LITERATURE REVIEW ON KNEE PROSTHESIS USING ROBOTIC SYSTEM AND MECHANISMS

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Abstract: The knee joint is complex in the human body, which undergoes critical loading condition while performing different physical activities such as walking, running, in rotational motion, sitting, static position, standing etc. The knee joint has three parts – femur, tibia, and patella. It has two articulation components; one is in between tibia and femur & another between the femur and patella. This paper presents the review of the work going on biomechanics of knee joint. This paper presents the mechanical design & analysis of various model formations, two/ three-dimensional model, experimental studies of knee geometry &forces acting on knee joint using different mechanisms (four, five and six). The mechanisms suggested by different authors have been discussed and comparisons of results are made.

***Index Terms* - Knee geometry, knee joint, finite element method, (four, five and six) mechanisms, biomechanics.**

I. INTRODUCTION

Biomechanics is the study of the structure and function of the mechanical aspects of biological systems, at any level from whole organisms to organs, cells and cell organelles using the methods of mechanics. The study of biomechanics ranges from the inner workings of a cell to the movement and development of limbs, to the mechanical properties of soft tissue and bones. [1]

The important part of human body movement is knee geometry, in which various knee views has been shown in different planes and how the forces act on tibia and femur are studied. Comparisons are made between forces acting on knee and experimental studies of knee geometry presented by various researchers has been discussed [2].

In last few years of research, Instead of traditional uniaxial knee joint the prosthetic knee technology has been developed by multiaxial knee joints with better bionic performance. Patients comfortability and stability of walking movement can be improved by four bar mechanisms [3, 7, 9, and 11] with the bionic relative instantaneous center of rotation (ICR).

The geared Five bar (GFB) mechanism is capable of fine turning its relative ICR & ankle trajectory. It consist of a closed-chain five bar and a gear mechanism. [4]. The controllable degree of freedom [DOF] helps in different walking situations by enabling the properly optimized GFB mechanism.

The six bar mechanism –ankle mechanism is used to coordinate motion between knee and ankle joint while walking and squatting. As this mechanism is used in prosthetic knee, this paper discussed the advantages of it in the kinematic and dynamic points of view [5, 6]. This paper shows that six-bar mechanism is better to achieve the expected trajectory of the ankle joint in swing phase than the four-bar mechanism.

II. MODEL FORMATION OF KNEE

The model develop to motion was essentially from the ligamentous structures and the contact Forces. Loading conditions were limited to ligaments of the knee joints and was not subjected to external axial compressive loads.

Mathematical model

Using the coordinate system the mathematical model of human limbs is developed. Coordinate system was developed three positive axes, x- axis was oriented in higher up (superior) direction, y-axis was oriented in anterior direction, and z- axis was extended from the origin towards the left of the body. This coordinate system is used to calculate interactive forces & torque.

Finite element analysis model

In the treatment of osteoarthritis the design of prosthesis of knee is developed in the 3D model of normal and OA knee joint. Finite Element Analysis (FEA) result includes the stresses and strains induced in the knee articular cartilages and meniscus during single-leg stance.

A non-linear finite element model consisting of bony structures (tibia and femur), their articular cartilage layers, medial and lateral menisci and four primary ligaments (cruciate and collaterals) is used to reduce the cost of computation without sacrificing kinematic prediction, bones and implant components were considered to be rigid for all analyses with component contact defined by a previously verified pressure-over closure relationship.

Knee geometry

Magnetic resonance imaging (MRI) is used for soft tissue and computerized tomography (CT) is used for bones, with images taken from a normal adult volunteer to get the geometrical data of model developed. From knee geometry based on Eulerian angle, the proximal coordinate system is fixed to femur and is represented by capital letters I, J, K. & distal coordinate system is fixed to tibia and is represented by lower case letter i, j, k. here k – axis is used to define the flexion- extension motion and also i-axis is used to defines the internal-external rotation. Patella allows the femur and tibia to extend up to 0^0 to 180^0. In figure 1 (a) and (b), the sagittal view & frontal view moments were calculated from force plate & forces are shown in figure 1 (c), which is free body diagram of the leg in frontal plane from a vertical jump and figure 2 (a). Shown the translation & rotation as expressed in the knee joint coordinate system for femur, tibia and sensor coordinate system, then figure 2 (b) shows the simplified knee joint force model represents total joint forces (Resultant). In this given knee geometry, unknown forces are known by moment equation and forces are explain in various views. Knee geometry plays an important role in the present paper.

