected growth showed that at least 33 per cent of this should be eliminated. On May 20, 1936, an operation for arrest of growth was performed at the lower end of the right femur.

Postoperative Measurements

Date	Age	R. Leg	L. Leg	Difference
10- 2-36	10 yrs.	28¾ ins.	26¾ ins.	−2 ins.
2-26-37	11 yrs.	28¾ ins.	27¼ ins.	−1½ ins.
1-29-38	12 yrs.	30¼ ins.	29 ins.	−1¼ ins.

Although growth in the right leg had been retarded, there was still a discrepancy of one and one-quarter inches to be overcome. Operative fusion of the epiphyses of the upper end of the tibia and fibula was performed on February 16, 1938.

Postoperative Measurements

Date	Age	R. Leg	L. Leg	Difference
5 -1-38	12 yrs.	30¾ ins.	29½ ins.	−1¼ ins.
9-23-38	12 yrs.	31¼ ins.	30¼ ins.	−1 in.
12-30-38	13 yrs.	32 ins.	31½ ins.	− ½ in.

As a result of operations, the growth in the normal extremity has been reduced to three and one-half inches while the short, paralyzed leg was increasing five inches in length.

Review of the published reports and of our own cases leads us to conclude that destruction of the epiphyseal cartilage by operation at the lower end of the femur and/or the upper ends of the tibia and fibula is a simple and safe method of retarding growth. It is to be recommended as an effective means of equalizing leg length during the growing period.

II. SURGICAL RECONSTRUCTION.—(1) *Bone Lengthening Operations:* Codivilla was the first to devise a method for lengthening a long bone, as well as the first to employ the principle of direct skeletal traction. In 1905, he reported 22 cases, chiefly malunited fractures, in which he had performed an oblique osteotomy and applied traction by means of a pin inserted into the os calcis. He had increased the length by from 3 to 8 cm. A firm anatomic foundation for bone lengthening was laid by Magnuson,[42] in 1908, when he reported the results of experiments in animals which demonstrated that operative lengthening of a normal extremity could be performed without interfering with the blood supply or nerve function.

Putti, in 1921,[51] reported a method for the operative lengthening of the femur, and was the first to make use of the principle of skeletal distraction. He first performed a long oblique osteotomy of the femoral shaft and then applied an apparatus consisting of two pins which were inserted from the lateral surface, one into the femoral condyles and the other into the greater

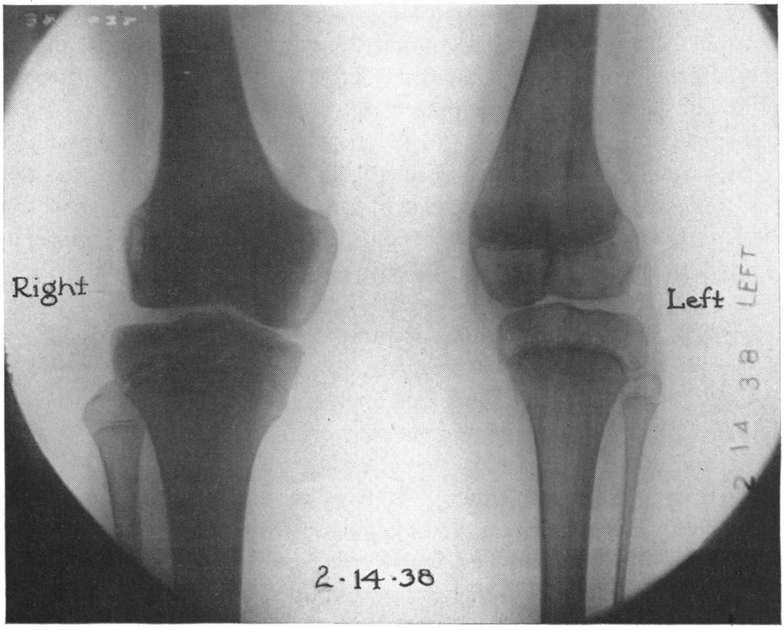

FIG. 4.—Case J. M. Roentgenogram taken 21 months after epiphysiodesis at right distal femoral epiphysis. Complete fusion has been obtained with three-fourths inch correction of discrepancy of length.

trochanter, and of a telescoping side-bar which was securely fastened to the protruding ends of the pins and could be gradually lengthened by turning up a screw-thread. Putti's method was tried by other surgeons but never became popular because of difficulty in controlling the alignment of the fragments.

