

BIOMECHANICAL BASIS OF THE TIBIAL RECURVATION OSTEOTOMY

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Introduction:

Tibial recurvation osteotomy which was introduced by Lok, et al. (8) more than ten years ago has been applied to over 140 patients with a high rate of success. Results depend on the pre-operative functional status of the different muscles of the hip and the lower extremity. The operation is primarily performed on poliomyelitis patients with loss of quadriceps function where there are no other muscles of substantial mass for surgical transfer and knee arthrodesis is not desirable. In principle it is aimed at modifying the knee joint angle so that the knee is locked at an angle of recurvation early during stance. This allows the patient to walk without the aid of his hand to stabilize the knee or without the support of a prosthetic device. Knee stabilization is thus accomplished with minimal muscle power that is with whatever muscle function exists (Fig. 1 & 2).

The technique and the complications that may arise were reported previously (8). The size of the recurvation angle appropriate for each patient is different and depends on available muscle strength; particularly of the gluteus maximus and the triceps muscles. Determination of the recurvation angle has until now been based on experience. In what follows we attempt to establish objective criteria for determining the recurvation angle appropriate for each patient by following a biomechanical approach.

Comparative Biomechanics of the Normal and Recurvation Osteotomized Knee:

As has been pointed out by Maquet (9), during symmetrical stance on both legs the center of gravity of the body, the hip joint, the knee joint and the ankle joint all lie on almost a vertical straight line in the sagittal plane so that muscular force necessary to maintain body equilibrium is "theoretically negligible". In the

poliomyelitis patient's static equilibrium in the sagittal plane can only be established if the knee joint is locked in hyperextension. Dynamic situations such as during gait require more complex analysis because additional forces of inertia are involved due to accelerations and decelerations of the body and the limbs.

Using the data of Braune and Fischer (1,2,3,4 5,6,7) Maquet calculated the magnitudes and directions of the inertial forces along the three coordinate axis for each phase of the gait cycle. The resultant P of these forces and the downward force P_7 due to the partial body weight (i.e. weight of the head plus trunk plus upper limbs plus the swinging lower limb plus the loaded thigh) was found for each phase. Since the inertial forces change in both sense and magnitude as the body moves, the magnitude and direction of the resultant force change also. This force is almost always eccentrically exerted on the tibial plateau. To balance this eccentric force additional forces arise in the muscles, tendons and ligaments surrounding the knee. In addition, during phases 12-15 (stance on the right leg) because the resultant force passes behind the knee it must be balanced by a force acting in front of the knee. This frontal force is provided by the tensions in the quadriceps muscle and the patellar tendon.

Obviously if the line of action of force P had passed through the axis of flexion of the knee, the above frontal force would not be necessary to stabilize the knee. In the poliomyelitis patient the quadriceps and triceps muscles and frequently other leg and hip muscles are inactive. Table I shows a classification of these patients into different categories. This classification is based on the function tests of the muscles involved (II). As seen in the table, all patients lack

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quadriceps and hamstring functions. Triceps and gluteus maximus functions range from zero to normal.

It is known that the knee is mostly in a flexed position during normal stance on one leg (10). Therefore if this flexion moment can be decreased or eliminated the quadriceps force necessary for the opposite extension moment can be decreased or eliminated. This can be achieved by tibial recurvation osteotomy which results in shifting the knee flexion point (G) in the sagittal plane to or very near the line of action of the sagittal component P_{V7} of the resultant force P in the following manner. (Fig. 1)

Figure 3 illustrates the successive positions of the femur and tibia in the sagittal plane during the stance phases 12-23 (i.e. when full load is being carried by the right leg). The sagittal component P_{XZ} of the force P for each phase is also shown. The coordinates of S_7 and point G as well as the knee flexion angles used to construct this figure were taken from Maquet (9). These data belong to Subject I of Braune and Fischer. Hip joint (point H) coordinates are not reported by Maquet. So we first measured its coordinates from a figure (Figure 9 of Maquet) of the body position in phase 12 drawn to scale and determined the distance between point H and S_7 . Using the newly found coordinates of the hip joint and the known coordinates of point G the position of the femur and its length between H and G could be determined. With the additional knowledge of the knee flexion angle (Angle of Fischer) during each phase the position of the tibia could also be drawn. It was assumed that the distance S_7 -H remains constant for all phases.

