International Journal of Basic and Applied Medical Sciences ISSN: 2277-2103 (Online)
An Online International Journal Available at http://www.cibtech.org/jms.htm
2012 Vol. 2 (2) May-August, pp.1-14/Adhikari et al.

Research Article

ARTHROKINEMATICS REVISITED AT KNEE

***Swapan Kumar Adhikari[1], Rajeeb Kumar Roy[2], Sailendra Bhattacharyya[3], Indra Datta (Mandal)[4] and Shibendra Kumar Saha[5]**

[1]35/1, Krishnataran Naskar Lane, Ghusuri, Howrah - 711107, West Bengal, India
[2]Department of Mathematics, Kendriya Vidyalaya, Cossipore, Kolkata
[3]Bhattacharyya Orthopaedics & Related Research Centre, Narayanpur, Gopalpur, Kolkata
[4]Department of Anatomy, Institute of Post Graduate Medical Education & Research, Kolkata
[5]C.G.-5, Sector - II, Salt Lake City, Kolkata
**Author for Correspondence*

ABSTRACT

Arthrokinematics is the general term for specific movements at any joint. Normal joint movement is necessary to ensure long-term joint integrity. Joint surfaces move with respect to one another by rolling, sliding, and spinning. This paper focuses on how joint surfaces normally roll and slide. This paper ignores the spin component to some extent.

In this paper we have analyzed biomechanically the activities of knee in different postures and also at rest in human beings.

Key Words: *Arthrokinematics, Knee-Joint*

INTRODUCTION

Structure

The human knee (Figure1) is a masterpiece of anatomical engineering. It is placed midway between the supporting columns of the torso. It is subjected to stress and strain during weight bearing and locomotion. Massive condyles take care of weight bearing. During locomotion, it exhibits wide range of movements. Strong ligaments resist lateral stress and helps in operating the lever effect of long bones e.g. femur and tibia.

Figure 1: Bony structure of knee-joint

To combat the downward pull of gravity and to meet the demands of violent locomotion such as running and jumping, knee is provided with powerful musculatures around it. Nature thus meets the requirements of stability and mobility in the knee-joint.

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In a closed kinematic chain the knee-joint works in conjunction with the hip joint and ankle joint to support the body weight in static erect postures like sitting, standing and squatting. Dynamically the knee complex is responsible for mobility during locomotion.

Kinesiology:

Kinesiology is an emerging science. It is a branch of biomechanics. It deals with all sorts of movements. Two relevant fields of study may be considered here: i.e. osteokinematics and arthrokinematics.

Osteokinematics deals primarily with overall bone movements and arthrokinematics is concerned with articular mechanics such as rolling, sliding, and spinning. All active and passive movements are normally pain free. Arthrokinematic motions when restricted will limit physiological movements and may generate discomfort.

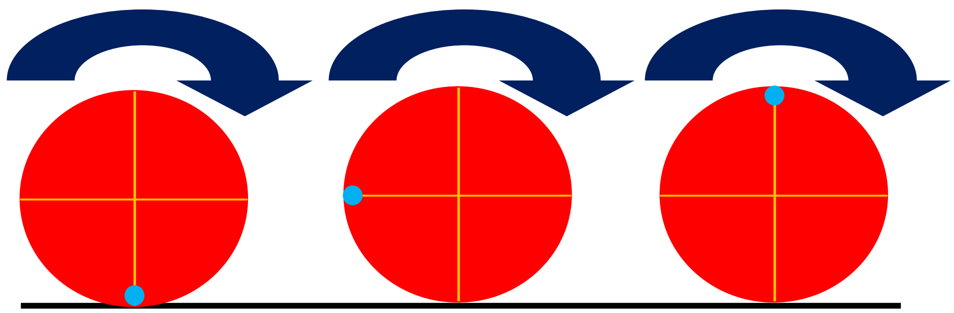

Figure 2A: Pure rolling

In rolling (Figure 2A) new points on one surface come into contact with new points on the other surface of say wheel. It only occurs when the two articulating surfaces are incongruent.

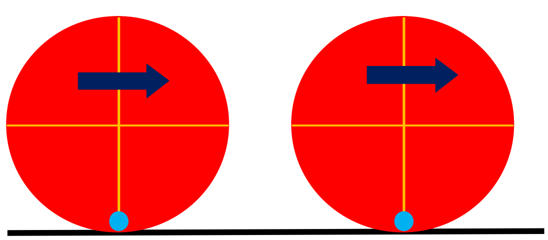

Figure.2B: Showing only sliding

Sliding (Figure 2B) is translatory motion in which one constant point on one surface is contacting new points or a series of points on the other surface. Pure sliding can occur when two surfaces are congruent and flat or congruent and curved. Sliding also referred to translation.

Spinning (Figure2C) is rotation around a longitudinal stationary mechanical axis (one point of contact).

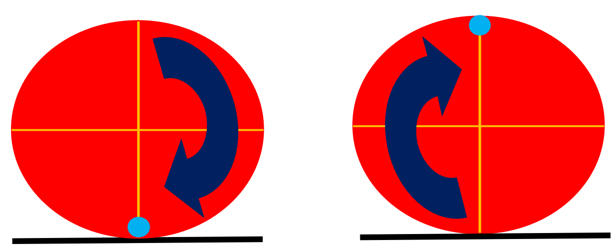

Figure.2C: Showing only spinning

Rolling (Figure 2D) & Sliding: Since there is never pure congruency between joint surfaces; all motions require rolling and sliding to occur simultaneously. This combination of rolling and sliding is simultaneous but not necessarily in proportion to one another.

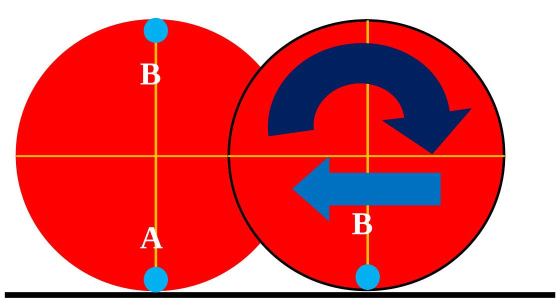

Figure.2D: Showing rolling accompanied by sliding

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MATERIALS AND METHODS

We have based our study on the standard anatomical structure of knee-joint. Different aspects of the direction of forces during various active movements have been analysed. Results are then expressed mathematically.

