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# LEG LENGTH EQUALIZATION

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I wish to sincerely thank Dr. Richard D. Smith for his counseling and guidance in the preparation of this paper, and to my wife for her typing.

Inequalities of bone length are an important cause of deformity of the human body. Shortening of an arm can be disquised by clothing and is of little significance. A discrepancy in leg length produces a definite disability. It was the recent epidemic of poliomyelitis in this area which prompted my interest in the topic. Nothing new is presented, but perhaps by bringing the attention of others to this topic, some child may be more nearly able to have a normal body and lead a normal life.

Numerous diseases and deformities result in a shortening of one of the lower limbs. Impaired function during its longitudinal growth, paralysis due to nerve injury or following poliomyelitis, trauma, osteomyelitis, mal fractures and congenital anomalies are amongst the commonest causes of length discrepancy. In such cases, the ineqality of the limb length is the result of growth retardation and does not entail premature closure of the epiphyseal cartilages, although certainly premature epiphyseal closing causes leg length disparity when it does not involve all epiphyses of both legs.

Ross[1] states that there is usually roentgenographic evidence of growth disturbance present prior to development of marked inquality of limb length. The early alterations of the epiphyseal cartilage, which are evidence of growth disturbance at the knee, are thinness of the epiphyseal cartilage and the presence of a transverse zone of dense bone on its metaphyseal aspect. He also states that there is no way to produce resumption of normal growth from an epiphyseal plate which has undergone partial or complete fusion.

Basically there are only two ways to equalize leg lengths, namely shorten the long leg or lengthen the short leg. As a rule, orthopedic surgeons will be content to accept an inch difference in leg lengths, assuming compensation for this will be provided by tilt of the pelvis. Until the advent of anesthesia a limb showing shortening could be successfully treated only by a high shoe or some type of prosthetic appliance. The built up shoe is still occasionally used for discrepancies up to one inch.

Rizzoli[2] of Bologna, Italy, was probably the first to equalize leg length deliberately. In 1845 he permitted the fragments of a fractured femur to override three inches so that the length was equal to that of the other femur which had previously been fractured. Impressed by the ease of this procedure, two years later he produced a fracture of the femur with an osteoclast which he devised.

Rizzoli's successor, Codivilla[3] shortened a femur by open operation; more important he lengthened a short tibia. Even before Codivilla there had been attempts to lengthen the short leg. Overriding, partially united fractures were rebroken and pulled down with skin traction. But sloughing of the soft tissues of the heel and dorsum of the foot was the rule, and the method was considered impractical until Codivilla pulled directly on a pin in the calcaneus. When he reported the method in this country in 1904, he emphasized the fact that the soft parts and particularly the blood vessels and nerves, could not be lengthened as readily as the bone.

In 1913 Magnuson[4] published a paper on experimental one-stage lengthening of the femur with a step-cut osteotomy. A 32 pound pull was sufficient to get $\frac{1}{4}$ to $\frac{1}{2}$ inch lengthening of a dogs femur. Length was maintained by immediate fixation with ivory screws. In another paper Magnuson[5] reported fourteen cases of femoral lengthing by this method, with temporary toe drop in three cases and death from shock in one.

In 1921, Putti[6] who was Codivilla's successor, published a paper on "Operative Lengthening of the Femur" and added improvements to the technique. He applied traction and counter-traction directly to the shortened bone. His apparatus consiste of two metal pins driven into the proximal and distal fragments, projecting only on the outer side of the limb where they were connected by means of a spring-loaded telescopic tube. No other external fixation was used until elongation was complete, when the whole limb waw fixed in a plaster spica. Difficulty in maintaining alignment, and some delay in union, were experienced.

In 1927 Abbott[7] described a method of tibial elongation, which with modification became a standardized operation in America. In his first series of six cases he considered it unwise to lengthen the tibia more than two inches, but greater increases have been obtained by many surgeons. After dividing the tibia, traction and counter-traction were maintained by Steinmann pins above and below the osteotomy. The steps of Abbott's operation were: (1) Lengthening of the tendo achilles; (2) osteotomy of the fibula; (3) insertion of the drill pins; (4) osteotomy of the tibia; (5) application of the distraction apparatus. He divided the periosteum of the tibia completely around the bone, and the deep fascia on the antero-lateral aspect of the leg. Subsequent writers emphasized the importance of dividing these structures together with the interosseus membrane and the fibular intermuscular septum.