It remained for L. C. Abbott[1] to devise a method which put leg lengthening on a practical basis. He selected the tibia and fibula as the ideal site for lengthening and after preliminary lengthening of the tendo achillis and oblique division of the shaft of the fibula, he performed a tongue and groove osteotomy of the shaft of the tibia, the tongue being long enough to overlap the other fragment after the desired lengthening had been obtained. Pins were passed through the upper and lower ends of the tibia and their projecting ends fixed to rigid, telescoping side-bars on both sides of the leg, the apparatus when assembled forming a rigid unit and serving as a support for the extremity. Lengthening of approximately one-eighth of an inch a day was obtained by turning up screws until the desired amount was gained. Abbott published the first report of his method in 1927, and it was immediately adopted by other surgeons. He later modified it by employing four pins, two in each fragment to obtain better control of alignment. Other surgeons have devised ingenious modifications of his apparatus, but one and all have employed the same basic principles.

Lengthening of the femur presents more of a problem than that of the bones of the leg, owing chiefly to its deeper situation and stronger muscle attachments which make the control of alignment of the fragments after osteotomy more difficult. Abbott and Crego,[2] in 1928, described a method with one pin inserted through the condylar region and a second pin passed obliquely downward from the anteromesial aspect of the thigh through the upper third of the shaft and emerging at the posterolateral surface. By means of appropriate apparatus attached to the ends of the pins and also supporting the leg, lengthening was obtained gradually. This method proved too difficult, however, and never became popular. Modifications have been tried and femoral lengthenings are still undertaken, but their number in proportion to lengthenings of the lower leg is relatively small.

From this brief review it will be seen that more than ten years' experience with leg lengthening operations has accumulated, and a fairly accurate evaluation of the procedures can now be made.

A survey of the literature revealed reports by 11 different authors of their experience with leg lengthening operations. Of these, 224 were of the tibia and fibula and 46 of the femur. Lengthening was obtained in all but seven cases, regardless of complications. Average reported gains varied from 1.9 to 2.25 inches. The maximum amount gained from lengthening of one bone was 3.5 inches, but by combined lengthening of the femur and tibia in different stages, as much as 4.5 inches was obtained.

Numerous complications were reported and appeared to be of sufficient frequency and gravity to warrant careful consideration (Table V). Of these, the most disturbing was postoperative infection, which occurred in 22 out of 270 cases, an incidence of 8 per cent. Since several of the authors did not report their complications in detail, it is probable that this figure should be even higher. While it is impossible in this group of cases to separate the infections involving the site of osteotomy, and which were of major significance, from those that were confined to the pin wounds, of only local importance, it is evident that the former occurred entirely too frequently for comfort and are the natural consequences of a procedure that necessitates extensive exposure and traumatization of bone. It is important to point out, however, that only one death was reported in the entire series and aside from this case there were no amputations.

Without doubt, the tendency after tibial lengthening for the fragments to angulate anteriorly, and either protrude directly through the wound or cause necrosis of overlying skin with exposure of the bone, contributed to the high

TABLE V

REPORTED RESULTS OF LEG LENGTHENING OPERATIONS

Author	Number of Lengthening Operations: Tibia and Fibula	Number of Lengthening Operations: Femur	Average Length Gained (inches)	Complications Reported: Protrusion of Fragments or Skin Necrosis	Infection and Osteomyelitis	Delayed Union	Non-union	Fracture	Nerve Injury	Foot Deformity	Death	Failure to Gain Length
Abbott	48	25			2			7	3	Many	0	
Stephenson and Durham	15	2		2	3							
Carrell	21	7								1		3
Brockway	41	5	1.9 ins.	5				2				
Janes	5		2.25 ins.		3		1					
Moore, J. R.	10				0	?			0	2		
Compere		5			4	1	2		1		1	?
Bcsworth	19		1.9 ins.	2	2	3	4			6		
Alcorn	37		1.5 to 2 ins.									4
Haboush and Finkelstein	17			4	6	1	2			2		
Present report	11	2	1.9 ins.	5	2		3	1	1	3	0	0
Totals	224	46	2 ins.	18	22	5	12	10	5	14+	1	7

incidence of infection. This difficulty was encountered more frequently in the early experience and was largely overcome by the introduction of the four pin method.

