A Review on Biomechanics of Knee Joint.

Prof. K L Bawdekar[1], Vishwajeet Deshmukh[2], Shirish Bhand[3], Manish Dangat[4], Mayuresh Urit[5], Rushikesh Raskar[6]

[1]Prof. K L Bawdekar: Proffesor (HOD) Dept. of Civil Engineering, MIT Polytechnic, Pune
[2]Vishwajeet Deshmukh: Student, Dept. of Civil Engineering, MIT Pune
[3]Shirish Bhand (Student)
[4]Manish Dangat (Student)
[5]Mayuresh Urit(Student)
[6]Rushikesh Raskar

Abstract - *In this paper we describe the basic knowledge about the knee biomechanics which is thought to be useful in understanding how the forces act on the tibia and femur while designing the knee joint. The components in the design of knee joint and the geometry related to it. In addition to this the static and dynamic analysis has also been discussed. The several important mechanical goals in the design of total knee replacement in order to restore joint function for the lifetime of patient.*

Key Words: Biomechanics, knee geometry, joint moments, joint forces.

1. INTRODUCTION

Biomechanics is the science of movement of a human body in which muscles, bones, tendons and ligaments work together for the movement of human body. Mind is to control the movements like a machine. The intrinsic mechanics of this machine gradually became clear through the work of the scientists. The knee joint is flexed and attached to the bone of the thigh. Quadricep muscles are bounded under the knee. Various forces acting on the knee and excessive pressure on the ligaments due to over load in various activities take place, which effects the functioning of knee [1] (Bhaskar Kumarmadeti, Srinivasa Rao chalamalasetti, S. K. Sundara siva rao bolla pragada)

Knee allows locomotion with minimum energy requirements from the muscles and stability for accommodating for different terrains. The knee joint has biomechanical roles in allowing gait by flexing and rotating and at the same time, provides stability during the activities of daily life. It shortens and extends lower limb as required and transmits forces across it [2] (Dr. Arun Pal Singh)

Knee joint, which includes three independent joints and one joint cavity, is the largest and the most complex joint in human body. It is very important to study the relationship between the internal structure and the external performance, and there are many literatures on the spherical trajectory of knee joint's motion centre, the maximum range of static motion, the mechanism of double joints' muscle and the relationship between the strength and the flexion/extension angle of knee joint. However, in order to imply the biomechanics characteristics of knee joint motion it is more important to understand the relation between the external performance and the internal mechanic structure. The muscles and bones that affect the knee joint motion make up a mechanic system, including muscle torque. A muscle moment consists of two parts, the force of muscle and the force arm. The force of human muscle cannot be measured accurately. However, the law of muscle force changes can be obtained by measuring the muscle length changes, including absolute length and respective length, although the length changes are uncertain to be linear with the force changes.

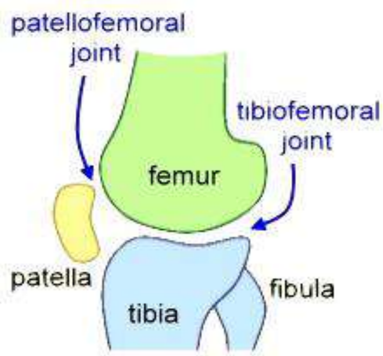
1.1 ROLE OF KNEE JOINT COMPLEX

To allow locomotion with:

A] Minimum energy requirement from muscles.

B] Stability accommodating for different terrains.

To transmit, absorb and redistribute forces caused during the activities of daily life.



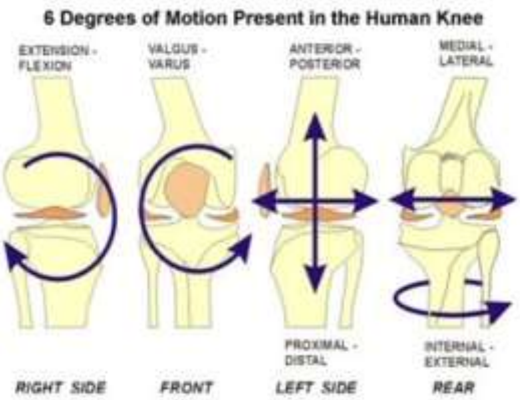
Right Knee Complex
Medial View

1.2 FUNCTIONAL CONSIDERATIONS

The primary motion of the knee joint is flexion and extension in the sagittal plane. The kinematics of the femur and tibia during this activity are determined prim aril y by the geometry of the femoral condyles and tibial plateaus, the muscle force s exerted across the joint, and the constraints of the cruciate ligaments. In the sagittal plane, a femoral condyle may be approximated by two radii. One radius forms the anterior portion of the condyle and contacts the tibial plateau at and near extension. A second smaller radius forms the posterior portion and contacts the plateau in flexion. The tibial plateaus are relatively flat. Based on the bony geometry alone, contact between the condyles and the plateaus would occur over a very small area, producing large contact stresses. Fortunately, the menisci and articular cartilage distribute joint loads more uniformly over a larger area [3] (Timothy M. Wright)

2. MOVEMENTS OF KNEE

Knee Joint produces Functional shortening and Lengthening of extremity. The knee is comprised of tibiofemoral joint and patellofemoral joint.



