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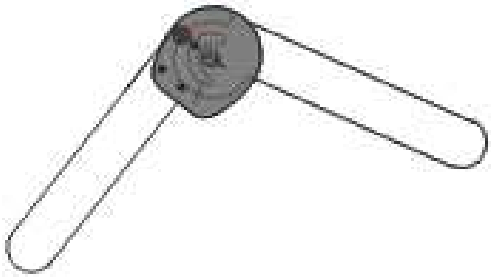
THE ROTO-TRANSLATIONAL EVALUATOR OF THE KNEE.



The movement of the knee flexion occurs during the first 30° according to a circular path around a fixed center (up to 135°) andfollowed by a roto-translation phase characterized by a progressive decrease of the distance between the instantaneous center of rotation and the articular surface.

However, we have to consider a further movement associated with the roto-translation, which is the automatic longitudinally rotation of the tibia, as a consequence of the different conformation of the femoral condyles, respectively, outer and **inner** compartment.

More precisely, although keeping the roto-translational motion as a reference, it takes on different values depending on the sector considered (Fig.1).

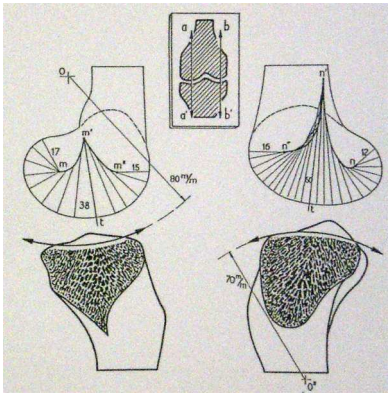
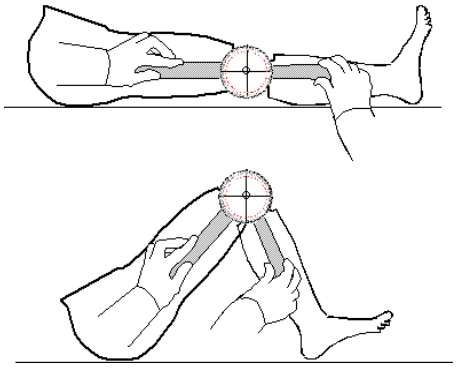


Fig. 1

Anyway, it is on the anterior-posterior, which is the greater range of motion and that leads us to consider that all the experimental results obtained on the antero- posterior be considered a "middle" of the trajectory of the internal and external sector.

Although roto-translational motion of the knee was known since the early studies (the first model proposed by Rond is dated 1913), the evaluation system has always been limited to a goniometric circular measure (Fig.2) and does not take into account the linear translation inevitably involves, after 30° sliding between tool and limb. In fact, if we keep fixed the instrument to the distal thigh, the arm of the goniometer moves relative to the leg; if we keep fixed the instrument to the proximal leg, it is the arm that moves relative to the proximal thigh.

This means that the goniometer is unable to ensure that all points of contact remain constant from the beginning to the end of the assessment, by failinig the main feature of which must be a device evaluation.

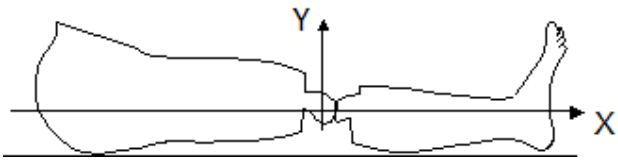


The new assessment tool of the knee

For a proper evaluation of the roto - translational motion of the knee, therefore, it is essential that the device reproduces the same characteristics of the motion with a relevant reference scale.

To make more explicit the above, it is essential to consider the leg with the thigh in line with the longitudinal axis corresponding to the X axis which orthogonally intersects Y axis which perpendiculary passing through the initial center of rotation of the knee.

Automatically, the Y axis cuts horizontally the femoral condyle (Fig.3).



To describe the progressive shift of the axis of rotation of the knee, determinated that Ra is the first radius of rotation that lies on the Y axis (Fig. 4), the trajectory of flexion-extension of the leg on the thigh can be analytically defined:

for $\alpha < 30°$ knee motion can be described as a system disk that rotates around a fixed center (initial center of rotation) : the trajectory performed by the point P (as a distal end of radius Ra) has the equation of a circle $X^2+Y^2=Ra^2$;

for $30° \leq \alpha < 135°$, the center of rotation moves towards the articular surface by an ammount equal to Δ_x.

