DEVELOPMENT OF A CLASSIFICATION SYSTEM ON ANKLE-JOINT STIFFNESS

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INTRODUCTION

In running the injuries to the lower leg are described to e.g. insufficient shock absorbtion properties and/or insufficient stability properties of the shoes [Clarke et al, 1984, Nigg, 1986].

In a previous study [Wijlens, 1990, van der Zande, 1990] a classification system for running shoes has been developed on the aspects stability and shock absorption based on a mechanical test protocol. If corresponding features *can* be quantified for the (lower) legs of the runner, running shoes can be selected more carefully. For example, a runner with less stiff ankles may need shoes which have high stabilizing properties, whereas runners with stable ankles may ask for (more) shock absorbency of their shoes. Consequently, classification systems may contribute to the reduction and/or prevention of running-related injuries.

The limited amount of studies to quantify the ankle-joint behaviour have studied the in vitro ankle stiffness or laxity as a Function of several ligaments [Chen et al, 1988, Siegler et al, 1990]. Mizrahi et al. [1990] studied with a mechanical setup the dynamic behaviour of the ankles of 6 persons during sudden inversion. In the present project we have focused ourselves on the development of an in vivo method to quantify the stiffness of the ankle for inversion and eversion rotations. Aim of this study is to develop a classification system for the ankle stability in sideward rotations of the foot.

METHODOLOGY

THE ANKLE LOADING APPARATUS

In order to determine the ankle stability a so-called ankle loading apparatus has been developed (Fig 1).

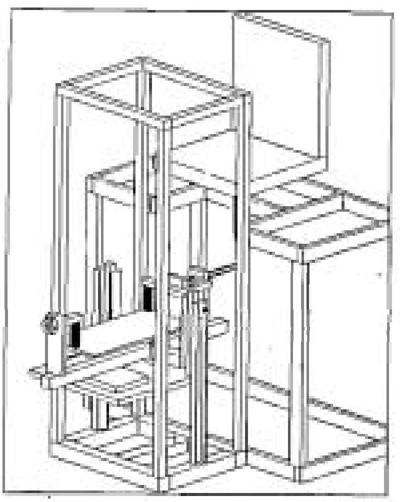


Figure 1. Overall view of the ankle loading apparatus

The foot of a person to be tested in sitting position is placed on a platform. The forefoot is fixed by straps while the calcaneus is kept in place by a circular bag filled with sand and hardened by taking air out of the bag. The lower leg is kept in vertical position by straps. The leg is allowed to rotate around and translate along the vertical axis of the lower leg.

By rotating the platform, the foot can be moved through plantar/dorsal flexion, abduction/adduction and inward/outward rotation. In the first two planes of motion discrete positions of the foot are prescribed while the inward/outward motion is imposed in a motor-driven way. The moment of force resulting from the inward/outward rotation is measured using 3 force-transducers and the inward/outward rotation is measured by a goniometer.

The three axes of rotation of the apparatus (fig *2) can* be parallel moved accommodating individual differences in ankle dimensions. The axial load upon the lower leg can be varied in discrete steps.

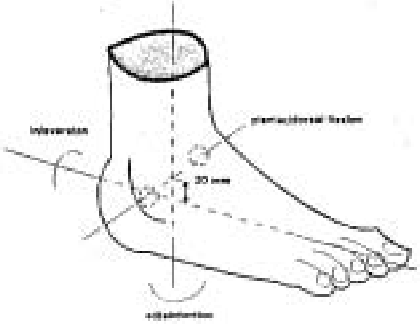


Figure 2. The position of the three axis of rotation of the ankle loading apparatus in respect of the foot and lower leg. The intersection point of the plantar-dorsal axis lies 20 mm proximal of the centrepoint between the lowest points of the medial and lateral malleoli.

MEASUREMENTS

To obtain the ankle dimensions a 3D-coordinate measuring system is used. The positions of the lowest points of the medial and lateral malleoli are palpated and measured. These data are used to position the foot in the apparatus with respect to the 3 axes of rotation of the apparatus (fig 2)

In this study, the moment of force (M) as function of rotation (Φ) is measured during inversion/eversion cycles in two positions of the foot (table 1). The safe range of motion of the foot in the ankle is first measured by hand. These manually obtained results are used to adjust the stroke of the motor within this safe range of motion. No axial load is applied upon the tibia.

Two measurement runs of each 5 cycles are performed (velocity 0.15 cycles/s). For reasons of preconditioning effects only the data of the second run are analyzed. Two groups of persons are tested at present: one group of 14 volunteers without ankle complaints and another group of 6 with ankle complaints.