Purpose of this Study

Knowledge of arthrokinematics is essential for the orthopaedic surgeons. We have tried to analyse the normal anatomy in the light of biomechanics. Surgeons can take advantage of such review and analysis.

DISCUSSION AND RESULTS

Body-Weight Transmission

Body-weight (Figure3) is coming down through head of the femur (H) and consequently goes towards the foot where it absorbs ground reaction force. The forces of body-weight are acting through knee. Here we have considered vertical line AOC, along which body-weight is terminating at C (Central point at the ankle-joint where total body weight is transmitted to the ground).

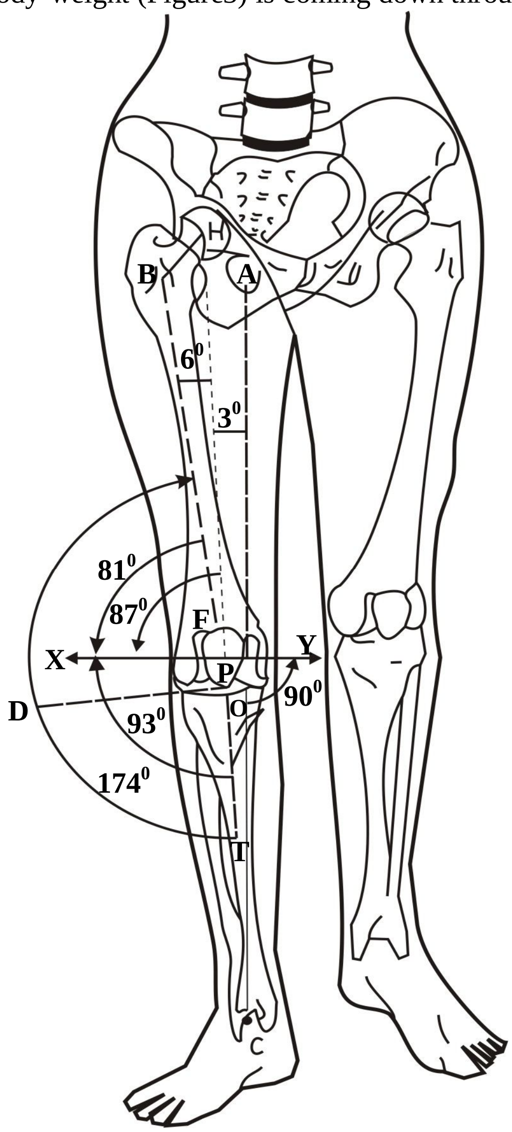

Figure 3: Showing lines of forces transmitting body-weight towards ground. BF is the line of force through femur. XY is horizontal line. HP is the line connecting centre of head of femur and centre of patella.

Now let us consider total body = 2W kg where we assume W kg through each leg. Here W is acting vertically at the centre of the head of femur. Then W along BF and terminating towards O = $W.\cos6^0.\cos3^0 = 0.993\times W$ kg.

Then, tibia absorb weight = $0.993W \times \cos174^0 = 0.0124\times W$ kg. Naturally fibula being feeble bone transmits only 2.5% of body-weight.

The anatomic (longitudinal) axis of the femur (BF) is oblique, directed inferiorly and medially from its proximal to its distal end (2, 8). The anatomic axis of the tibia (OC) is almost vertical. Consequently, the femoral and tibial longitudinal axes normally form an angle medially at the knee-joint of 185^0 to 190^0, i.e. the femur is angled off vertical 5^0 to 10^0, creating a physiologic (normal) valgus angle at the knee. The mechanical axis of the lower extremity is the weight bearing line from the centre of the head of the femur to the centre of the superior surface of the head of the talus. This line normally passes through the center of the knee-joint between the intercondylar tubercles and overages 3^0 from the vertical given the width of the hip-joints as compared to spanning of the feet. Because the weight-bearing line (ground reaction force) follows the mechanical rather than the anatomic axes, the weight-bearing stresses on the knee-joint in bilateral static stance are equally distributed between the medial and lateral condyles, without any concomitant horizontal shear forces. This is not necessary the case in unilateral stance or once dynamic forces is introduced to the joint. Deviations in normal force distribution may be caused, among other things, by an increase or decrease in the normal tibiofemoral angle.

Axes of movements at knee:

XX' is transverse axis about which flexion-extension occur; YY' is the vertical axis used to measure

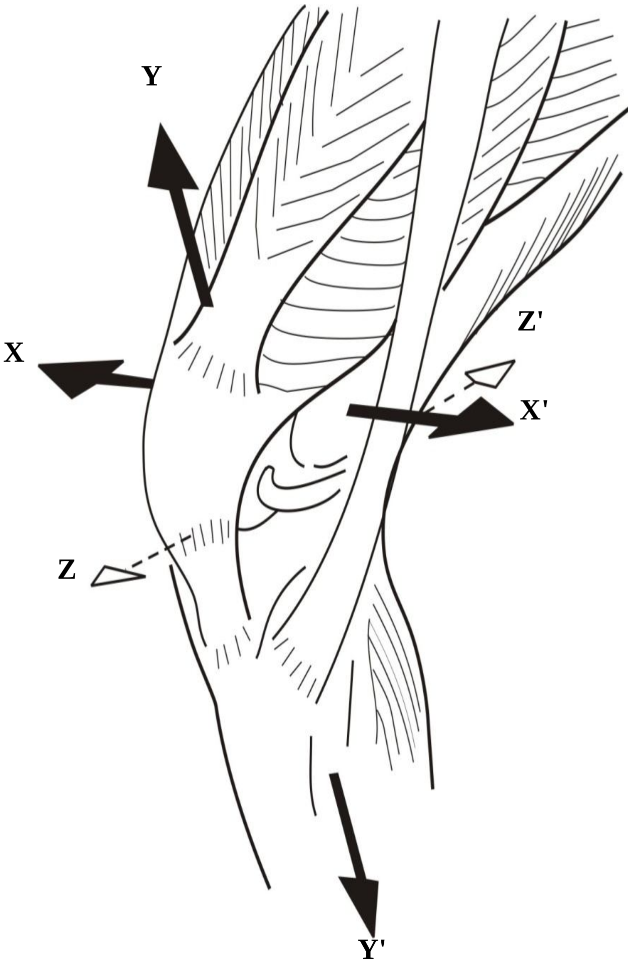

Figure 4A: Choice of axes at knee in semi-flex position.

