Analysis of Passive Polycentric Knee Joint

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Abstract

Polycentric knee prosthesis use four bar mechanism to enable natural gait performance by amputees. Human knee primarily comprising of 3 bones, namely femur, tibia and patella along with ligaments called ACL (anterior cruciate ligament), the PCL (posterior cruciate ligament) which restrain the motion between bones. Conventional Single axis knee prosthesis rely on friction adjusted by a bolt for gait control. Other expensive knee prosthesis use hydraulic system to regulate swing of prosthetic shin with change in walking speed. This paper talks about a passive prosthetic knee joint design which has coupler link acting as ligaments and knee stiffness similar to that of natural knee.

Keywords: passive knee joint, prosthetic knee, knee torque characteristics

Introduction

Amputation causes impairment in balance, walking co-ordination and inculcation of fear of falling[1]. The vascular disease or accidental trauma are responsible for happening of amputation at large scale and due to this demand for knee prosthesis is high[2]. The WHO (World Health Organisation) estimated that there are about 30 million amputation in developing countries as 2010[3].

There are many polycentric prosthetic knee in the market which utilize either actuators or artificial muscles for controlling knee movement and torque for standard gait[4].The model under consideration has a polycentric knee with passive joint system which returns energy during later phase of gait cycle after push-off. Natural knee torque characteristics is replicated by a bungee cord acting as a tendon with nonlinear load-deflection curve[5].

The objective of this study is to achieve kinematic performance of knee prosthesis similar to that of natural knee. This includes achieving non-linear torsional stiffness of knee, mathematical modelling of governing torque-deflection equation and validation of range of motion. Kinematic model of knee joint was used to find knee torque characteristics. Experimental verification of knee torque was carried out by measurement of force required to flex the knee with incremental change in flexion angle.

Methodology

The product of the force applied to a joint and the perpendicular distance between the line of the force and the joint centre of rotation can be defined as knee torque. Tendons bind muscle and bones and are made up of longitudinally running collagen fibres. Bungee cord exhibits similar structure with latex fibres in place of collagen tightly packed together. Force Applied by Quadriceps tendon *Figure 1* and Patellar tendon in *Figure 1* at a distance enables angular displacement of tibia with respect to femur.

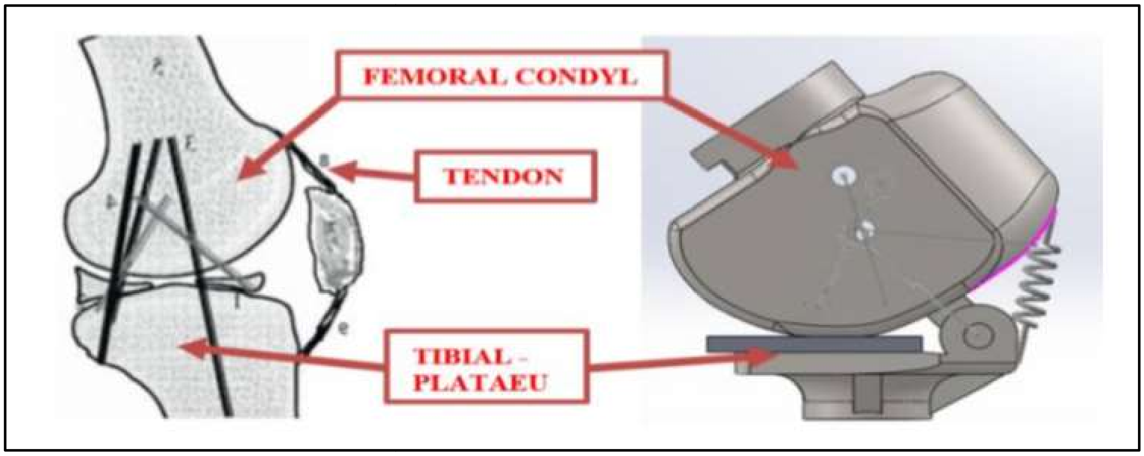

Figure 1. Structure of Human Knee Vs Prosthetic knee

Polycentric Knee Mechanism

For a polycentric knee femoral condyle rolls and slides on tibial plateau with the help of ligaments. For passive knee joint motion the Anterior Cruciate Ligament (ACL), the Posterior Cruciate Ligament (PCL) perform restraining action to assist relative movement between femur and tibia. Each of the ligaments was displayed as a straight rigid link that is associated with the tibia at one end and the femur at the other end. Revolute joints were used make a four bar mechanism which mimics motion of Tibia and Femur relative to each other as shown in **Error! Reference source not found.**. The co-ordinates of ACL and PCL with reference to centre of femoral condyle was calculated from O'Connor [6].