Table 1 Positions of the foot in the ankle loading apparatus during which inversion/eversion measurements were performed.

position	angle of plantar flexion [°]	angle of adduction [°]
neutral position	0	0
flexed position	20	10

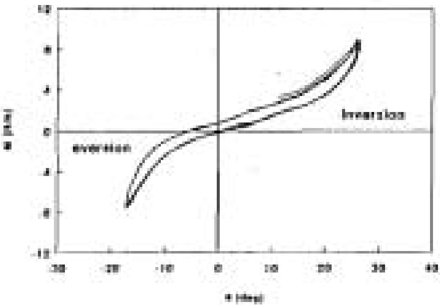
RESULTS AND DISCUSSION

In figure 3 a typical result of moment versus inversion/eversion angle as found in the tests is shown. In each situation differences can be seen between upward and backward part of the cycle. The curves as well as the measured moments and angles are similar to those found by Chen et al [1988] during in vitro studies. The 5 cycles are averaged to 1 M-@-curve and fitted with a fifth grade polynom (fig 4). On basis of the differentiated M-@-curve ($dM/d\Phi$) as a function of Φ (fig 5) a division is made into primary and secondary stiffness-areas. The primary stiffness-area is the angle-range where $2*[dM/d\Phi]_{min} > dM/d\Phi > [dM/d\Phi]_{min}$. This division is similar to that made by Quin et al [1991] for the knee. The curve and values of the found $dM/d\Phi$ versus Φ relation are similar to the (recipoce) results of Chen et al [1988]. Based on the processed data several parameters are deduced such as primary stiffness (Ko) and mobility (Om) **(fig** 6).

With regard to the selected parameters, primary stiffness and mobility reproducibility tests reveal short term differences during successive measurements of less than 3% (standard deviation). Long term reproducibility tests with time intervals of several days show differences up to 15 % (standard deviation).

In both the neutral and the flexed position the primary stiffness shows to be linear related to the mobility (a higher stiffness results in a lower mobility) (fig 7, 8). In the flexed position the primary stiffness is less than in the neutral position.

Using the primary stiffness results of the 'sound' group in the flexed foot position a starting classification is made in terms of 'stiff', 'neutral', and 'lax' (fig 8). The results of the 'injured' ankles in this classification show that most of these ankles belong to the 'lax' category. Biomechanical and epidemiological studies are necessary to evaluate the ultimate effects of combined foot/shoe classifications.



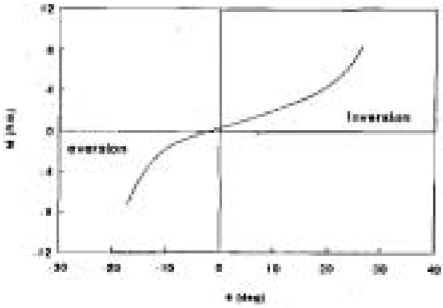


Figure 3. (left) Measured moment (M) versus inversion/eversion angle (Φ).
Figure 4. (right) Averaged and fitted moment-angle-curve

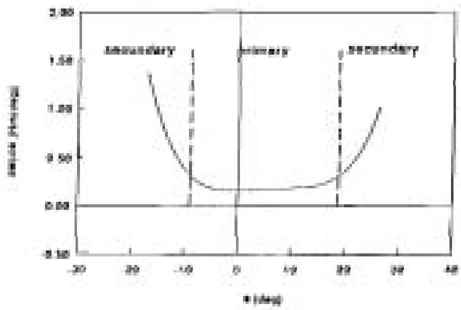


Figure 5. $dM/d\Phi$ as a function of inversion/eversion angle. A division is made into primary and secondary stiffness areas.

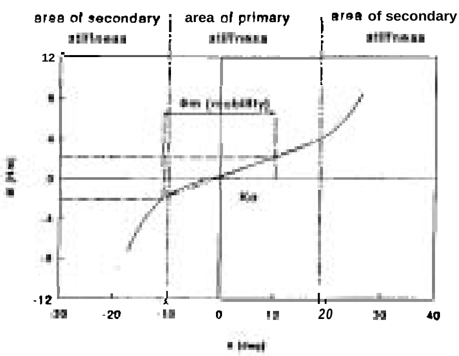
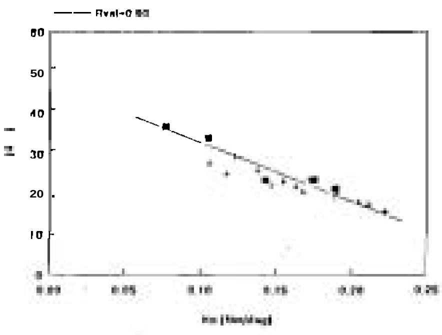


Figure 6. Selected parameters for description of the M-Φ relationship.



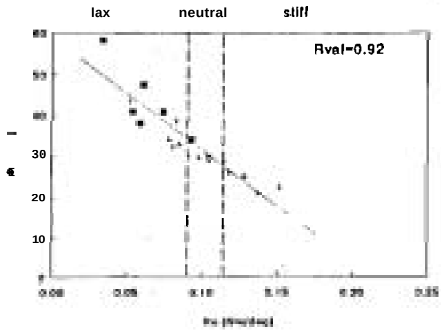


Figure 7. (left) The mobility Φm as a Function of the primary stiffness (Ko) for all tested persons; neutral position. (+ results for the group with sound ankles; # results for the group with injured ankles).

Figure 8. (right) The mobility Φm as a function of the primary stiffness (Ko) for all tested persons; flexed position. (+ results for the group with sound ankles; # results for the group with injured ankles). In the figure a starting grouping of ankles is made in stiff, neutral and lax.

CONCLUSIONS

The ankle loading apparatus seems to be a useful and objective tool to measure and analyse ankle stiffness and can thus be used as a basis for classification of ankle stiffness.

Based on this study a starting classification is made in stiff neutral and lax ankles. The 'injured' ankles appear to be mainly in the lax-category.

More biomechanical and epidemiological studies are needed e.g. to create and validate a definite classification, and to determine the influence of axial loading.

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