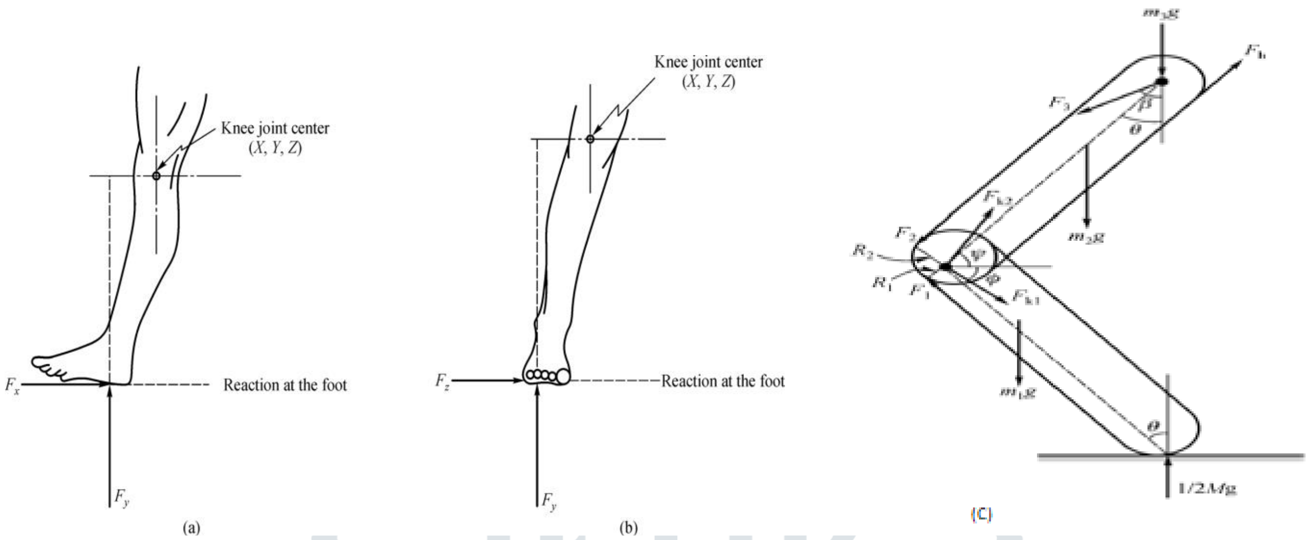

Fig. 1 (a) Sagittal view; (b) Frontal view; (C) Free body diagram of dancer leg

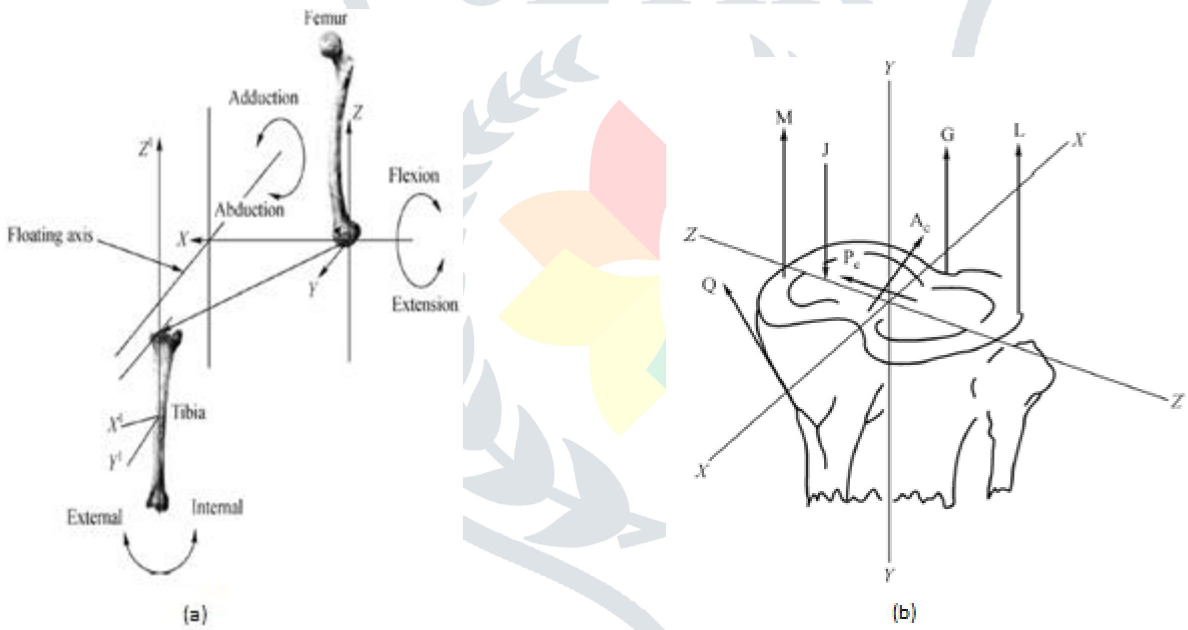

Fig. 2 (a) Tibiofemoral joint coordinate system; (b) Simplified knee-joint force model

Experimental study

Experimental study has been performed on knee joint, In this experimental set up with the help of strain gauge transducer, forces are measured to calculate movements by which knee center of rotation was estimated. Kinematics was