The new coordinates of point P become :

$$X1 = X + \Delta_x$$

$$Y1 = Y + \Delta_y$$

The equation of the center of rotation of the knee (instantaneous center of rotation) turns out to be:

$$X1^2 + Y1^2 = Rb^2$$

When Rb is the true radius of rotation that change with the change of α with Rb<Ra.

When α is the angle between the X axis and the radius of rotation , the values of X, X1, Y1 and Y can be obtained that way :

$$X = Ra \operatorname{sen} \alpha$$

$$Y = Ra \cos \alpha$$

$$X1 = Rb \operatorname{sen} \alpha$$

$$Y1 = Rb \cos \alpha$$

So, for a given value of α between 30° and 135° the position of the instantaneous center of rotation can

be calculated :

$$\Delta_x = X1 - X = (Ra - Rb) \text{ sen } \boldsymbol{\alpha}$$

From 30° of flexion and later (up to 135°) the center of rotation , initially placed in the origin of the reference frame, slides vertically to the articular surface along the X axis by an amount equal to $\boldsymbol{\Delta_x}$. The radius Ra remains unchanged in its length and drags the point P falling on a spiral path toward the center.

This determines that the distance between P and the origin of the reference system X-Y is reduced (Rb) (Fig.4 [note]).

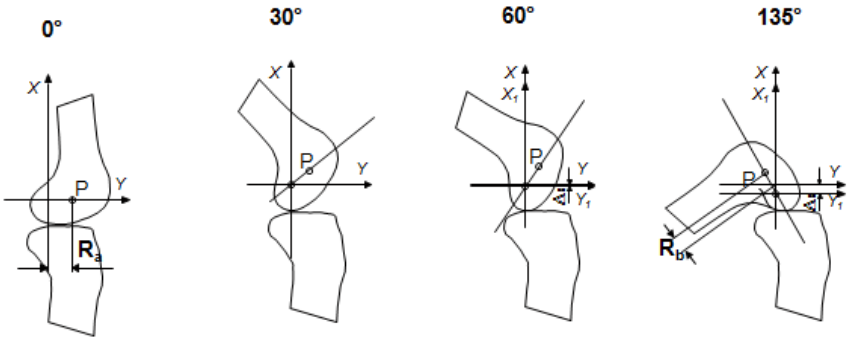


Fig.4 [note] - the analysis shown in the figure has been made keeping the Xaxis as an extension of the longitudinal axis of the thigh in line with that of the leg.

After the 30° , therefore , Rb, whose first end is always centered in the origin of the reference system X,Y, to change of **α**, will take different angular values than those of Ra, who remains the effective radius of the knee (Fig. 5) .

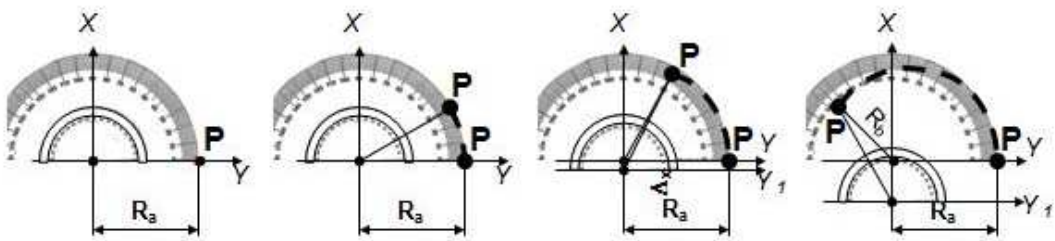


Fig. 5

The new reference unit – the roto-traslation amount

In roto - translational motion the point P follows a curve with a spiral trend falling towards the center, while the other end of the radius Ra slides along the X axis.

This implies that the scale for the real evaluation of the angle of the knee seen as a reversal of the Y-axis must be built according to the different movement of the two ends of the radius Ra.

The division into notches on the angular scale in no longer as regular as usual in a goniometer but raises above 30°, a subdivision according to the modified axial translation.