Among the other complications reported were fracture of the osteotomy tongue in some instances of tibial lengthening, and separation of the fragments after femoral lengthening. These conditions resulted in delayed union when allowed to persist but were generally corrected by secondary operation with insertion of bone grafts to bridge gaps between the fragments and secure union. Callus formation and bone healing were delayed in some cases even when there was good approximation of fragments, and several instances of nonunion were reported for which bone grafting operations were necessary. Late fractures through the site of the healed osteotomy were not uncommon, as shown by Abbott's report of seven such complications out of 25 femoral lengthenings and occasional mention of similar experiences by other authors after tibial lengthening. Nonunion followed some of these fractures.

TABLE VI

LEG LENGTHENING OPERATIONS AT THE HOSPITAL FOR RUPTURED AND CRIPPLED

Case	Diagnosis	Shortening	Lengthening Obtained	Complications	Result at Last Visit
L. S.	Polio.	4 ins.	2¼ ins.	Tilting, projection of fragments, osteomyelitis, compound fracture, bone graft, refracture, amputation of leg	4 years later: Poor
E. W.	Old epiphysitis	1½ ins. Femur	1 in.	Tilting of fragments	Not known
P. M.	Polio.	1⅝ ins.	2¼ ins.	Slough, projection of fragments, osteomyelitis	3 years later: Poor
M. H.	Polio.	1½ ins.	Lengths equal	None	5 years later: Good
H. N.	Cong. shortening of femur	4 ins. Femur	1 in.	Secondary hemorrhage, infection, loss of peroneal nerve supply	4 years later: Paralysis persists
S. G.	Polio.	3 ins.	2½ ins.	None	4 years later: Fair
M. B.	Old epiphysitis	1¾ ins.	1⅜ ins.	Protrusion of tibial fragment through wound	7 years later: Good
P. D.	Polio.	2¾ ins.	2½ ins.	None	6 years later: Good
K. C.	Polio.	3¼ ins.	2 ins.	Slough, exposure of bone	3 years later: Fair
E. F.	Polio.	2¼ ins.	1 in.	Slough, protrusion of fragment	1½ years later: Fair
T. L.	Polio.	1¾ ins.	2½ ins.	Displaced epiphysis and overlengthened leg	3 years later: Good. Equal length
A. B.	Polio.	2 ins.	1½ ins.	Nonunion. Bone graft	4 years later: Good
A. M.	Polio.	3 ins.	2¾ ins.	Slight infection about pins	5 years later: Result good. Short leg ¼ in. longer

Other common complications were nerve paralysis and muscle contracture. The nerve most frequently injured was the common peroneal, giving rise to equinovarus deformity of the foot. Foot deformity was also frequently produced by uneven tension of muscles following elongation of the bones. The rigidity of some of these contractures was so great that some basis was afforded for the view that they might be of ischemic origin.

At the Hospital for the Ruptured and Crippled, 11 operations to lengthen the tibia and fibula were performed and two to lengthen the femur (Table VI). The results were considered good in six, with an average lengthening of two inches; fair in four; poor in two and unknown in one. The most common complication after tibial lengthening was anterior protrusion of the fragments, which led to exposure of the bone in six cases. There were two cases of non-union of the tibia. Union was obtained in one, following a bone graft, but the other was complicated by bone infection, and when last seen this patient was still walking with a caliper brace.

That end-results of bone lengthening operations should not be judged too early is shown by the following case report:

Case Report.—L. S., white, male, age 22, was admitted to Hospital for the Ruptured and Crippled in January, 1934, with a history of poliomyelitis at the age of one year, with resulting weakness of the right lower extremity. Examination showed flexor power of the hip weak, extensor power fair, abduction absent; quadriceps muscles poor, biceps strong, but other hamstring muscles weak; very little power in the soleus-gastrocnemius group, tibialis posticus muscle weak; the other muscles controlling the foot good. There was a four inch shortening of the right leg and an operation to lengthen the lower leg was advised.

Operation.—February 1, 1934: Lengthening of tibia and fibula by the Abbott method and application of four pin extension apparatus.

Subsequent Course.—The patient made a good immediate recovery. The leg was gradually lengthened and by February 26, 1934, a gain of two and one-quarter inches had been obtained, which was considered sufficient. Six weeks after operation, a small area in the operative scar broke down and discharged a small amount of seropurulent material. The drainage quickly ceased; there was good callus formation and union seemed solid. The pins were removed and a plaster encasement applied. This was changed at the end of four months, at which time some drainage from the operative area was found and there was a small piece of bone exposed in the wound. The patient was discharged to the out-patient department on crutches with the leg in plaster. This was removed January 4, 1935, and a brace fitted. The wound was still draining and bone surface was exposed. Measurement showed the left leg only three-quarters of an inch longer than the right.