measured using a triaxial elecrogoniometer. Fig. 3 (a) shows, the robotic system to control forces & moments at the human knee joint. This forces & moments has taken in 6 degree of freedom of the unconstrained human knee joint vs time relationship. Using the robotic system force and moment were controlled for the joint testing.

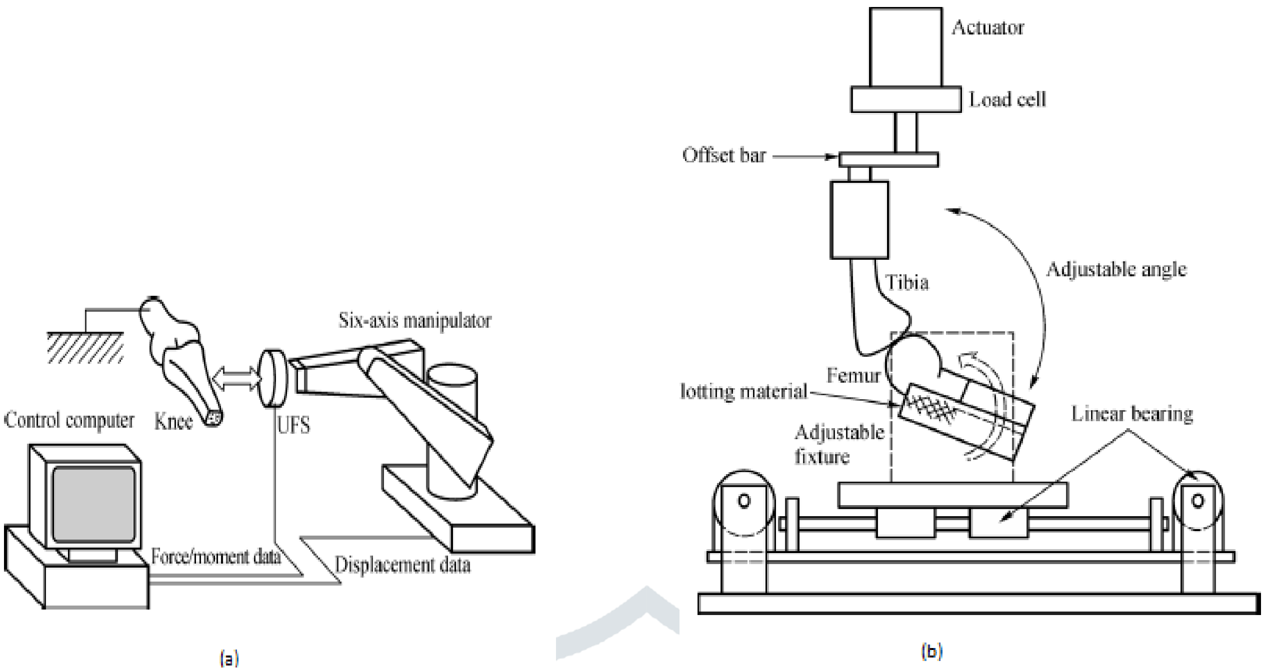

Fig. 3 (a) Robotic system to control forces and moments at the Human knee joint; (b) Tibia and femur joint loading arrangement