In 1936 Abbott and Saunders[8] offered a refined techinque of leg lengthening. Meticulous but extensive dissection was carried out preliminary to four pin traction and distraction. Also that same year Compere[9] summarized the case for and against bone lengthening. He found that every surgeon who had attempted the operation had encountered complications. These can be divided into three groups. They are: (1) due to overstretching; (2) due to interference with the blood supply to the fragments; (3) due to insufficient fixation of the fragments.

Allan[10] believes that the last two groups of complications could be overcome or avoided by alterations in the operative technique and the retentive apparatus. Compere encountered such complications as stretch paralysis of the sciatic or external popliteal nerve, increased weakness of lengthened muscles in old cases of poliomyelitis, fracture of the osteotomy fragment, malunion, delayed or non-union, osteomyelitis from wound infection or lighting of a silent bacterial focus, traumatic arthritis, and limitation of motion in the knee, late fracture, pressure or stretch necrosis of the skin in the zone of lengthening, necrosis of bone due to excessive periosteal stripping, malposition of the foot due to rotation following lengthening, circulatory disturbances with prolonged edema in the lengthened limb, displacement of the head or of the distal end of the fibula when this bone is not lengthened as much as the tibia, and protrusion of the osteotomy fragment of the tibia through the skin. In 1935, in addition to discribing similar complications in his series of forty-six lengthening operations, Brockway[11] stated that in a number of patients operated on during the growth years, the lengthened leg was again one inch or more short at maturity.

Contraindications to leg lengthening are as follows: (1) Shortening of less than three Cm; (2) an age of under fifteen or sixteen years; (3) any patient who is sufficiently tall to permit shortening the longer leg or who will not be psychologically disturbed because of loss in standing height; (4) weak or paralyzed muscles of the hip or knee; (5) shortening so marked that maximum lengthening will not sufficiently equalize the extremities to enable discarding shoe elevation or other appliance; (6) history or clinical and roentgen-ographic evidence of previous osteomyelitis in the short leg, or other pathology in the bone to be lengthened, such as fibrocystic disease; and (7) congenital short leg, as in absence of part of the bone to be lengthened or other severe deformities in which an artificial limb may give a better functional result.

Observations have been made by Allan[10] on the reaction of tissues to the operation. In bone the response is similar to that which occurs after fracture, though it is somewhat delayed. Within two months the radiograph shows bone laid down in parallel lines between the fragments, suggesting that osteogenic material is strung out across the gap. Since it is known that the periosteum is intact it is likely that much of it comes from that source. In somefemoral lengthenings the rate of new bone formation has been so fast that distraction has had to be stopped before the proper length was secured. The bone density is the same as that seen after a fracture, except that where a complete gap occurred through the breaking of a tongue or from over-distraction, increased density resulted. All bones returned to normal radiographic appearance within a year or so of consolidation. In one case of congenital shortening of the femur where the bone before operation was of ivory-like density, the osteotomy was made through the dense part, and after healing a much more normal texture was observed, suggesting that nutrition of the bone had been improved.

Muscles react badly to stretching. They offer little resistance, but it is difficult to maintain their nutrition, especially in the lower leg. As soon as they are in moderate tension the patient finds it difficult to maintain toe movements. By the time the traction apparatus is removed there is a marked degree of muscle wasting. Since, however, most below-knee cases have had infantile paralysis, and usually have a stabilized foot, or one which will have to be stabilized, this wasting is not of primary importance.

Probably the most resistant structures to stretching are the periosteum, the interosseus membrane, and the deep fascia. It is for this reason that many writers advocate free division of these structures. It is doubtful, however, if the advantages so gained outweigh the many disadvantages. If a positive method of elongation is employed great resistance can be overcome. It is likely that the pain which is experienced arises from these structures, and that the rate of elongation must be adjusted accordingly.

The blood vessels appear to be able to withstand much stretching, provided that it is done slowly. In not one case in Allan's series was there any hint of vascular embarassment, apart from local skin anemia due to uneven pressure.

The nerves are less immune than the arteries. In a large proportion of Allan's cases, nervous damage already existed, so that observation of the effects on motor power could not be assessed. In cases in which normal function was present, observation of toe movements was carried out. In lower leg cases, as length increased, the toes became drawn into plantar flexion, and it was difficult to distinquish between inability to dorsiflex through nerve failure, and inability to dorsiflex through increased tension of the flexor tendons. Three cases had hypoesthesia in the toes; otherwise there was no sign of interference with the internal popliteal nerve. Definite signs of external popliteal palsy were seen in fourteen cases, six in femoral, and eight in tibial lengthenings. In tibial cases the loss in conductivity was transient, all cases recovering before the apparatus was removed. The invrease in length be fore the nerve was affected varied from one and a half inches to four and a quarter inches. The vulnerability of the external popliteal nerve to stretching may be explained by its fixation where it winds around the neck of the fibula. It must be remembered, however, that in below the knee-cases the degree of stretching of the nerve is much less than half the lengthening of the bone, because the muscles receive their nerve supply in the upper half of the leg. In above-knee cases, the nerve is stretched to an extent equal to elongation of bone. It can therefore be stated fairly that the external popliteal nerve and the component part of the great sciatic nerve may be stretched two inches in the thigh over a period of four to six weeks without losing conductivity, and that it may be stretched three inches with only temporary impairment.