Figures 4B: Showing choice of axes at knee to demonstrate different movements at knee

amount of flexion and extension and ZZ' axis perpendicular to both the axes i.e. perpendicular to plane containing XX' and YY' axes (12). It is the axis where abduction and adduction occur (Figure 4A & 4B).

Mechanism of joint stability and distribution of forces:

Lower limb stands on various positions from slightly flexed to hyper-extended (Knudson, 2007). When knee is straight with slightly flexed position (Figure5A) the force due to body-weight acts along vertical axis (red arrow). This is behind the flexion axis as well as extension axis (flexion axis is line connecting center of head of femur to the point of contact of femoral condyle with tibial plateau and extension axis is the line connecting the point of contact between femur and tibia to the point of contact tibia and talus). In this position, quadriceps contracts to prevent further flexion. Quadriceps is thus responsible for erect posture of man. The natural tendency of knee is to hyper-extension. This tendency is restricted by

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posterior ligament as shown black in the Figure-5B. In this type of erect posture *(genu recurvatum)* (18) quadriceps plays no role. Therefore, even after paralysis of quadriceps a person is able to stand and walk but with extended knee. In this position axis of thigh (axis of femur) will run obliquely inferiorly and posteriorly.

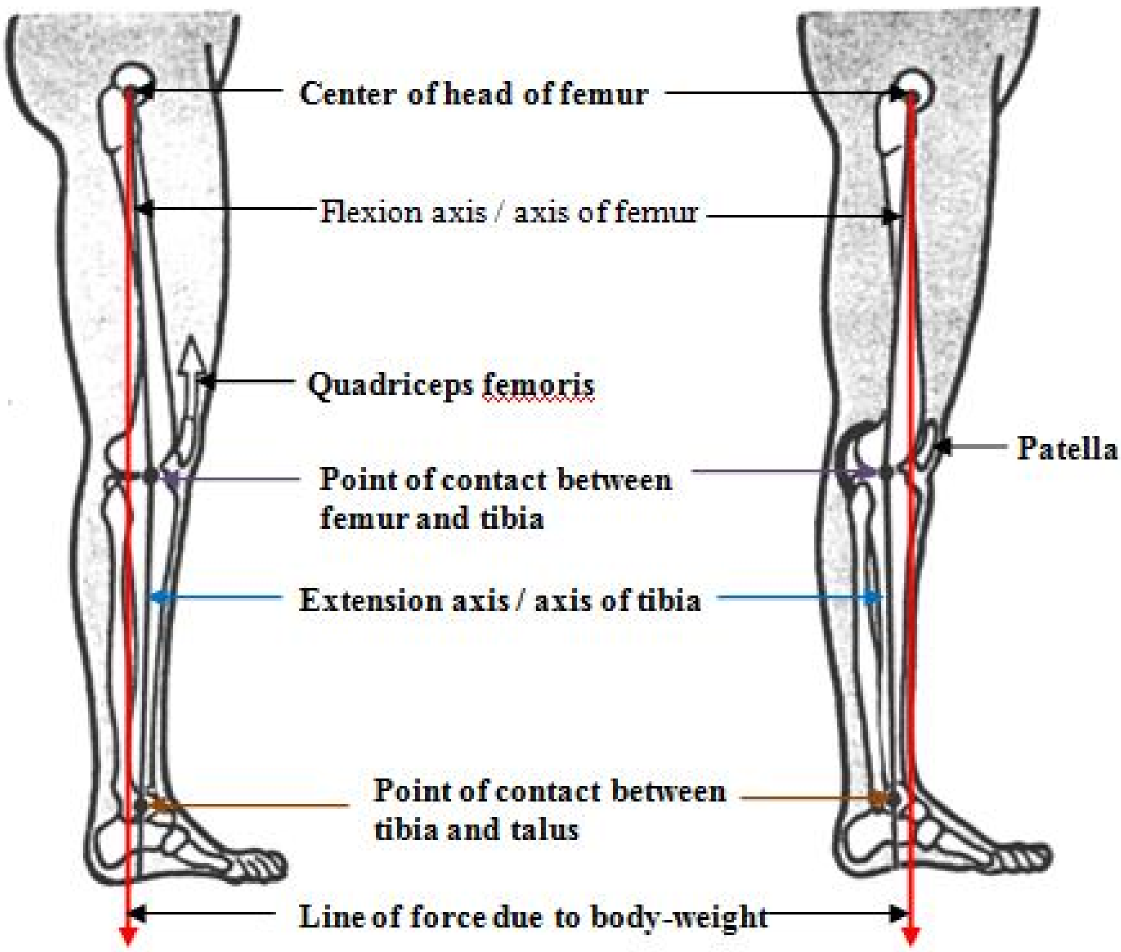

Figure 5A (Left): Knee is straight and very slightly flexed.
Figure 5B (Right): Knee is hyper-extended.

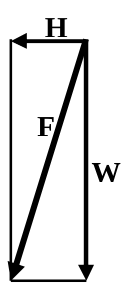

Figure 5C:

In hyper-extensions during acrobatic events active force along this axis (F) can be resolved horizontally (H) and vertically (W) where H tries to accentuate hyper-extension and W represent the body-weight (Figure5C). This arrangement of parallelogram of forces shows that for a particular person W is fixed where obliquity of F with may vary according hyper-extensivity at knee (15). More hyper-extension will yield more obliquity posteriorly causes intensification H vector (length of H will increase i.e. magnitude will increase) which stretches the posterior ligament. Then *genu recurvatum* will be too severe. It is important to note that limitation of hyper-extension of knee is not provided by bony contact but with related ligaments and

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muscles.

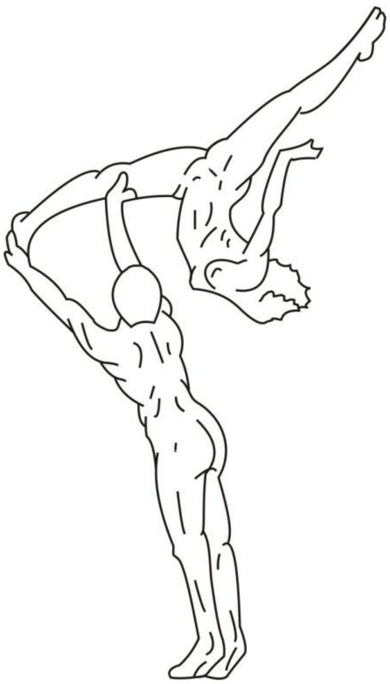

Figure 5D: Hyper-extension at knee by gymnasts.