A fixture recorded the motion of the femur in the X (anterior-posterior), Y (medial-lateral) plane and rotation of the tibia about its axis during tibiofemoral joint loading as shown in Fig. 3 (b). In this experiment, by taking several specimen (tibia and femur) for 60° and 120° knee flexion the maximum peak load was 6.8 kN for 60° and 5.1 kN for 120°, respectively, and average peak load was 4.9 kN for 60° and 4.4 kN for 120°, respectively.

III. CONSTITUTION AND DESIGN OF MECHANISMS

3.1 Four Bar Mechanism

Four-bar linkage knee mechanisms are easily available for the trans-femoral amputee, but they are fitted in a limited number of cases although they may offer functional advantages to certain amputees.

The four bar mechanism as an efficient method to transfer power and motion. cruciate ligament of the knee form two of the four bars with the ends of the tibia and femur composing & the remaining two components of this unique four bar system these. For the mathematical methods we use geometry and analysis. On the basis of the dimensions of the four-bar linkage the relevant geometrical parameters of the knee will be determined. This leads to a system of nonlinear equations. The four-bar linkage will be calculated from the limits of the constructively accessible parameters by means of a quadratic approximation. By adapting these requirements to the dimensions of the human knee, it will be possible to obtain valuable indications for the design of an end prosthesis which imitates the kinematics of the natural knee.

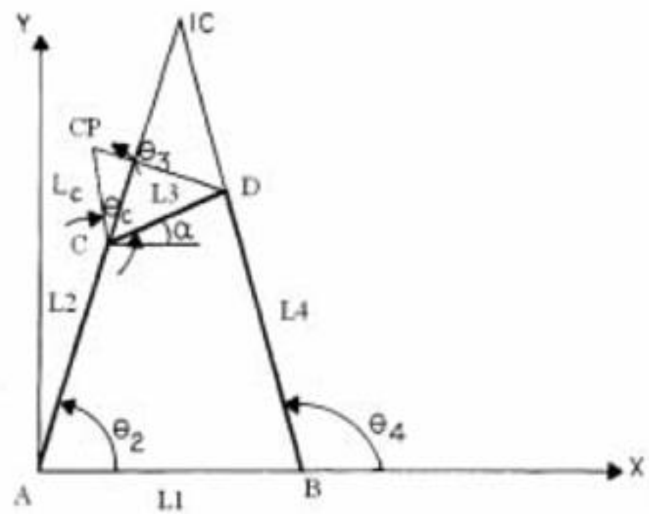

Fig. 4 Typical four bar mechanism

3.2 Five-Bar Mechanism

The mechanical design, dynamic analysis and angle trajectory analysis of a knee joint is showed in five-bar mechanism. Multiaxial knee joints provides patients with the bionic ICR. This ICR makes the performance of a prosthetic knee joint closer to the real knee in physiology.

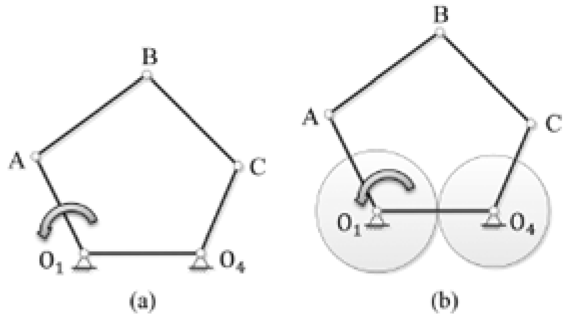

Fig. 5 (a) Five bar mechanism; (b) Geared five bar mechanism.

