Development of Strength Testing Machine for Artificial Ligaments

Yognandini Ramteke
Research Scholar
Department of Mechanical Engineering
G.H.Raisoni Academy of Engineering and Technology
Nagpur, India
ramteke.yognandini@gmail.com

Ashish Deoghare
Professor, Department of Mechanical Engineering
G.H.Raisoni College of Engineering
Nagpur, India
ashish.deoghare@gmail.com

***Abstract*— Ligament injury occurs due to repetitive loading on the tissues which causes damage to the musculoskeletal. It affects the natural performance of the bio-system. The properties of soft tissues like ligaments, tendons, cartilages etc and hard tissues like bones get changed. It changes the natural function of the system. Normally, wounded ligaments is treated by using conservative method of treatment or surgically or by completely replacing it by artificial ligaments. In the present work, mechanism is proposed. It is use for measuring the different properties of the artificial ligaments. The major emphasis is given on how to perform the testing to know the strength of the artificial ligaments for the cyclic loading. The developed mechanism of lower limb includes structures of the bones, joints, artificial ligaments and various links. The mechanism demonstrates the way of feasibility to implant artificial ligaments in upper and lower extremities region. It is beneficial to know the implant status prior to the surgery. Thus, it helps the surgeons to proper maintain the integrity without losing the skeletal damage and structural stability. It aids to know the desirable characteristic of artificial ligament such as mechanical properties and joint forces.**

Key words: - Bio mechanical model, Artificial Ligaments, implant model, strength testing

I. Introduction

Ligaments are tough fibrous band of connective tissue that serves to support the internal organs and hold the bones together in proper articulation at the joints. Clinical reports point out that ligament injury cases are very stiffly increasing because of day to day repetitive activities, aging, and the pattern of load sustained by the skeletal system [10, 11, 12]. The biomechanics study plays prominent role in restoring injured ligaments. The biomechanical approach is carried out in the area which includes injury diagnosis, ligament repair, rehabilitation and joint bracing. Removal of the injured ligaments and replacing it with the artificial ligaments is one of the remedy for treatment [13]. Literature survey reveals that, researches have contributed this area through vibration analysis, kinematic analysis, FEA etc [8, 9, 10]. It majorly addresses the aspects of material study. In the present research work a mechanism is purposed which is combination of electro-mechanical system. The work is further extended to include the maximum complexity of the anatomical structure with the aid of computer aided model. The skeletal model is prepared in ADAMS software to investigate the joint forces and reactions. The simulation is carried out by considering the various aspects of anatomical organs.

II. Material and Methods

A. *Link-Segment Model*

Mechanical equilibrium refers to a system in a state of balance between opposing forces and moments. The basic principles governing equilibrium based models are predicated by Newtonian laws. According to Newton's first law of motion, for static equilibrium where position or velocity is constant, the sum of forces (**F**) and moments (**M**) acting on the system must equal zero.

$$\Sigma \mathbf{F} = 0 \qquad (1)$$

$$\Sigma \mathbf{M} = 0 \qquad (2)$$

Categorize loads as being either external or internal exerted on the human body because of day to day activity. To clarify, external loads are weight being lifted or exerted on the human skeletal [5]. It has the effect of gravitational and inertial forces whereas, internal loads have the effect of the restorative forces generated by tissue such as muscles and ligament structures. To study the effect of external loads a link-segment model is proposed. The human body can be compartmentalized into linked body segments, each treated as a separate entity which can be represented as a free-body diagram. In the current study the free body diagram analysis begins with skeletal segment from forearm. Equilibrium equations are used to satisfy both force and moment equilibrium constraints. Link segment model of the human skeletal system is shown in Fig.1. The equilibrium is used to yield the joint reaction force and moment acting on the segment. Analysis continues until the kinetic information is obtained for the joint of interest.

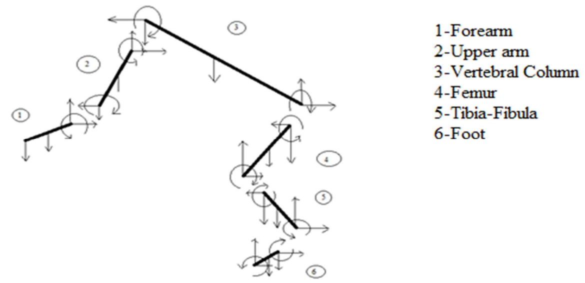

Fig. 1. Link- segment model

To understand the concept, free body diagram of forearm and upper arm is shown in Fig.2. (a) and (b). The detailed force and moment transfer is carried out as described below.