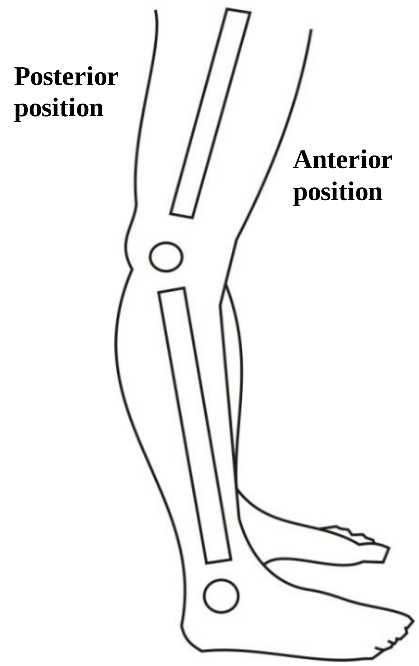

Figure 5E: Position at knee due to hyperextension

Such type of hyper-extensions is seen among the acrobatic events of gymnasts (Figure5D).

In the position of hyper-extension (Figure5E) ligaments are overstretched to the extent of permeability of absorbance of posterior tensile force (Figure5F). For this case further accentuation of *genu recurvatum* is essential.

Normal extension and flexion of knee:

In normal extension of knee the body will pass through a point away from ankle-joint (Figure5G) (Adhikari, 2000). In normal flexion of knee, fulcrum at hip will be at cavity-head of femur. Similarly, role of fulcrum at knee joint and ankle joint will be played by patella and talus respectively (Figure 5H).

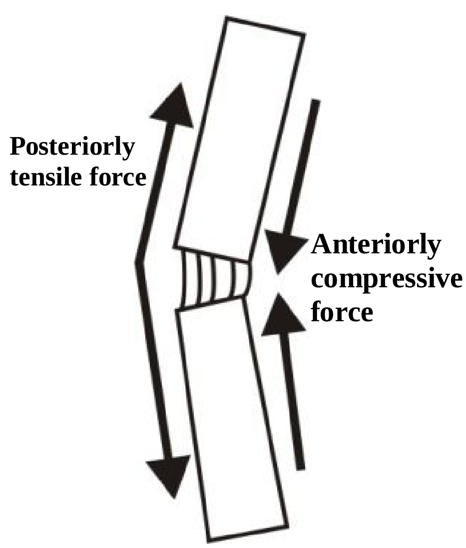

Figure 5F: Forces acting at posterior and anterior position of knee

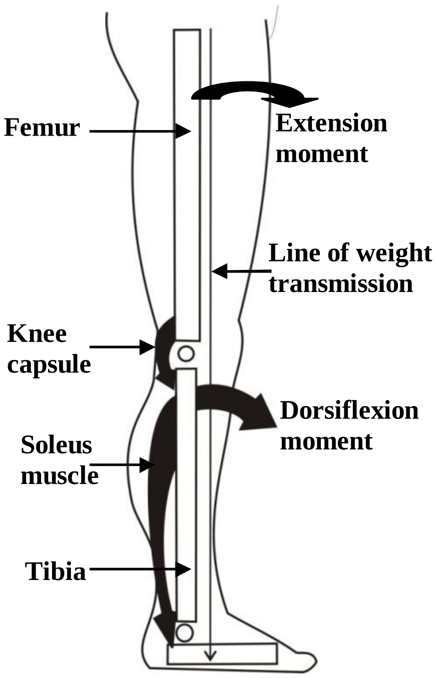

Figure 5G: Effective muscles activities creating moments for extension movement.

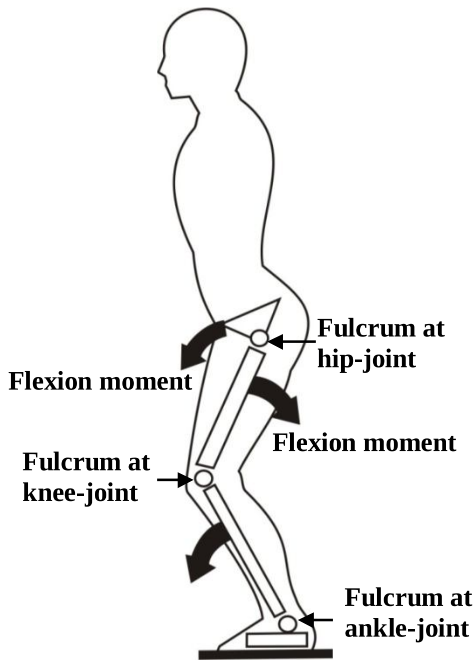

Figure 5H: Effective mechanical devices for flexion movement.

Directions of Movements of Femoral Condyles in Flexion and Extension

Suppose the tibia is fixed. Movements will be possible only due to smoothness of the surfaces of condyles assisted by muscles and ligaments (19).

In flexion: the femoral condyles experiences two types of motions free rolling (Figure 6A) and rolling with sliding (Figure6B). In such condition extension is essential with sliding back accompanied by slight rolling (Figure 6C).

The synovial fluid (lubricant at knee-joint) is forced to flow anteriorly (Figure7A) or posteriorly (Figure7B) and may as per the movement of the joint (7C).