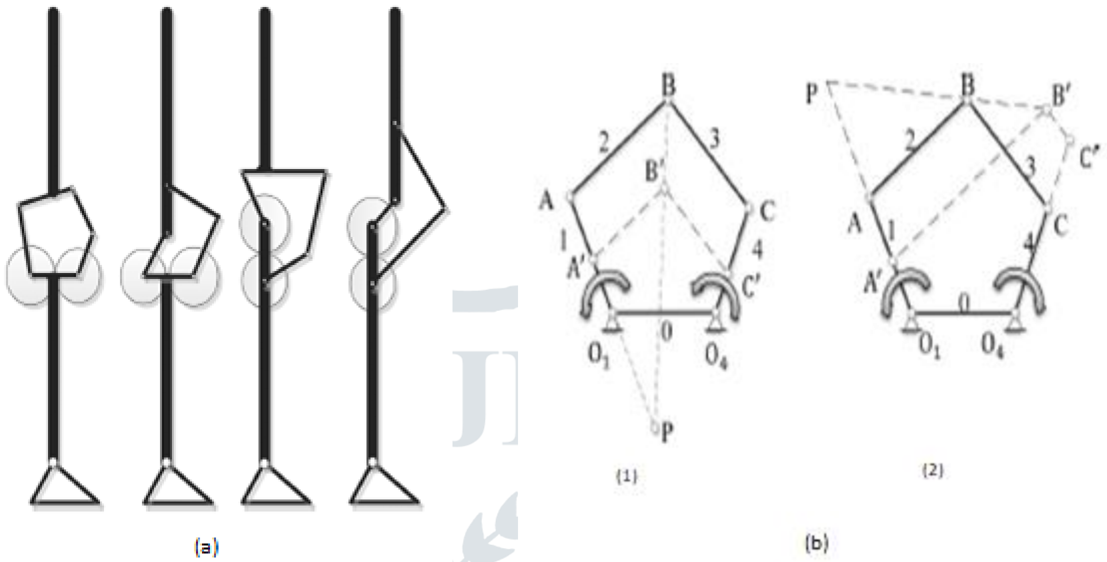

Fig. 6 (a) Four configuration of GFB mechanism prosthetic knee; (b) Two conditions of relative ICR O_1O_4 and AB. (1) Rotate in the same direction; (2)Rotate in the opposite direction.

On the basis of relative ICR of the knee joint the four configuration has to be chose, which each configuration can provide. Two driving components in five-bar mechanism are used to simplify the GFB mechanism and the ratio of these two driving components' angular velocities just equals to the gear ratio.

To solve the relative ICR of O1O4 and AB, the "Angular Velocity Vector Method" is applied. The direction of a point's angular velocity vector is perpendicular to its linear velocity. In the closed chain O1ABCO4O1, the linkages are numbered from 0 to 4 (Fig. 6 (b)). In the five-bar mechanism, as is a point of both linkage 2 and 3, it can be obtained that

$$\vec{\omega_B} = \vec{\omega_{BA}} + \vec{\omega_A}, \quad \vec{\omega_B} = \vec{\omega_{BC}} + \vec{\omega_C}. \qquad (1)$$

According to the geometric relationship of the Five-bar mechanism in Fig. 6, the following can be obtained:

$$x_A = x_{O_1} + l_1 \cos\theta_1, y_A = y_{O_1} + l_1 \sin\theta_1 \qquad (2)$$

$$x_B = x_A + l_2 \cos\theta_2, y_B = y_A + l_2 \sin\theta_2 \qquad (3)$$

$$x_{O_4} = x_{O_1}, y_{O_4} = y_{O_1} - l_0 \qquad (4)$$

$$x_C = x_{O_4} + l_4 \cos\theta_4, y_C = y_{O_4} + l_4 \sin\theta_4 \qquad (5)$$

$$x_B = x_C + l_3 \cos\theta_3, y_B = y_C + l_3 \sin\theta_3 \qquad (6)$$

$$\mathrm{n} = \omega_4/\omega_1 \qquad (7)$$

3.3 Six -Bar Mechanism

Six-bar mechanisms have two fundamental types, the Watt type and Stephenson type as shown in figure 2.The particular objective of design parameters is to form the six-bar knee mechanism so that the shank is fixed to link 5 or 6 while the thigh is fixed to link 1. Otherwise, if the shank is connected to link 3, then the function of the six-bar knee mechanism will be the same as that of four-bar mechanisms.