Stress Analysis

The X-ray images of human knee were traced with the help of solid modelling software to make a profile of femoral condyle of prosthetic knee as shown in *Figure 2*. Tibial plateau was expected to be flat and size of both tibia and femur were made to be fit in the box of the human knee. B-spline profile of femoral condyle had maximum arc radius of 147mm at the bottom. CAD model was analysed to check the von misses stress with respect to tibia-femur contact stress in human knee joint. A load case of 784N load in Z direction along the direction of tibia was applied. Von misses stress in prosthetic knee joint was found to be 53 % less compared to stress in human knee joint[7]. Tibial plateau was assigned fixed support so that stress is induced at the tibia-femur interface.

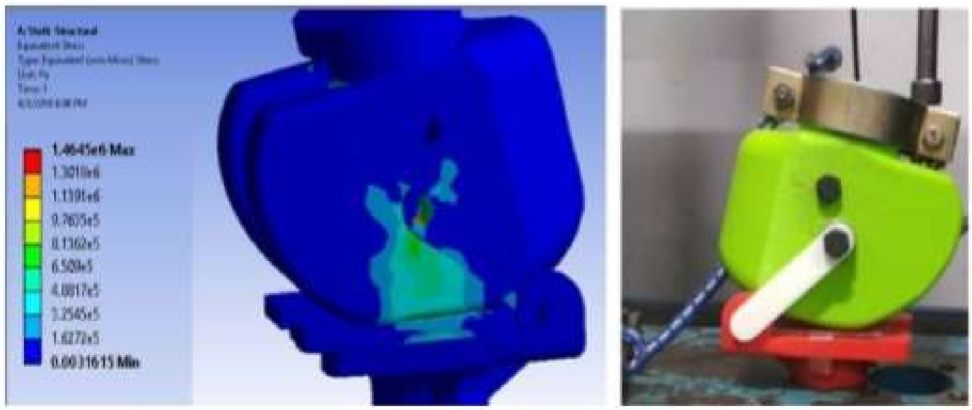

Figure 2. FEA analysis of prosthetic knee joint and experimental setup

Torque Response

The experimental and mathematical model of knee was determined by using power regression of torque Vs flexion angle data. The verified mathematical modelling is used to predict the real knee torque at different angle during gait or stance condition. The governing equation of the resisting torque was formulated from mathematical model and experimental results by performing regression analysis by using equation 5. Where, A and B are the constant for the lines with uncertainty less than 10%. By substituting the values in the equation the results obtained are shown in *Figure 3*.

$$T = A\,\phi^{B} \tag{6}$$

	Peak Torque (Nmm)	Constant A	Exponent B	Range of motion (degree)
Simulation	90	11.044	0.4753	75.9
Experimental	61.25	11.631	0.3389	73.5
Error	28.75	0.587	0.1311	2.4

Figure 3. Peak torque values from multibody simulation and experiment

The suitable equation for both mathematical model and experimental data has confidence level (R2)values varies from 0.906 and 0.945 which indicates the degree of agreement between actual values and formulated governing equation. Knee torque value for both experimental data and mathematical analysis peaked between 70^0 to 75^0 flexion angles in comparison to $81^0$for human knee[8].

Result and Discussion

The test for range of motion was performed first, angles were measured before and after full flexion of knee. The base of the tibial member and one end of the bungee cord was fixed to the worktable as shown in *Figure 2*. Force essential to turn femoral condyle of prosthetic knee was measured by attaching UTM probe to the clamp on prototype. Vertical displacement of UTM pickup point on knee clamp enabled rotation of femoral condyle. Torque was calculated by product of force by UTM and the moment arm length from prototype geometry.

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