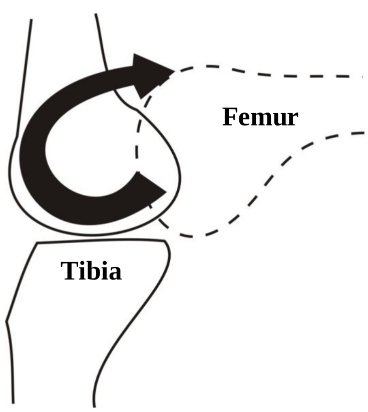

Figure 6A: Pure rolling in flexion

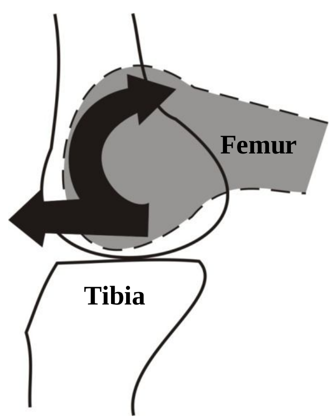

Figure 6B: Rolling & sliding in flexion

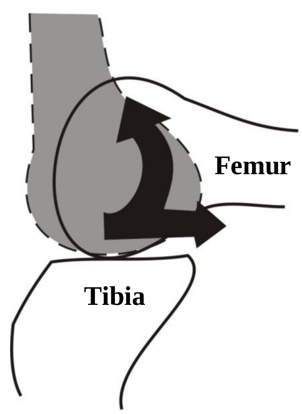

Figure 6C: Rolling & sliding in extension

Figure 7A: Flow of synovial fluid in extension

Figure 7C: Position of synovial fluid in semiflexion

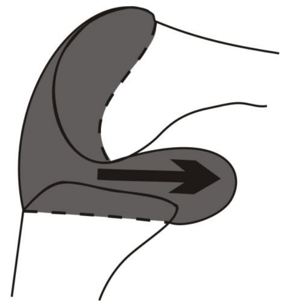

Figure 7B: Flow of synovial fluid in flexion

Rotational Movements

The quadriceps femoris is extensor muscle of the knee and is very powerful whereas its average cross-sectional area = 148 cm^2 and can be shortened to the extent of 8 cm which exert force up to 42 kg. wt. It generally counteracts the effect of gravity. As we have explained above in hyper-extension it plays no role but as soon as flexion is initiated the quadriceps immediately appears in action to prevent fall resulting from knee flexion and these muscles keep balance of knee as well dislocation of patella which is embedded within it (Figure 8) (16). Rotation is always around the vertical axis of knee (YY', Figure9A).

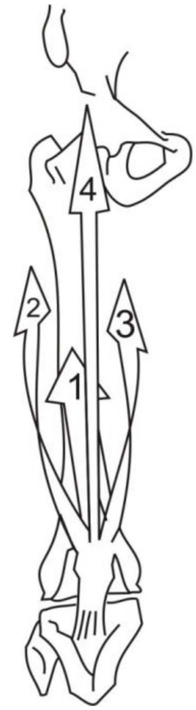

Figure 8: Quadriceps muscles: 1. *vastus intermedius;* 2. *vastus lateris;* 3. *vastus medialis;* 4. *rectus femoris*

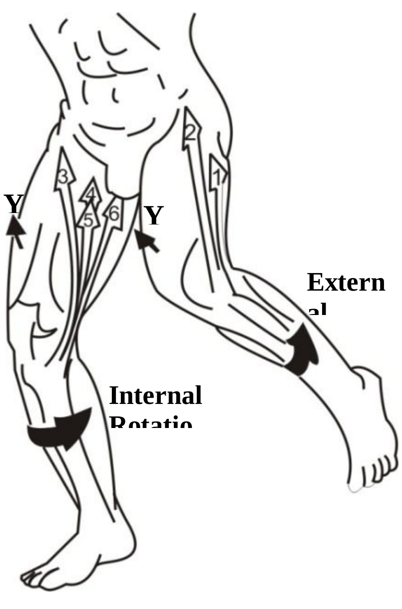

Figure 9A: Showing rotation of legs: (A) Lateral rotation by (1) *biceps;* (2) *tensor fasciae latae.* (B) Medial rotation by (3) *Sartorius;*

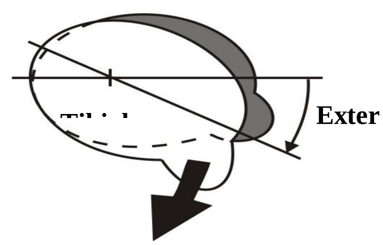

Figure 9B: Showing

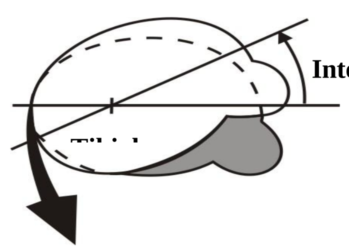

Figure 9C: Showing

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The lateral rotation is at knee which rotates left tibia externally (Figure 9B). At the same time the muscles of right leg pulls tibia posteriorly and medially (Figure 9C). The combined power of medial rotator (2 kg. wt.) is slightly > that of lateral rotator (1.8 kg. wt.).

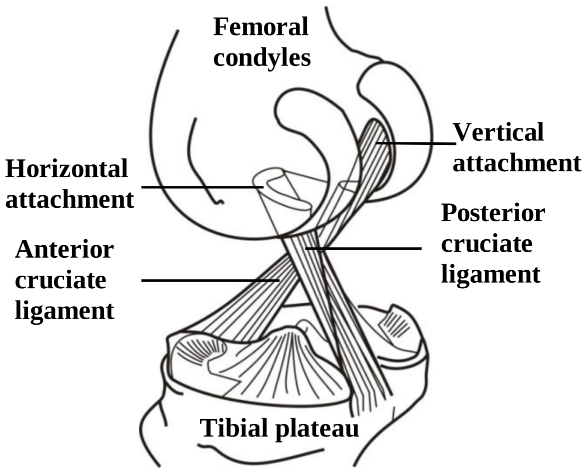

Figure 10A: Arrangement of cruciate ligaments

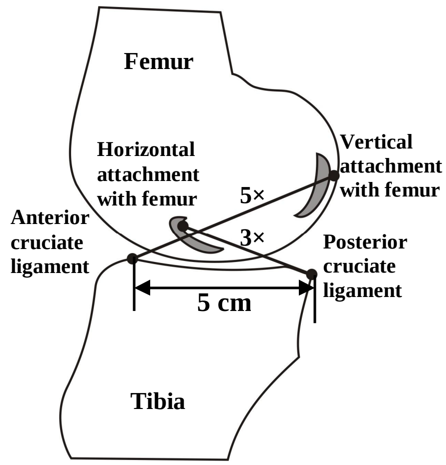

Figure 10B: Sagittal section cruciate arrangement

Role of Cruciate Ligaments in Different Movement

Cruciate ligaments are crossed to each other. Anterior cruciate ligament runs obliquely superiorly and laterally whereas posterior cruciate ligament runs obliquely medially, aneriorly and superiorly. But in sagittal plane anterior cruciate ligament is obliquely and is running superiorly and posteriorly whereas posterior cruciate ligament is also oblique and runs superiorly and anteriorly (6). The cruciates always keep constant length ratio with variable angles. The posterior cruciate is always shorter in length and keep the ratio 3:5 with anterior cruciate. In an adult tibial insertion of cruciates are nearly 5 cm apart (Figure 10B). In extension anterior cruciate is nearly vertical whereas posterior cruciate is nearly horizontal as per their insertions with femoral condyles (Figure 10A & 10B).