A line drawn from point G perpendicular to the line of action of P_{XZ} is the moment arm of force P_{XZ} . It is this moment that should be reduced, and there are two ways in which this can be accomplished: 1. shifting the line of action of P_{XZ} forward, 2. reducing the moment arm. Figure 4 shows (for phase 17) how point G can be brought nearer the line of action of P_{XZ} by modifying the knee angle in an unnatural manner. However in this position the forward extension of the femur is restricted to accommodate the total length of the limb while allowing a stride length as before. The recurvation angle meeting these requirements can be determined graphically as follows. First an arc which has a radius equal to the tibial axis and centered at foot contact point is drawn. Next a second arc centered at the hip joint and having a radius equal to the femoral length is drawn. The two arcs intersect each other at two points one of which is the normal knee center G during the considered phase. The second inter-

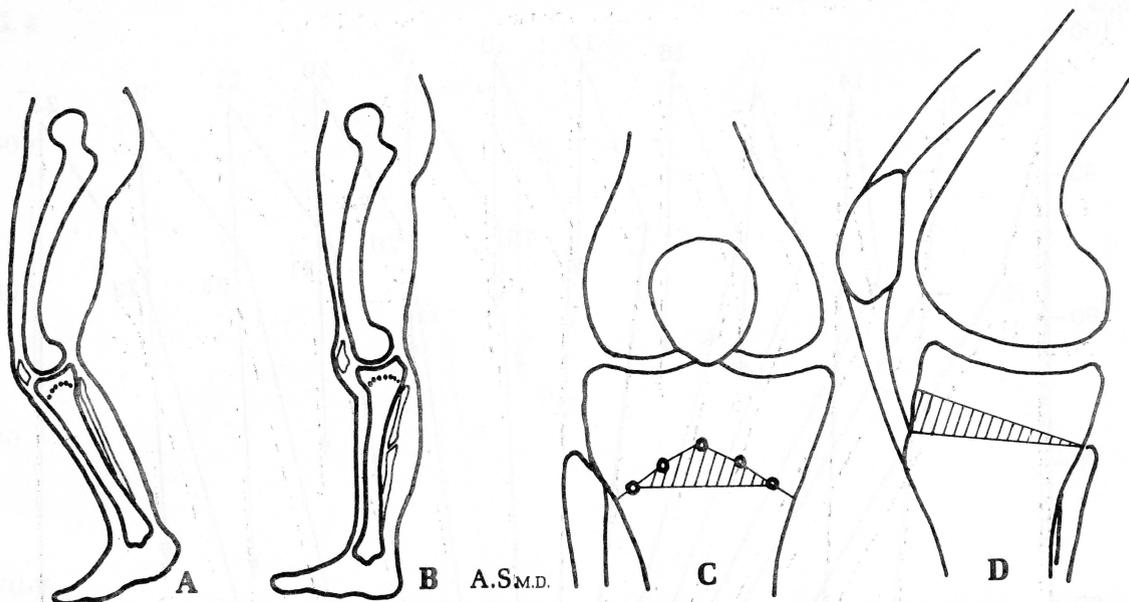
section point G' defines the position of the modified knee center having a recurvation angle of Θ which is necessarily equal to the knee flexion angle for that phase (for example 8° for phase 17).

However it is seen that during phases before phase 17 the distance between the new knee center (point G') and the line of action of P_{XZ} is still not zero although it is reduced considerably. So there will still be an appreciable flexion moment tending to buckle the knee. To reduce this moment further the patient can shift the line of action of force P_{XZ} forward by a torso maneuver that brings the partial center of gravity S_7 further to the front. Since such a maneuver during heel strike (phase 10) will also increase the horizontal component of P_{XZ} the orientation of the latter will be changed towards point G'. Indeed this maneuver is quickly learned and executed by patients who receive this operation. This fact allows a further reduction of the recurvation angle to a minimum value determined from phase 17, another critical phase of stance.