The patient was readmitted May 20, 1936, for muscle transplantations of the right thigh and hip, at which time the scar over the tibia was healed and there seemed to be firm union. He was still wearing a brace but chiefly for support of the knee. The operations were performed without event in two stages on May 22, and June 12, 1936, respectively. Each was followed by immobilization of the leg in plaster for a period of two to three weeks. The patient was discharged July 21, 1936.

October 3, 1936: Patient was readmitted because of a fracture of the right tibia sustained from a fall while playing football. The upper fragment of the fibula penetrated through the skin anteriorly. The wound was cleansed and dressed and a plaster encasement applied. Discharged November 4, 1936.

January 5, 1937: Readmitted because of pseudarthrosis of the right tibia. A massive onlay graft from left tibia was applied to right tibia and fixed with Sherman steel screws. Progress was uneventful and he was discharged March 23, 1937, with the leg in plaster, using crutches.

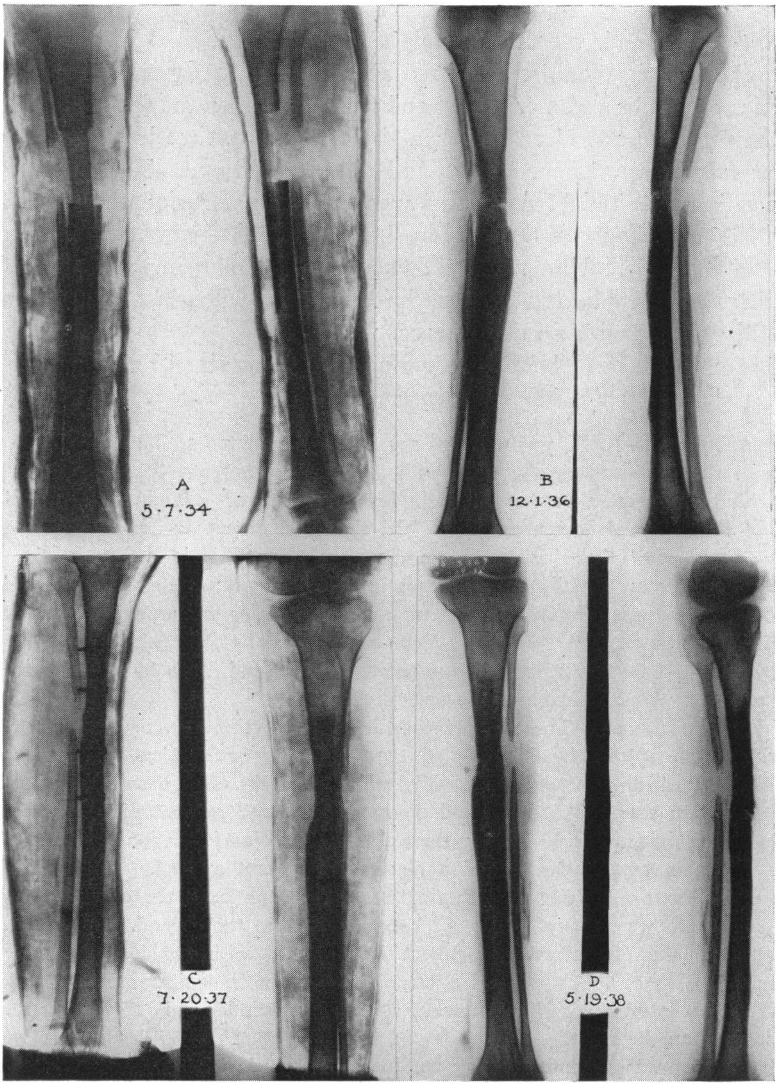

FIG. 5.—Case L. S. (A) Roentgenogram in plaster four months after lengthening operation. Two and one-fourth inches of lengthening obtained. (B) View taken ten months after original operation and two months after fracture from a fall. (C) Six months after massive onlay graft for nonunion of fracture. (D) Refracture of tibia following healing of previous nonunion, four years after lengthening operation.

July 20, 1937: Readmitted because of intertrochanteric fracture of right femur sustained by a fall while walking on crutches with his leg in plaster. The grafted area of the right tibia seemed solid. A plaster spica was applied. This was removed eight weeks after injury; roentgenologic examination showed good callus formation.