In femoral lengthening it was the rule for the knee joint to stiffen temporarily, especially if one of the traction wires was placed anywhere near the joint, whether above or below. The stiffness usually passed off after a few weeks of exercise. The knee is usually unaffected in tibial lengthening. The hip was never affected.

Other than surgical means of lengthening have been attempted. The acceleration of growth by sympathectomy has been advocated by

Harris.[12] The increment of length obtained after this operation is usually too small to be of practical importance unless there is some clinical evidence of associated vasomotor disturbance.

Animal experimentation, according to Barr et al,[13] has failed to confirm the belief that lumbar sympathectomy will stimulate growth of the lower extremity. Cannon,[14] after performing unilateral ganglionectomy in young kittens, stated that there was no demonstrable difference between the two sides, and concluded that the sympathetic system is not concerned with growth of the skeletal system. Harris and McDonald's[15] experiments confirmed Cannon's findings. The same conclusion was reached by Bacq,[16] studying the hind limbs of albino rats, Bisgard[17] studying the limbs of goats, and Simon, working with the forelimbs of rabbits.

Harris[12] also reported a case in which an increased rate of growth followed lumbar ganglionectomy. He reported a case in which left lumbar ganglimectomy was done for Hirschsprung's disease; in this instance, too, there was an increased rate of growth in the lower extremity.

Ogilvie[18] noted that early postoperative results were favorable following ganglionectomy in four cases of poliomyelitis. The circulation improved markedly and one patient had the desired increase in rate of growth of the extremity.

Review of the literature suggests that ipsilateral lumbar ganglionectomy has, in some instances, a stimulating effect upon the growth of the shorter extremity of a patient with poliomyelitis. This stimulation is probably the result of increased blood flow which occurs after ganglimectomy.

Osmonde-Clarke[19] mentions workers in Sweden who have produced arteriovenous fistulae to increase blood supply to stimulate growth of the short limb. Acceleration of growth rate has been produced but the probable cardiac changes make the method hazardous.

Professor J. Trueta[20] reported ten cases of children with overgrowth of long bones associated with osteomyelitis. In these cases, as well as fractures in the shaft with overgrowth, the diaphysis, particularly the marrow cavity, was involved primarily. Similar changes have been produced experimentally in rabbit tibia by blockage of the nutrient foramina with wax. The report of this investigation was preliminary and no conclusions were drawn.

Tucker and Carpenter[21] report a case of marked inequality of limb length due to localized neurofibromatosis. At the time the lesion, which sprung from the tibial nerve, was explored, the lower limbs were of the same length and diameter. Eleven months later, the affected leg was one and a half inches longer, most of the growth increase was in the tibia.-

Numerous instances of overgrowth due to various local processes in the extremity have been recorded in recent years, but the first detailed observations were made more than a century ago by Stanley,[22] whose description of overgrowth of long bones was followed shortly thereafter by a similar and equally famous report by Paget.[23] In 1869, Von Langenbeck[29] also described in detail the overgrowth of long bones. Working on the premise that suppuration in the bone accompanied by sequestration acts as a stimulus to growth, Von Langeback undertook to reproduce these conditions in a dog by using ivory pegs. He introduced these pegs into the left femur and tibia of an eight week old dog. No infection occurred and the wound healed by primary intention. Fifteen weeks later, when the animal was sacrificed, there was 0.5 cm overgrowth in both the femur and the tibia.

In 1910, Meisenbach[24] attempted to stimulate growth of long bones locally by injecting various chemicals as well as Staphlococcus aureus vaccine through a large-caliber needle into the upper end of the tibiae close to the epiphyseal plates of growing rabbits without effect. In addition, using a small trocar, he inserted graphite plugs into the bone. Formalin produced more reaction than any of the other materials employed causing an increase in the thickness of the cortical bone and at the same time producing premature ossification of the epiphyseal cartilage.

Bohlman,[25] in 1929, described experimentation on ninty-two guinea pigs. He drilled holes in four different locations in each of a series of four animals, Twenty-two different materials or combination of substances were placed in the drill holes. These included, among others, iron, copper, wood, ivory, Staphlococcus aureus vaccine, and oils of various kinds, Bohlman concluded that foreign material not only did not produce an increased growth in length of bones, but often actually caused a pronounced shortening.