Once the knee is locked at a given recurvation angle during heel strike the leg is maintained in this position throughout the following phases. During the later phases the knee joint remains always behind point S_7 . Phase 17 is critical in that point S_7 is almost straight above point G at this instant. Therefore the knee may be driven to instability by buckling if it is not locked properly, since also the horizontal inertial component of P_{XZ} is zero at this instant (see Fig. 2). The degree of recurvation necessary to prevent this instability can be determined by the graphical method described earlier and turns out to be approximately 8 degrees. We consider this value as the optimum value that will be adequate for all phases provided that the gluteus maximus and the triceps muscles are sufficiently functional and the patient employs the torso maneuver mentioned above.

Finally a comment should be made about the functional status, passive length of the triceps muscle and/or the Achilles tendon. If the triceps is functional or the Achilles tendon or this muscle is short, dorsiflexion of the foot is limited so that the loading point of the forefoot is shifted forward. This in turn has the effect of lengthening the tibial mechanical axis thus effectively increasing the recurvation angle.

Indeed, our more recent practice shows that two additional operations in the lower extremity, namely Achilles tendon shortening and a reverse Lambrinudi operation at the foot articulations combined with tibial recurvation osteotomy can give satisfactory results even in the most unfavourable cases included in Table I.



Schematic illustrations of the lower extremity before the operation (a), after the operation (b). A dome shaped osteotomy is applied above the tibial tuberosity (c and d).

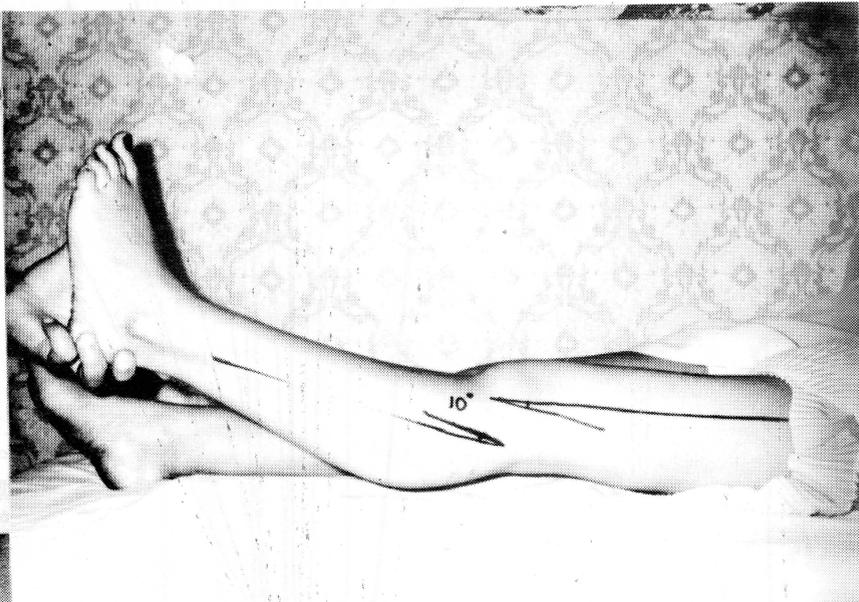
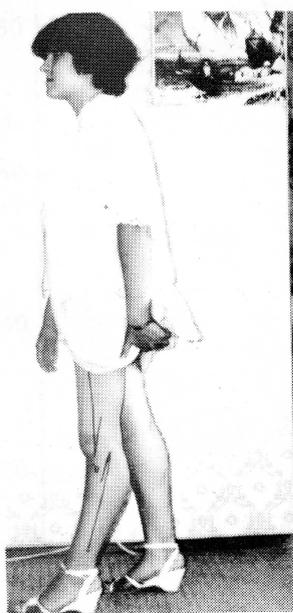


Fig. 2 A Sagittal views of the patients posture (a), and leg after a 10° recurvatum osteotomy (b).

TABLE I
FUNCTIONAL STATUS OF MUSCLES IN RECURVATION OSTEOTOMISED PATIENTS.