September 29, 1937, nine months after the bone grafting operation, the scews were removed from the right tibia as there was a small draining sinus in this area. He was discharged October 27, 1937, walking with a long caliper brace.

May 19, 1938: Readmitted because of a refracture of the right tibia sustained while turning in bed. There was still a small draining sinus. Since osteomyelitis was present and the tibia was sclerotic and thin, it was decided to amputate the leg. This was done May 25, 1938. He made a rapid recovery and was discharged.

August 15, 1938: An artificial leg was fitted and when last seen, December 10, 1938, he was walking quite well and was satisfied with his status.

SUMMARY.—We feel that bone lengthening operations, although feasible, are formidable procedures and should not be undertaken lightly. They necessitate prolonged hospitalization, and are frequently followed by serious complications which may still further impair the function of an already crippled leg. Previous infection of one of the bones of the leg to be lengthened should be considered an absolute contraindication, no matter how long it appears to have been healed. Failure to observe this rule may lead to disaster. Our survey showed that lengthening operations were performed more frequently for shortening resulting from poliomyelitis than from any other condition. Yet we believe that it is precisely in such cases that the results are likely to be the most unsatisfactory. Not only are partially paralyzed muscles apt to be still further weakened by stretching but the small atrophied bones are made still smaller and more brittle by elongation. The full consequences of bone lengthening operations under these conditions are not revealed except by prolonged follow-up studies.

From our observation and experience we believe that bone lengthening operations should not be performed until growth is well established, and then only when the musculature of the leg is normal or approximately normal. In general they should be reserved for individuals of short stature who are unwilling to make any sacrifice of height by shortening of the longer leg.

Leg Shortening Operations.—Shortening of the bones of the longer leg, in order to achieve equality of length, is a much older procedure than attempts to elongate the short leg by operation. Steindler credited Rizzoli with being the first to undertake this procedure. Sayre, in 1863, advocated fracturing the shaft of the femur and allowing the fragments to overlap the necessary amount. In 1908, Glaesseur reported three cases in which he had performed an oblique osteotomy and obtained sufficient overriding to overcome a discrepancy of leg length. Shands, in 1907, reported three similar cases. Brooke[16] was the first to report shortening of the lower leg. He described two successful cases in 1927, in which he had removed segments of bone one and two inches long, respectively, and applied inlay grafts, obtaining solid union in four months. He also reported shortening the femur by a step-cut method, with fixation of the fragments by two beef bone screws.

Camera[21] was the first to devise a standard method and to report any considerable series of cases. In 1933, he described his technic, which consisted of resecting a portion of the femoral shaft of the desired length, cutting this into a diamond-shaped peg, which was then used as an intramedullary graft to fix the fragments together. The wide portion of the diamond served to prevent the graft from penetrating too far into either fragment. He reported a series of 32 cases. As complications, he cited two cases in which the fragments separated, necessitating reoperation and insertion of a metallic suture, three postoperative infections, and two cases of delayed union. The average period of external fixation of the limb was 50 days.

Moore,[45] also in 1933, reported a series of 13 femoral shortenings. He resected sufficient bone but left a spike projecting from the distal fragment that could be shoved up into the intramedullary canal of the proximal fragment for purposes of fixation. The average amount of shortening obtained was two and one-half inches, and the average period for complete union was two and one-half months. He reported no instances of infection, malunion or nonunion.

In 1935, White[60] reported a simplified method of femoral shortening, in which he performed a transverse osteotomy of the shaft, overlapped the fragments the necessary amount and fixed them together by inserting two long pins in an oblique direction upward and inward from the lateral side. The wound was closed with the ends of the pins protruding, which were incorporated in the plaster spica encasement. The pins were removed at the end of seven weeks, and the plaster encasement at the end of eight weeks. A caliper brace was then applied, and worn until the end of four months. He reported 47 cases treated by this method, their ages varying from eight to 42 years; the majority, however, were under age 14. The average amount of shortening obtained was two and one-half inches, with a maximum of three and one-eighth and a minimum of two inches. In the younger children, he shortened one-half an inch more than was necessary, in order to allow for continued disturbance of the growth rate, and expressed the wish that he had been even more radical. He encountered infection in four cases, with seropurulent discharge about the pin wounds, all of which cleared up in less than two weeks. Two ring sequestra separated from the pin wounds in another case and were extruded. Good functional results were obtained in all the cases.