Degrees of freedom of knee:

The knee joint is a modified hinge joint with gliding function too. It has got six degrees of freedom

- 3 rotations
- 3 translations

In sagittal axis it has flexion-extension movement, in frontal axis, it has a varus-valgus rotation and whereas in transverse axis there is internal-external rotation)

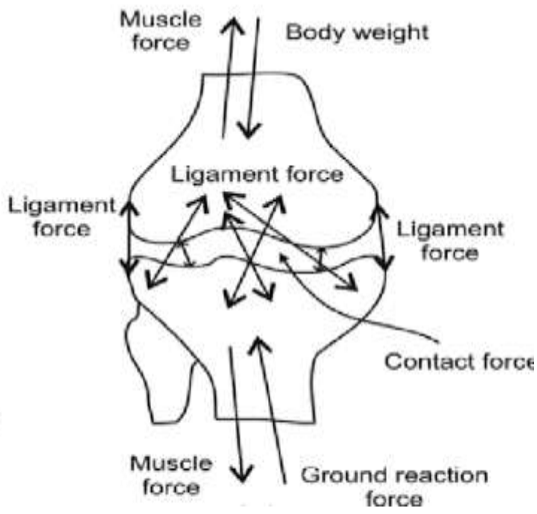
- Flexion-Extension: 3 degrees of hyperextension to 155 degrees of flexion
- Varus-valgus: 6-8 degree in extension
- Internal-external rotation: 25-30 degree in flexion
- Translation
- Anterior-posterior: 5–10 mm
- Compression: 2–5 mm [patellar compression]
- Medio-lateral: 1-2 mm

There are four main movements that the knee joint permits:

- Extension: Produced by the quadriceps femoris, which inserts into the tibial tuberosity.
- Flexion: Produced by the hamstrings, gracilis, sartorius and popliteus.
- Lateral rotation: Produced by the biceps femoris.
- Medial rotation: Produced by five muscles; semimembranosus, semitendinosus, gracilis, sartorius, popliteus.

3. KNEE FORCES

Forces transmitted by the knee joint are of great clinical significance. Forces transmitted across the knee joint during normal walking range between 2 and 3 times body weight. This is in part due to the kinetics of acceleration, the high moments generated at the knee, and simultaneous contraction of multiple muscles. Therefore the net effect of each additional kilogram in body weight is multiplied 2 or 3 times at the knee [4] (Darryl D. D'Lima1, Benjamin J. Fregly2, Shantanu Patil1, Nikolai Steklov1, and Clifford W. Colwell Jr.1)



Forces in Knee joint

At present, knee joint forces are determined either by direct measurement using an instrumented knee prosthesis or through mathematical modelling, i.e. inverse dynamics. The advent of instrumented knee prostheses has made it possible to measure knee joint force *in vivo*; however, the *in vivo* direct measurement data mainly concerns forces generated by small to moderate flexion. Data from instrumented prostheses about forces at high flexion are not yet available [5] (S. Hirokawa, M. Fukunaga, and M. Mawatari)

Table -1: Knee angles when knee joint forces become maximum and their values at various rising conditions

	Knee angle when knee joint force is max [?]	Maximum knee joint force [BW]
Rising with legs parallel		
Arms not used	125.5±10.7	4.3±0.5
Arms used	90.1±11.3	2.8±0.8
Rising with one foot forward		
Arms not used		
The forward leg	69.1±10.8	69.1±10.8
The trailing leg	150.4±10.2	2.2±0.5
Arms used		
The forward leg	88.1±10.8	2.1±0.5
The trailing leg	57.8±10.4	2.3±0.6

3.1 CALCULATION OF NET JOINT FORCES (NJFs) AND MOMENT (NJM) AT KNEE

Example:

Assuming NJFa's (Ra_x and Ra_y) and NJMa for Ankle.

Calculate the NJF's and NJM at the knee. Assume that the mass of the shank is 5.68 kg, the horizontal acceleration of the shank CM is –0.65 m/s^2, and the vertical acceleration of the shank CM is 17.90 m/s^2. In addition, the moment of inertia of the shank is measured as 0.0535 kgm^2 and the angular acceleration of the knee is 54.284 rad/s^2.

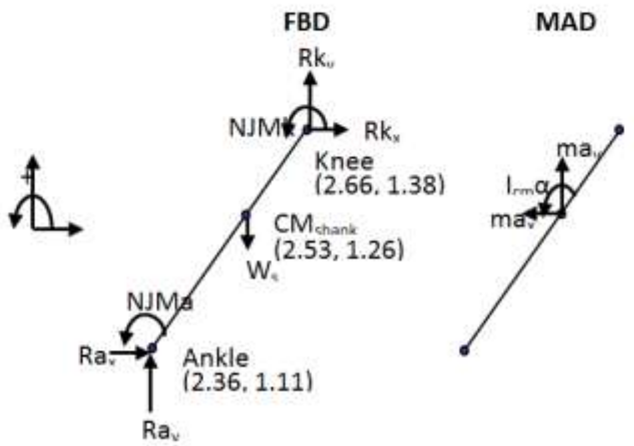


Figure: FBD and MAD of the shank segment at toe-off. In this diagram, assuming everything acts in a positive direction. Calculations may prove otherwise.