Category	Quadriceps	Hamstring	Triceps	Gluteus Max.
1	0 (Zero)	0	Fair-Good-Normal	Fair-Good-Normal
2	0	0	0	Fair-Good-Normal
3	0	0	Fair-Good-Normal	0 or POOR
4	0	0	0	0 or POOR
5	0	0	0 but SHORT	0 or POOR
6	0	Good or Normal	Fair-Good-Normal	Fair-Good-Normal

FIG. 3

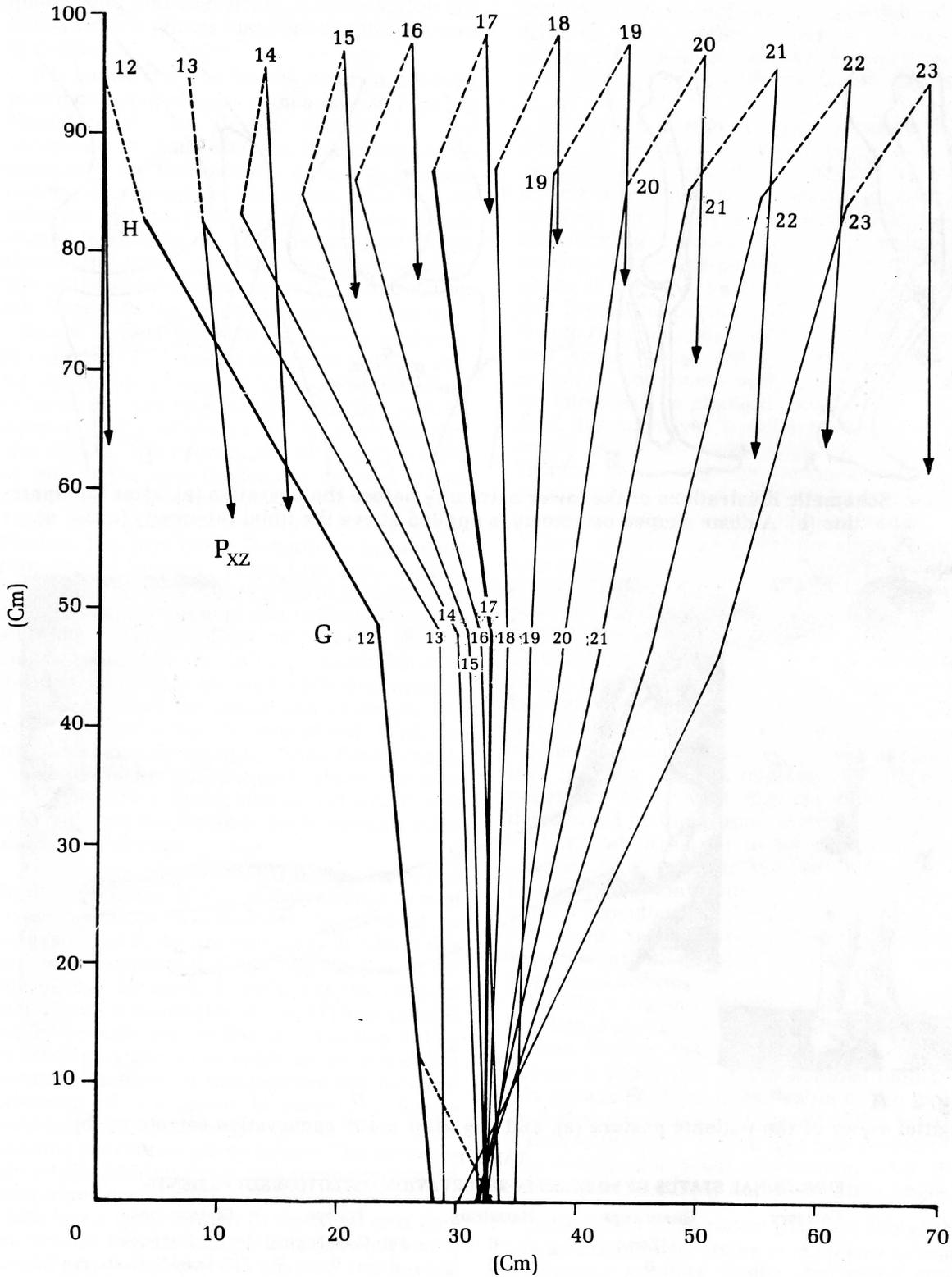
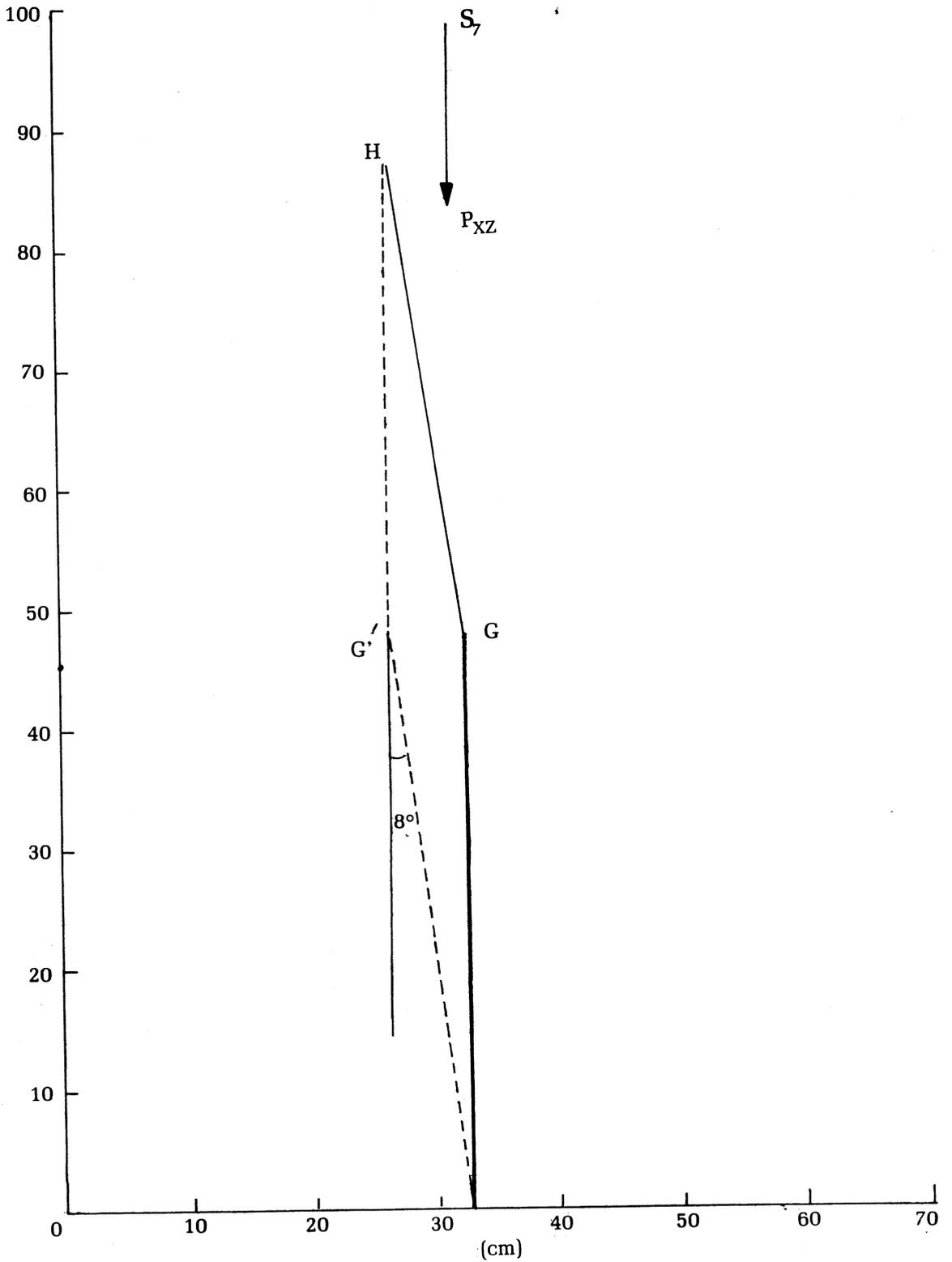


FIG. 4



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