At the Hospital for the Ruptured and Crippled, we have performed five femoral shortening operations according to the method of White. No complications were encountered, with the exception of one case in which pins made of a new type of steel were used and broke without, however, any loss of fixation. It was necessary to perform a later operation to remove the ends of the pins. An average shortening of two and one-eighth inches was obtained. To illustrate how much improvement in a patient's condition can be obtained by a combination of methods, the following case history is presented:

Case Report.—J. H., female, age 26, was admitted to the Hospital for the Ruptured and Crippled, May 5, 1937, with a history of infection of the right hip, probably tuberculous, at age 7. This resulted in ankylosis of the hip and failure of development of the right leg, so that for years she had walked with a limp and had to wear a lift, eight inches high, under her shoe. She did not complain of any pain but was anxious to have something done to equalize the length of her legs so that she might discard her raised shoe.

Examination showed bony ankylosis of the right hip and an underdeveloped right leg. The hip was fixed in a position of 45° flexion and 15° adduction. The right knee

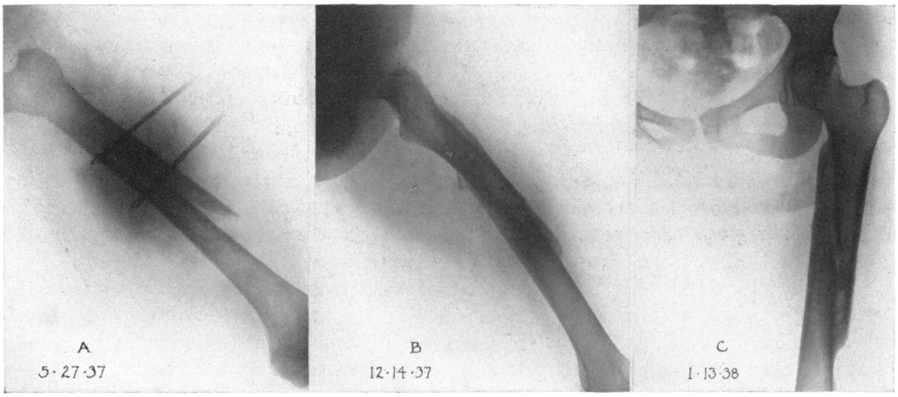

FIG. 6.—Case J. H. (A) Postoperative roentgenogram showing overlapping of fragments with three inches of shortening of femur and pins in place. (B) and (C) Views showing position and healing approximately eight months after operation.

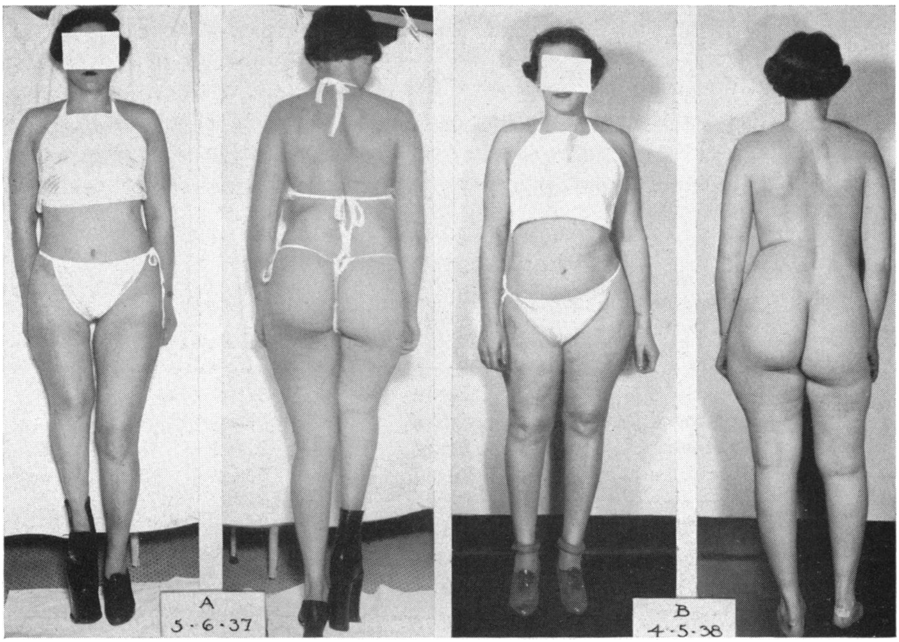

FIG. 7.—Case J. H. (A) Preoperative appearance of patient wearing eight inch lift on shoe. (B) Appearance after three inches of shortening of left femur, correction of adduction deformity of right hip and flexion deformity of right knee by osteotomies.

showed a normal range of flexion, but extension was limited at an angle of 165°. Measurements showed the length of the right leg 28½ inches, of the left leg 34½ inches, of the right femur 14 inches, and of the left femur 17½ inches. The flexed, adducted position of the right hip caused her to stand with marked lumbar lordosis and with the right side of the pelvis raised so that there was a relative increase of the shortening. (See Figs. 6 and 7.)