In 1933, Ferguson[26] found that stimulation of bone growth occurred as a result of drilling holes in the metaphysis and curretting the medullary canal. This procedure revealed some stimulation of bone growth, but the growth was not sustained.

In 1937, Wu and Miltner[27] performed experiments similar to those of Meisenbach, Bohlman and Ferguson with minor modification of technique. Their methods failed to produce significant increase in length growth. By chance, in several animals, it was observed that stimulation of growth was produced by the simple procedure of loosening or stripping the periosteum from the bone shaft. This operation was performed subsequently on twenty-two animals with uniform and significant results. Although the amount of length growth seemed small, it actually represented and increase of from five to fifteen per cent over normal growth of the bone during that period of time. Monthly roentgenograms showed that the most active stimulation of growth took place during the first three months following the operation.

During 1940 and 1941 Haas inserted foreign bodies about the epiphyseal plate experimentally. He used iron, copper, aluminum, magnesium and growth-hormone powder. No stimulation of longitudinal growth occurred in any of the experiments. Moreover, magnesium oxide powder caused tissue destruction with resultant retardation of growth. Because of the negative findings, according to Pease,[28] Haas did not report his painstaking work.

Chapchal and Zeldencrust,[30] in 1948, noted the effects of various metals and metal alloys on long bone growth. They concluded that some lengthening of bone was obtained but the amount of growth stimulation was minimal and uncertain. They noted also that, following the insertion of foreign materials, deformities of the bones resulted. They stated, therefore that the procedure was not suitable for human practice. Pease[28] however was not deterred by the above reported results. To him the procedure seemed so safe and so simple that he thought it feasible to correct potential disparity of only an inch. He selected ten cases, all children, five with congenital hypoplasia and five who had had poliomyelitis. He placed metal or ivory screws in the metaphyseal region close to the cartilage plate. In all of these an increase in the rate of growth occurred after operation. Although in cases of unilateral congenital hypoplasia prediction of growth rate was impossible, in poliomyelitis more exact estimate of growth was possible, although here too there are many variables.

How much growth stimulation can be expected is also variable. If extensive paralysis exists and inadequate use of the extremity decreases the normal stimulation resulting from stress and strain, more rapid degeneration of the cells in the epiphyseal plate can be expected. Skillful evaluation of the existing factors is important in selecting the optimum time to initiate growth stimulation. Obviously, the sooner more normal physiological conditions are restored about the epiphyseal plate of the paralyzed limb, the more favorable will be the results. Pease was of the opinion that if growth stimulating procedures were indicated, they should be started within two years after an attack of poliomyelitis. To study his results, Pease used orthoroentgenography as described by Green, Wyatt and Anderson.[31] He gave these children small doses of phosphorous either in its natural state or as phosphorized cod-liver oil. This produced in their bones dense layers of bone which were used to facilitate measurement. According to Adams[32] the dense layers of bone or "lines of arrested growth" are composed of normal compact bone. Pease learned that ivory screws were the best material to use, not because the other materials failed to stimulate growth, but because they caused less edema and local reaction, and were not eventually surrounded by a fibrous capsule which decreased the irritant and thus the growth-stimulating effect. He further learned that in time these screws absorbed, making removal unnecessary. In his series, accelerated growth occurred for a period of two to three years after operation, becoming less as the epiphyseal plate grew away from the region of the foreign material. In the event that the growth rate had slowed and the epiphyses remained open, a second screw was placed in the distal part of the femoral metaphysis close to the cartilage plate with resumption of an increased growth rate.

The other alternative to lengthening the short leg is the shortening of the longer, and in most cases, the normal limb. Leg shortening is considered by most to be the best approach to the problem. It is often difficult to obtain permission, for any procedure on a normal limb in the presence of an abnormal limb on the other side. There is also the psychological factor to be considered. It is felt that to reduce a mans height to below five feet six inches precludes the use of a shortening procedure. This seems to be a point of lesser consideration in Britain where the shortening procedures are preferred in almost every case. Shortening also has the disadvantage in that these operations can only be successfully performed on adults, because otherwise growth would continue to be unequal. One should not forget the fact that the muscles must adapt themselves in their functions to the new length of the skeleton. This usually happens although some muscular insufficiency may exist for a time.