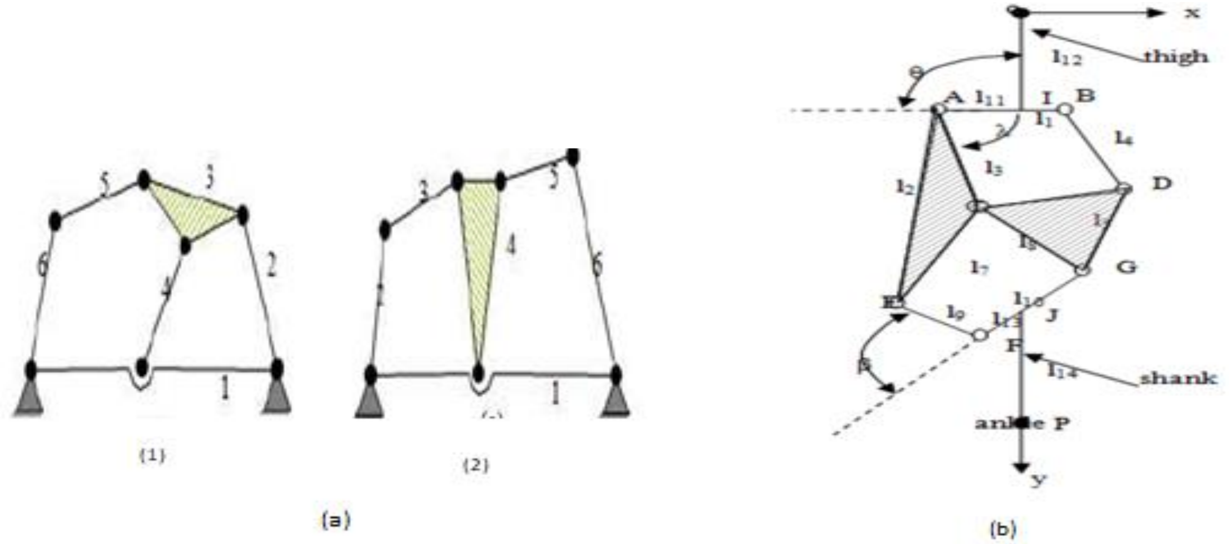

Fig. 7 (a) Basic six-bar mechanism: (1) Watt type and (2) Stephenson type; (b) Design parameters for optimization

Table 1: Comparison between four Bar, Five Bar and Six Bar Mechanisms & Robotic System in Human Knee Joint

Mechanism	**Advantages**	**Disadvantages**
4-Bar	Polycentric mechanism is used, it is combination of stability at full extension.	Higher cost
5-Bar (GFB Mechanism)	Geared five bar mechanism is capable of fine turning. GFB mechanism, which provides the patients with a better bionic performance and ankle trajectories more approximate to normal walking.	High weight
6-Bar	High kinematic stability on lands and speed ranges. This mechanism is better than other mechanisms.	A symmetric pattern. Also high weight
Experimental Study of Robotic System In Human Knee Joint.	Stress, strain & torques on knee joint can also be calculated to reduce complexity in the analysis.	Complexity increases while considering varying loads.

IV. CONCLUSION AND DISCUSSION

To reduce analysis complexity three dimensional finite element analysis models need to be generated, magnetic resonance scanner is used to make accurate three-dimensional models. The four bar mechanism is used to the comfortability and stability of walking movements by providing patients with the bionic relative instantaneous center of rotation (ICR). To perform and easily control diverse movements, the geared five-bar mechanism is good. The six-bar prosthetic knee mechanism has been investigated from kinematic and dynamic points of view in this paper. Also the comparison between various six bar mechanism shows that the performance of six bar mechanism is better than other mechanisms. A six-bar mechanism is more capable of maintaining stability in standing phase under interference.

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