First Operation.—May 8, 1937: Shortening of left femur by oblique osteotomy, overlapping of the fragments and pin fixation. Amount of shortening obtained, three inches. Application of plaster spica. Good postoperative recovery.

Second Operation.—May 24, 1937: Subtrochanteric osteotomy for correction of flexion and adduction deformity of the right hip. Plaster spica applied holding hip in position of 10° abduction and 15° flexion. Uneventful convalescence.

Third Operation.—June 21, 1937: Supracondylar osteotomy of right femur to overcome flexion deformity of right knee. Bilateral plaster spica.

Subsequent Course.—The patient did well. Union of the left femur and of the right hip appeared solid August 10, 1937, and the plaster was removed. A plaster leg encasement, to support the region of the right knee, was worn until August 31, 1937. She was then given exercise treatment in the pool, and weight bearing was permitted September 15, 1937. She was discharged one week later.

Patient was examined in the End-Result Clinic, October 18, 1938, at which time she stated that she was very pleased with the result. She walked well with a one-quarter inch lift under her right heel. The right hip was fixed in 10° abduction and 25° flexion. The right knee could be completely extended and flexed to an angle of 80°. The length of the legs, when measured from the anterior superior spine, was: right 29 inches, left 31¾ inches; when measured from the umbilicus: right 33½ inches, left 34¼ inches. The abducted position of the right hip was sufficient to cause enough relative lengthening of the leg nearly to compensate for the two and three-quarters of an inch actual shortening present.

Summary.—We feel that leg shortening operations are practical procedures; that the technic varies with different surgeons, with the preference, however, either for the resection of a portion of the shaft with fixation by an intramedullary graft or for a simple overlapping operation with fixation by pins; that the complications are few and that the functional results are good (Table VII).

Table VII

REPORTED RESULTS OF LEG SHORTENING OPERATIONS

Author	Number of Shortening Operations: Femur	Number of Shortening Operations: Tibia	Average Shortening Obtained	Complications Reported: Separation of Fragments. Reoperation	Complications Reported: Infections	Complications Reported: Delayed Union	Complications Reported: Non-union	Results
Brooke	1	2	1⅔ ins.	0	0	0	0	Good
Camera	32	0		2	3	2	0	Good
Moore	13	0	2½ ins.		0	0	0	Good
White	47	0	2½ ins.		4	0	0	Good
Present report	5	0	2⅛ ins.	0	0	0	0	Good
Totals	98	2	2 ins.	2	7	2	0	

There is a natural prejudice, both on the part of the surgeon and of the patient, against operating upon the normal leg when the other is already crippled, but the results show that the method is justified when there is serious discrepancy in length and particularly when the shortening is confined to the femur. The maximum amount of shortening reported was three and one-eighth inches, but Hey Groves stated that the normal femur might be safely shortened by 25 per cent of its total length. As far as loss of muscle power resulting from the shortening is concerned, we can confirm the statement of Hey Groves that: "It is very remarkable how the slack of four inches of muscle is taken up within a few months and the full muscular power of the leg regained." We are of the opinion that leg shortening operations ought not to be performed until after growth has been well attained, both for fear that a continuing disturbed rate of growth may lead to later discrepancy in the length of the limbs and also because the resulting hyperemia may lead to an increased rate of growth on the shortened side, similar to that which has been observed following fracture of the femur. Either of these factors might upset the results of equalization.

INDICATIONS FOR, AND EVALUATION OF, THE DIFFERENT METHODS FOR EQUALIZING LEG LENGTH

The purpose of the authors in preparing this report was to compare the relative merits and disadvantages of the different methods of equalizing leg length (Table VIII).