Taylor[33] and Shands[34] observed that leg shortening is much easier than lengthening. Many shortening procedures have been used throughout the years. Calve'[35] published his somewhat complicated methods of femur shortening in 1918. He achieved as much as 4 cm shortening and maintained the position by dovetail or tongue-and-groove approximation of the ends of the femur. The technique was simplified considerably by J. Warren White[36] in 1935. After a transverse osteotomy overriding was maintained by two pins incorporated in plaster, which were withdrawn after eight weeks.

It is generally recognized that Ollier[37] was the first to arrest growth. He destroyed or resected what was left of the distal epiphyseal plate of the tibia and excised one or both epiphyseal cartilages of the fibula in the correction of varus deformity at the ankle. The first practical procedure for the regulation of growth of long bones was presented by Phemister[38] in 1932. He curetted and grafted one epiphyseal plate of a long bone at the time indicated by a composite growth chart. The operation was of less magnitude, and it did not carry as much risk of complication as the previous ones. Failure to stop growth on one side of the bone occasionally caused angular deformity. Mistakes in estimating the future growth resulted in inadequate or excessive correction.

A successful epiphyseal arrest operation requires an accurate prediction of future growth of the patients bones. Baldwin,[39] Hatcher,[40] Gill and Abbott,[41] Green and Anderson[42] and others have contributed growth studies and have compiled growth and graphs. Even if one allows for familial tendencies, habitus, and bone age, these are only approximations. They must rely on actuarial computations based on averages. However, these growth studies are the basis for the prognosis in in any growth control operation. Their principle must be understood before any of the procedures for leg equalization is undertaken.

Roentgen radiation of the epiphysis has produced retardation of growth somewhat proportional to the amount of radiation. Bisgard and Hunt[43] relate that with rabbits they attained an injury of the cells of the epiphyseal cartilage plate at 50 to 100% SRD. With 400r they obtained a shortening of 5 mm in the femur of a rabbit. Barr[44] and his associates found that large doses completely stopped growth of the tibial epiphyses in albino rats; moderate doses retarded it. They and others[45] tried roentgen radiation on the epiphyses of children. The method was discarded because the results were not dependable and there was the hazard of soft tissue damage.

While looking for a method of stimulating growth, Haas discovered that the elongation of a bone could be retarded by encircling the epiphyseal plate with a wire loop. This proved feasible in both laboratory animals and in children. Growth was held back mechanically. When the wire loop broke or was removed, growth was resumed at about the normal rate. The implications were tremendous, for Haas had discovered the principle of temporary arrest of epiphyseal growth.

Stimulated by this work of Haas, in 1944 Blount began to use rigid staples for temporary epiphyseal growth arrest. Staples were used in American bone surgery as early as 1906,[47] and Venable and Stuck[48] report that they had been employed in Europe long before that time.

Blount[49] uses simple smooth wire staples made from three thirty-second-inch rods of 317 M stainless steel with a Rockwell hardness between 33 and 35 C. He learned early that bending, breaking and extrusion were mechanical problems to be solved. He has found that by using staples in series of threes he has minimized these difficulties. The operative technique is comparatively simple for the staples may be inserted "blind" without actually cutting through the cartilage cap and exposing the epiphyseal plate. Roentgenograms in two planes and careful follow up are imperative. Angular deformity and overcorrection have occurred when patients have failed to report regularly for observation. Deformities which are produced by mistakes of prediction or of technique may be corrected without osteotomy by rearranging the staples, if the child continues to grow.

The decision as to which epiphysis to fuse and when to do it is difficult, however the decision as to which epiphysis to staple is not a serious matter. Both the proximal tibial and distal femoral epiphyses should be stapled. When the individual bone is of the proper length, the staples are removed. Only two precautions are necessary to insure successful timing of the stapling procedure. The staples must be inserted early enough, but not usually before the eighth year, to assure correction before growth is complete. The patient must be observed closely so that the staples are removed at the right time. The staples may be left in place safely up to two years. The indications for removal of staples are not determined entirely by measurement, but by watching the patient walk. This is particularly true when an unstable hip, stiff knee, drop foot or other abnormalities influence the decision.

This paper attempts to point out the importance of limb length equality and is a review of the many methods devised to bring about such equality. No attempt has been made to notate the specific technical steps in each procedure, but some of the indications, contraindications and complications of the various methods are presented.

As we learn more about the factors influencing bone growth in the human, combinations of bone stimulation and retardation will be used more and more to equalize linear and angular deformities. Bone shortening operations can never be abandoned. Lengthening is occasionally indicated. Growth stimulation, although it is too early to draw conclusions, is not reliable in animals, but does seem promising in humans. Epiphyseodesis is still a useful operation when growth arrest promises only incomplete correction. Stapling will be of practical importance until a better method of growth retardation is found.

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