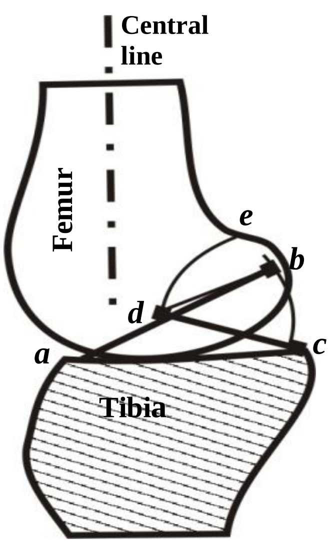

Figure 11A: Straight position

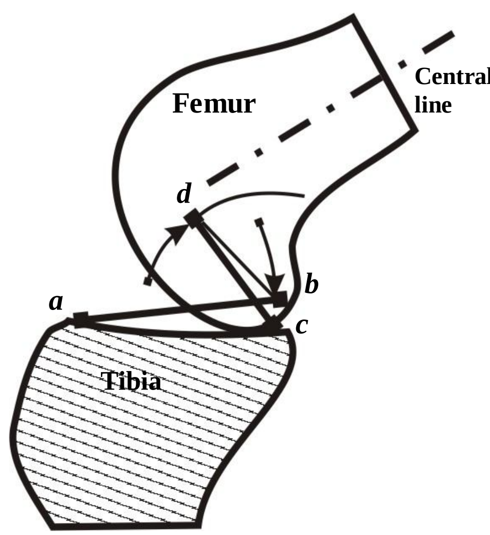

Figure 11B: Position in flexion

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Figures 11A and 11B are showing movements of cruciate ligaments in different stages of flexion. Here we have considered *ab* as anterior cruciate and *cd* as posterior cruciate ligaments. From the starting of flexion we see upper end *d* of posterior cruciate will move along the circular arc *de* with center at *c*. Similarly end *b* of anterior cruciate will move along circular arc *bc* with center at *a*. As the flexion progresses, *b* will come down to be nearly horizontal towards the point *c* where *d* will move along the arc *de* as shown by arrow (Figure 11B). This process continues upto 90^0 flexion where cruciate ligaments are nearly perpendicular to each other (Figure 11C). In full flexion 150^0 the anterior cruciate ligament is slowly slacken (Figure 11D).

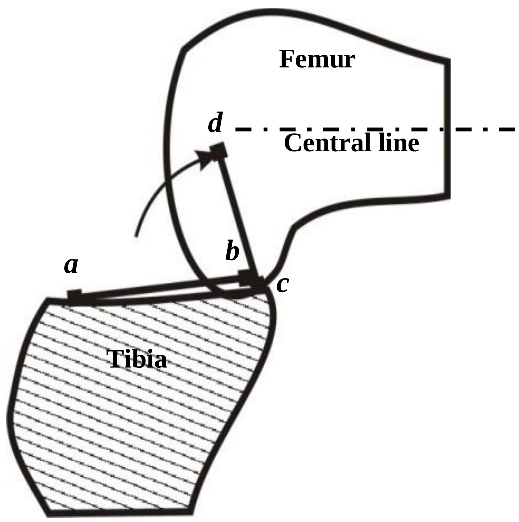

Figure 11C: Position in 90^0 flexion

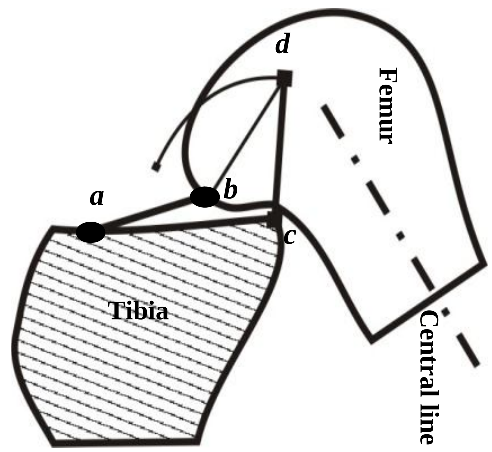

Figure 11D: Position in full flexion

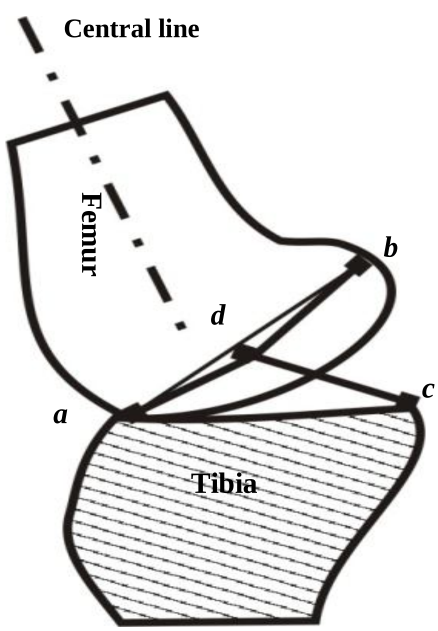

Figure 12: Cruciate ligaments in extension

During hyper-extension (Figure 12) both cruciates are stretched where anterior cruciate support the vault of the intercondylar notch at *d*. Cruciates are always in a stage of tension but cannot be stretched simultaneously as that anterior cruciate is stretched in extension whereas posterior cruciate is stretched in flexion.

Knee in Normal Condition

Normally there will be no sliding inside the knee whatever be its position. The profile of the posterior part of femoral condyle represents exactly the curve joining all the various positions of the tibial plateau from full flexion to full extension. The cruciate ligaments yield the curve as per flexion and extension of knee.

Locking movement:

In knee locking tibial tubercles enter into the femoral notch and fit tightly. Ligaments are also taut; menisci are tightly interposed and therefore lubricant cannot act. knee-locking is also known as screw home mechanism (10, 15). Unlocking is initiated lateral rotation of femur.