First, list all of the known and unknown variables.

Known:

Ankle (2.36, 1.11) m = 5.68 kg

CM_k (2.53, 1.26) a_x= -0.65 m/s

a_y= 17.90 m/s

Knee (2.66, 1.38) I_{cm} = 0.0535 kgm^2

Ra_x: 54.11 N α = 54.28 rad/s^2

Ra_y: 2633.23 N g = 9.81 m/s^2

Unknown:

NJMk: net joint moment at the knee

Rk_x: horizontal reaction force at the knee

Rk_y: vertical reaction force at the knee

Second, using these values and the FBD above, sum the horizontal and vertical forces in order to calculate the horizontal and vertical reaction forces at the knee.

Horizontal:

$\Sigma Fx = ma_x$

$\Sigma Fx = Ra_x + Rk_x = ma_x$

$Ra_x + Rk_x = ma_x$

$54.11 + Rk_x = (5.68 \text{ x } -0.65)$

$Rk_x = -57.80$ N

Vertical:

$\Sigma F_y = ma_y$

$\Sigma F_y = Ra_y - W_s + Rk_y = ma_y$

$Ra_y - (m*g) + Rk_y = ma_y$

$2633.23 - (5.68 \text{ x } 9.81) + Rk_y = (5.68 \text{ x } 17.90)$

$Rk_y = -2475.84$ N

Now, redraw the original FBD to reflect the actual directions of the forces at the knee. Thus using this revised FBD to calculate the NJM at the knee.

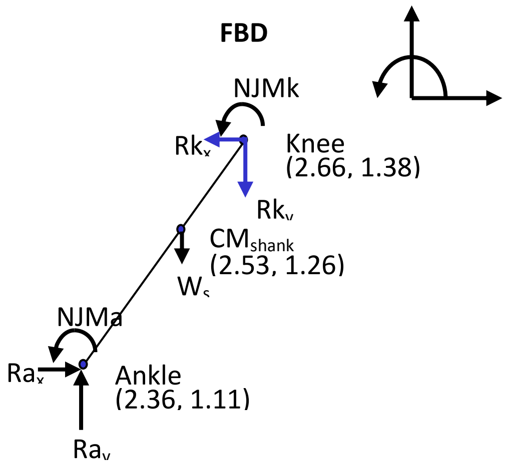


Figure: Revised FBD of the shank during toe-off. The forces acting at the knee have been redrawn to reflect the calculated values (horizontal and vertical both negative).

The next step is to calculate the moment arm of each force that is acting on the shank.

Ra_y: d1 = CM_x - $Ankle_x$ = (2.53-2.36) = 0.17 m

Ra_x: d2 = CM_y - $Ankle_y$ = (1.26-1.11) = 0.15 m

W_s: d3 = 0 (because the force of gravity acts directly through the CM)

Rk_y: d4 = $knee_x$ - CM_x = (2.66-2.53) = 0.13 m

Rk_x: d5 = $knee_y$ - CM_y = (1.38-1.26) = 0.12 m

Now that we know the values of all of the forces acting on the system and their distances from the CM, we can calculate the NJM at the knee. In this example, Ra_x , Rk_x, and NJMa (equal and opposite to example 1) create positive moments (counter-clockwise) about the knee; Ra_y and Rk_y create negative moments.

$\Sigma M = I_{cm}\alpha$

$NJMk + NJMa - (Ra_y \times d1) + (Ra_x \times d2) + (W_s \times d3) - (Rk_y \times d4) + (Rk_x \times d5) = I_{cm}\alpha$

$NJMk = I_{cm}\alpha - NJMa + (Ra_y \times d1) - (Ra_x \times d2) + (Rk_y \times d4) - (Rk_x \times d5)$

NJMk = (.0535 x 54.28) -164.8 + (2633.23 x .17) - (54.11 x .15) + (2473.84 x .13) - (57.8 x .12)

+ **NJMk = 592.3 Nm**

A positive NJMk indicates that you have assumed the direction of the NJMk correctly on the FBD. The knee NJM is *an* extensor moment. It is working together with the ankle plantar NJM to counteract the moments created by the ground reaction force at the foot.

4. CONCLUSION

The concept of biomechanics and the Knee joint complex has been shown in context with its role and functional considerations. The movements about the knee and their locations of production around the joint are categorized. The knee forces and the views of authors about it have been studied in this paper. Forces and moments should be resolved at the joints of human body, and all forces are obtained by solving the equations. Positions of knee with respect of the knee angle and the body weight has been studied and described in table. Above knee angles of 60 degree, the compressive force between the femoral intercondylar groove and the quadriceps tendon was quantified and found to increase linearly with increasing knee angle.

An example in detail about the calculation of net forces and moments for design of knee joint have been studied and described in the paper above.

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