TABLE VIII

COMPARISON OF METHODS OF EQUALIZATION OF LEG LENGTH

Method	Age	Period of Hospitalization	Seriousness of Procedure	Possible Correction
Local stimulation	3–14 yrs.	2 wks.	+	Slight
Lumbar sympathectomy	3–10 yrs.	3 wks.	+++	1 in.
Epiphyseal arrest	7–14 yrs.	3 wks.	++	4 ins.
Leg lengthening	over 14 yrs.	5 mos.+	++++	3 ins.
Leg shortening	over 15 yrs.	3 mos.+	+++	3 ins.

CONCLUSIONS

(1) Local stimulation of bone growth has not as yet been proved sufficiently successful to warrant clinical application.

(2) Lumbar sympathectomy, when indicated for the correction of circulatory disturbances in association with inequality of leg length, as frequently seen in poliomyelitis, may be expected to cause a favorable alteration of the diminished growth rate of the shorter extremity. Even when done before the age of nine years, improvement cannot be assured, and the greatest gain that can be expected is approximately one inch.

(3) Epiphyseal arrest in comparison with the other operative methods has the advantage of being a relatively minor surgical procedure. Few, if any, complications need be anticipated. Careful calculation is necessary to determine the age at which the operation should be performed, and which

epiphyses should be fused. This depends upon the age of the patient when first seen, the amount of shortening and whether or not it is increasing. When a gross discrepancy of length is to be overcome, the operation must be performed early. Complete fusion must be obtained in order to avoid any danger of later deformity due to asymmetric growth. This method offers the simplest and safest means of equalizing leg length. Its only drawback is that its application is limited to the growing period.

(4) Leg lengthening is a formidable procedure and frequently attended by serious complications. Until these difficulties have been overcome, its use should be limited to patients who are too old for epiphyseal arrest and are unwilling or ill able to sacrifice height by undergoing shortening of the longer extremity. Previous infection of a bone of the shorter extremity is a definite contraindication. We also warn against undertaking this procedure in a severely paralyzed or atrophic extremity.

(5) Leg shortening like epiphyseal arrest, has the disadvantage that it must be undertaken on the longer and usually normal leg. It is a relatively simple and safe procedure. Serious infection, nonunion, deformity and muscle weakness have not been reported. Although the operation has been performed almost exclusively upon the femur, it has also been undertaken successfully in the lower leg. The maximum correction so far reported is approximately three inches. Leg shortening should be advised only when growth is well established. Many patients show an aversion to loss of stature, but the elimination of the raised shoe more than compensates for this. Furthermore, it should be pointed out that a lowering of the center of gravity in a patient with a crippled lower extremity usually results in a gain of stability and an improvement of locomotion. Leg shortening, therefore, has the advantage over leg lengthening, in that it actually improves function.

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DISCUSSION—DR. CLAY RAY MURRAY (New York) said that Doctor Wilson and Doctor Thompson had presented one of the very best surveys of a difficult problem he had ever listened to. One of the most important features of the paper is that it did not stress so much the operative procedure as the evaluation that every one of the cases presented had been put through before any operative procedure was attempted. Studies of the development of the child's background, familial growth, the particular stage of growth the child happened to be in (the very active growth that children go through, or one of the latent periods)—all were carefully evaluated before either operative procedure was undertaken or before the time for such procedure was chosen. Even if a method is ideally carried out, and despite the method used, without extremely careful and prolonged evaluation before carrying it out, its value may be very largely lost.

DR. ALAN DE FOREST SMITH (New York) said that he had come to the same conclusions at the N. Y. Orthopedic Hospital as had Doctor Wilson, in evaluating the various methods of dealing with disturbance in the length of extremities. Leg lengthening is a very difficult and dangerous procedure, and fraught with many risks. It is reserved at the N. Y. Orthopedic Hospital for the very few cases in which the discrepancy is so great that it is impossible to overcome it by leg shortening.

Leg shortening is preferred in most cases by ephiphyseodesis in young children, before the end of their growth period, and by taking some bone out of the femur in adults and older children. Before dealing with this problem with entire success, it is necessary to have more data on the behavior of growth especially in poliomyelitis cases. Not enough is known about the effect of poliomyelitis on growth. From cases observed by Doctor Smith it is his opinion that they reach a stationary point at which there is no longer an inequality in rate, before the end of their growth period. A discrepancy in the growth of the extremities may result so that an extremity may lose an inch or two during a certain period of time. This difference then remains until the end of growth. If the behavior of these cases was more fully understood one would be better able to deal with them.