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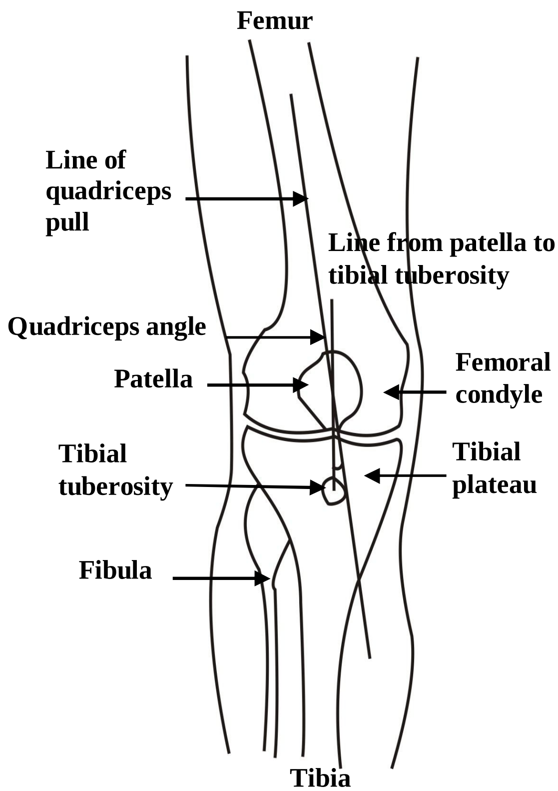

Figure 13: Demonstrating quadriceps angle

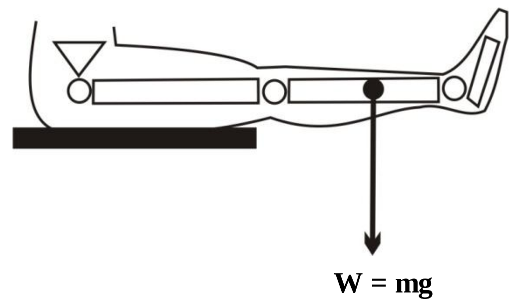

Figure.14A: Action of gravitational force on free leg is horizontal under sitting posture

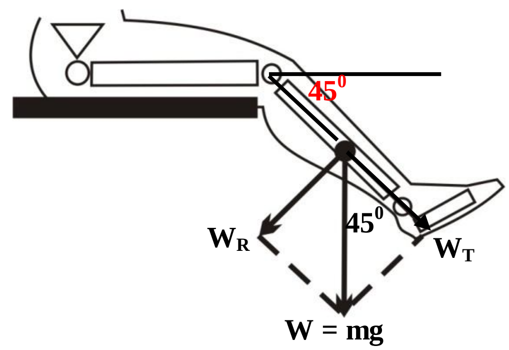

Figure 14B: Forces on free leg at 45^0 under sitting posture.

In Figure13 the quadriceps angle is determined by a line drawn along the general alignment of the thigh to the center of the patella. A second line is drawn from the middle of the tibial tuberosity to the center of the patella. The estimated normal angle among the males varies from 8^0 to 10^0 whereas in females it varies from 12^0 to 16^0. The significance of this angle is to estimate the muscle contraction i.e. quadriceps contraction as it has general tendency to straighten out this angle. The greater angle creates more pressure and obviously it produces lateral push to dislocate patella.

Action of Gravity in Non Weight-Bearing Position

In sitting posture W = weight of lower part of leg i.e. from knee-joint to foot = mg where m = its mass and g = gravitational force per unit mass (Figure 14A). At 45^0 flexion translational component of W = W_T is away from the knee towards foot and its component perpendicular to W_T = W_R = rotational component or flexion component. Here $W_T = W_R$ (Figure 14B). When leg is hanging freely and vertically in sitting posture then it is in neutral position. Here weight (W) will be downward and this force will be balanced by pull of knee ligament (P). In this stage P will be equal and opposite to W and create no pain. In this position we are

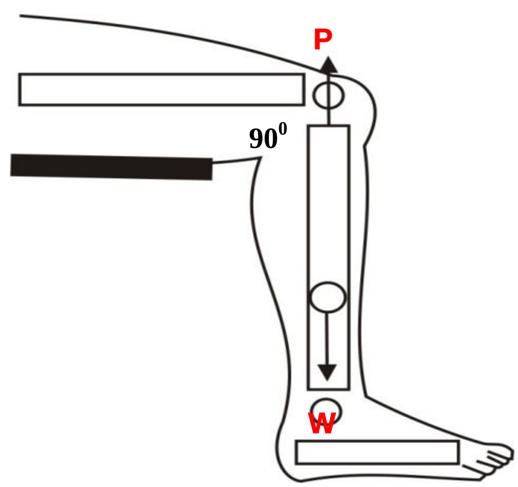

Figure 14C: Leg is in freely hanging position at sitting posture.

considering forces when leg is intending to extend from freely vertical posture. At this stage the quadriceps will be active and act vertically upward whereas W will be vertically downward (Figure 14C). Resolving the quadriceps-force (Q) into two perpendicular directions i.e. along tibia and its right angle we get Q_T and Q_S. Similarly for W we have W_T and W_S. There also act another force F_P along tibia is due to

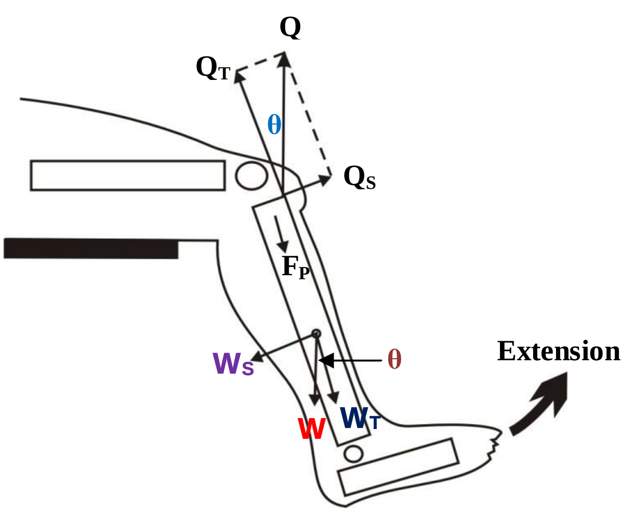

Figure 14D: Sitting posture with leg hanging and intend to extension

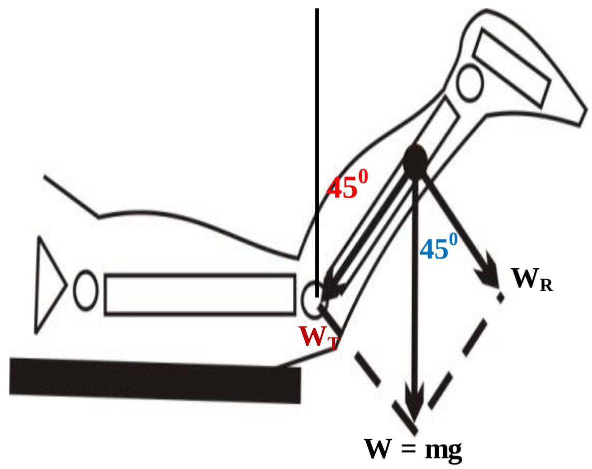

Figure 15: forces on free leg under inverted laying condition

push of the femur on tibia. In this position Q_T will manage F_P and W_T. But components Q_S and W_S are shearing forces. In motion towards extension intensity of $Q_S > W_S$ and naturally quadriceps apply more force. Consequently Q_T will be intensified which is essential to balance the work done by W as the leg will go up as we know Work done = mgh = W×h where h is the height upto which W is above ground. In stationary to any height $Q_S = W_S$ (Figure 14D)