In fact, given that the end of P of the radius Ra varies according to the following values :

$$Y1 = y$$

$$X1 = Ra \text{ sen } \boldsymbol{\alpha} - \boldsymbol{\Delta_x}$$

And observing two different readings on the scale (corresponding to different angles and at different experimental progressive values $\boldsymbol{\Delta_x}$) we have :

$$X1_1 = Ra \text{ sen } \boldsymbol{\alpha 1} - \boldsymbol{\Delta_{x1}}$$

$$X2_1 = Ra \text{ sen } \boldsymbol{\alpha 2} - \boldsymbol{\Delta_{x2}}$$

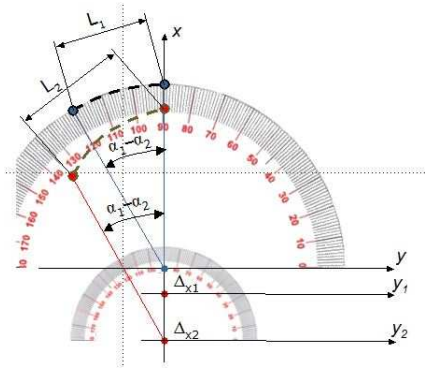
from which :

$$X1_1\text{-}X2_1 = Ra\ (\text{sen}\ \boldsymbol{\alpha}_1 - \text{sen}\ \boldsymbol{\alpha}_2)\text{-}(\boldsymbol{\Delta}_{x1}\text{-}\boldsymbol{\Delta}_{x2}).$$

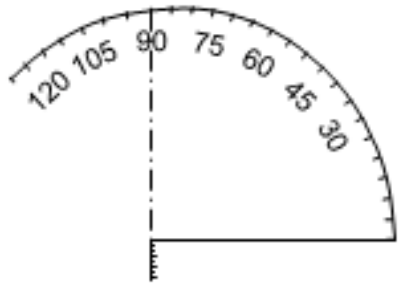
From this report we deduce that the difference increases because of ($\boldsymbol{\Delta}_{x1}$-$\boldsymbol{\Delta}_{x2}$) the discordant development from X axis with a consequent increase of the distance between two points after reading on the angular scale (Fig.6).

It seems important to point out that at 90° perpendicularity is perfectly appropriate in the two systems, which, however, differ from the vertical sliding $\boldsymbol{\Delta}_x$ of the instantaneous center of rotation of the new gradual scale.

After the 90° the variation of the distance between the notches (L2-L1) becomes increasingly important.

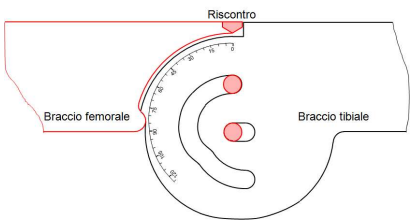


So, the new scale was built



Mechanical descrption of the instrument

The roto- translational evaluator is composed from two arms, a femoral and a tibial one. The distal part of the femoral arm has two pins (which reproduce the extreme points of radius Ra that lies on Y- axis) each of which articulates with two openings in the proximal part of the tibial arm.



These openings are shaped differently: one linear and central whose function is to follow the instantaneous displacement of the center of rotation during flexion from 30° degrees upwards (permitting vertical sliding of one end of Ra).

The other has a circular shape for the first 30° and then assumes a spiral shape falling towards the center , in which pin slides representing the second end of radius Ra .

The pins in holes system composes a complex system that in flexion-extension determines, after 30° a roto - translational motion (movement).

The new scale of measurement is ,then , placed on the tibial arm with the origin in the initial center of rotation.

Femoral arm has a "confirmation" that corresponds to the reference 0° of the new roto-translational scale when the symmetry axis of the femoral and tibial arms are coaxial.

Conclusion

The evaluator combines the physiological motion of the knee with a new reference scale not made on a goniometric distribution , but roto - translational which takes into account the degrees of flexion achived in function of the displacement of the instantaneous center of rotation to the plans joints.

This allows to the instrument , placed in contact with the thigh and leg, to remain fully in contact without slipping ,so, mantaining the points of contact from the beginning to the end of the evaluation , ensuring the repeatability of the measurement.