On lying prone the lower part of leg, is kept at an angle of 45^0. Here $W_T = W_R$ with same significance. But W_T is acting towards the knee (Figure 15).

Role of Patella

Patella (P) is embedded within quadriceps femoris (FPQ) where F is the point of tibial tuberosity i.e. attachment of quadriceps with tibia. Patella always moves in contact with femoral condyles on flexion as well as extension. Forces exerted on patella are: pull of quadriceps (Q) and patellar ligamental force (F). These two forces produce resultant force (R) which helps to compress patella with femoral condyles (Figure 16A). These form parallelogram of forces FPQR (7).

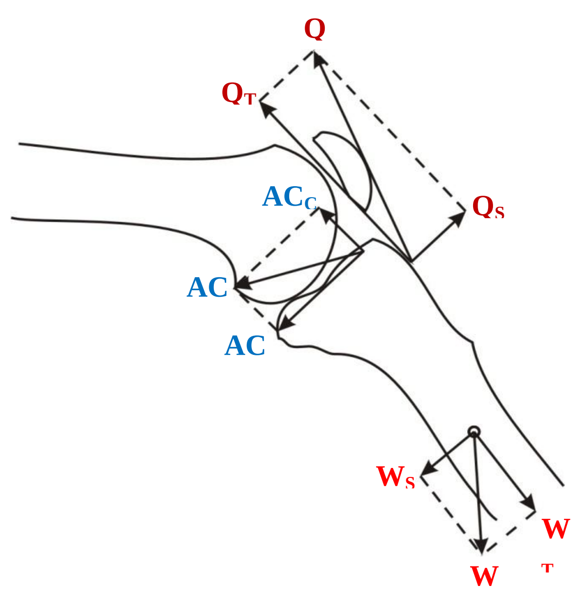

Figure 16 B: Balancing forces at

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Here we have considered force / pull initiated by quadriceps (Q) is tangential to patellar surface and it can be resolved in mutually perpendicular direction as Q_S and Q_T where Q_S rotates tibia i.e. shearing force between tibia & femur. Q_T is used to balance W_T i.e. component of body-weight (W). AC is the force initiated by anterior cruciate ligament where AC_C is contact component of anterior cruciate ligament to maintain compression between tibia and femur whereas AC_S is the shear component to produce counter shear Q_S and W_S (Figure16B).

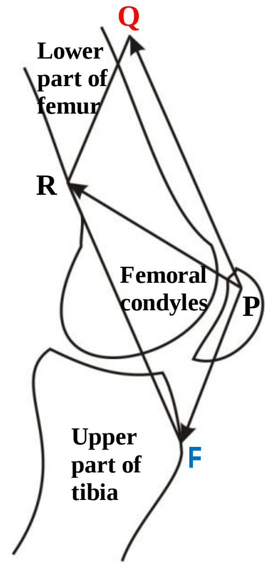

Figure 16A: Showing effective forces on patella.

Role of menisci

The menisci of the knee are important (13) in distributing and absorbing the large force crossing the knee joint. Although compressive forces in the dynamic knee-joint ordinarily may reach two or three times body weight in normal gait and five to six times body weight in activities such as 40% to 60% of the imposed load.

Figure17 is schematic representation of force distribution in flexion:

A - R is the reaction of meniscus on femur. It can be resolved into two mutually perpendicular components R_W to absorb body weight & R_S to produce shear by wedge-shaped meniscus.

B - C is the compressive force of femur on meniscus. It can also be resolved into two mutually perpendicular components C_S & C_W in similar manner.

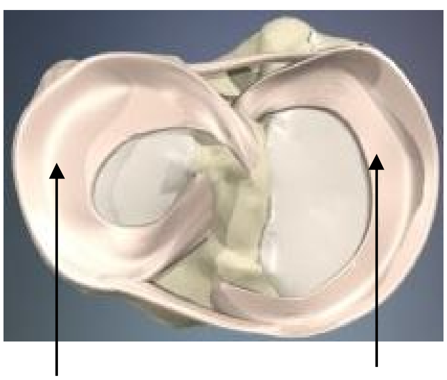

Figure 18: Menisci

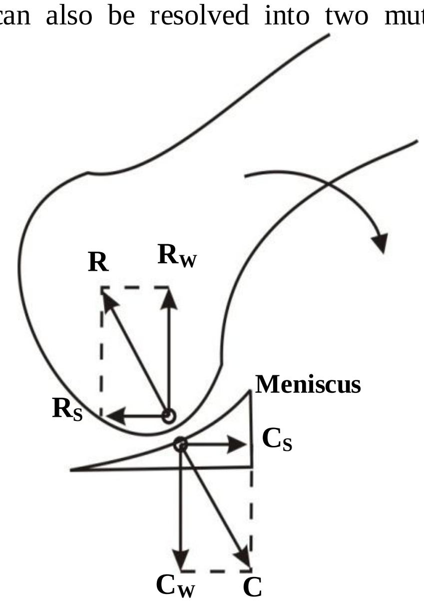

Figure 17: Showing reaction and compression for at meniscus

CONCLUSION

Knee-joint creates torque as well as shear around its mechanical axes passing through the joint. Total torque around knee-joint is positive. It creates angular acceleration.

Force components along the bony-levers create flexion and extension with very small amount of rotation. Frequent knee-locking in acrobats may be prevented by prior assessment of their range of flexion and extension.

Algebraic sum of linear components of effective and reactive forces at knee is zero. This imparts stability to the joint.

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