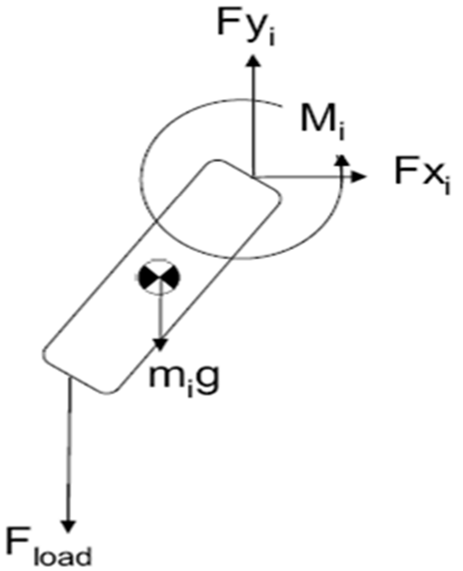

Fig. 2. (a) FBD of forearm

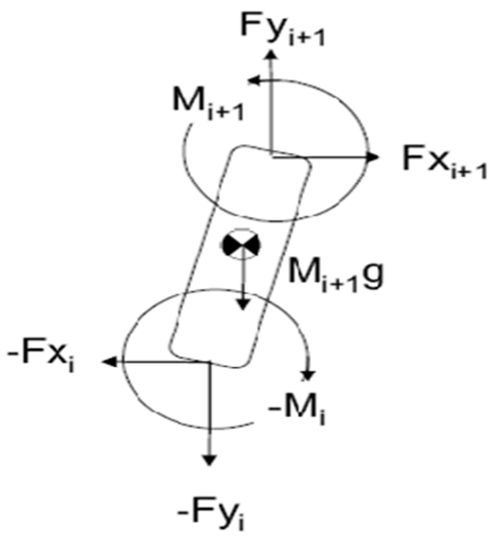

Fig. 2. (b) FBD of upper arm

Analysis can initiate with a bottom-up approach where ground reaction forces acting on the feet are considered as input to the model first or a top-down approach where forces acting on the hands are used to start the analysis. A top down approach is used in this method according to which the process starts form the uppermost portion of the body and can terminate at the desired position and locations. Starting with the first segment (i = 1), equations are written to satisfy both force and moment equilibrium constraints. The equilibrium equations with respect to Fig.2 are depicted below and such a method is extended for the other segments.

$$\sum \mathbf{F} = 0$$
$$\mathbf{F}_{load} + m_i \mathbf{g} + \mathbf{F}_i = 0 \qquad (3)$$

$$\sum \mathbf{M} = 0$$
$$\mathbf{r}_{load} \times \mathbf{F}_{load} + \mathbf{r}_i \times \mathbf{F}_i + \mathbf{M}_i = 0 \qquad (4)$$

where $\mathbf{F}_{load}$ represents the force from the object held in the hand, $\mathbf{r}_{load}$ represents the distance from the segment's center of mass to the center of mass of the object, m_i, represents the mass of the segment, ***g*** represents gravity, $\mathbf{r}_i$ represents the distance from the segment's center of mass to $\mathbf{F}_i$ (proximal end of the segment). Note on the figure that the *x* and *y* components of each force vector are shown. For analysis, these two components are combined to yield the vector incorporated into the above equations. Link-segment analysis yields two outputs: reaction force (**F*i***) and joint moment (**M*i***). Both the reaction force and joint moment produce an equal but opposite reaction force (–**F*i***) and joint moment (–**M*i***) that act on the distal end of the next segment ($i + 1 = 2$). Similar to the first linkage equilibrium Eqs. (1) and (2) are solved to yield the reaction force and moment acting on the proximal end of the second segment. Analysis continues until all of the segments have been incorporated into the model or until the kinetic information is obtained for the joint of interest. The conventional technique discussed above does not incorporate the effect of ligaments. In-fact it is integral part of the human body system. Hence a more realistic approach is explored which overcomes the drawback of the link-segment model.

B. Development of mechanisms

Proposed mechanism consists of a biomechanical model of the lower limb region. Models of the lower limb musculoskeletal system have enabled a wide variety of biomechanical investigations [2]. Models are often characterized by task and application to the patient population. In the present work the concept of modeling the body as a number of linked is based on the anatomical fact that the skeleton is composed of rigid bones, which are linked by various kinds of joints. Such a model is developed by dividing body into segments, which are assumed to behave as rigid elements and connected at joints. Goal is to developed a lower limb model and explain the strength testing mechanism and to determine the strength of the artificial ligaments.

Modeling is best way to obtain the information about the strength of artificial ligaments which is often complicated, costly and difficult to apply on human being. The proposed mechanism include the model of single lower limb consists of feet, tibia, fibula, femur and pelvic as shown in Fig. 3. The bone dimension is of 156 cm tall, 50kg weight female.

Fig. 3. Model Lower Limb

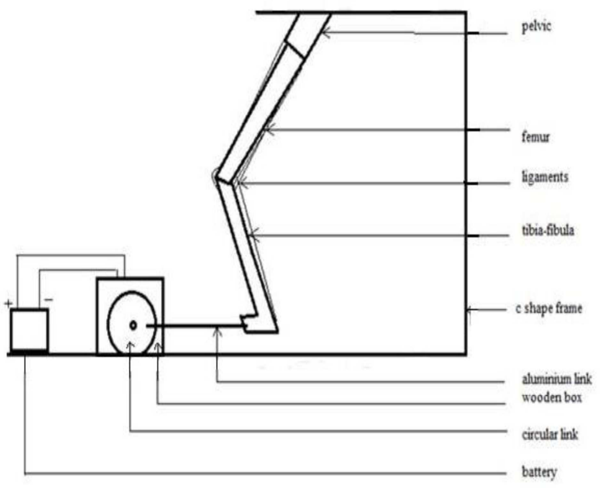

Fig. 4. Schematic representation of mechanism

The proposed mechanism also consists of ‘C’ shape iron frame, two aluminum links connected with the feet & fixed with another circular link. The circular link is made out of wood, motor covered inside the wooden box, battery, artificial ligaments made of any bio compatible material but of properties similar to that of ligaments of the human body. The pelvic section of the lower limb is attached to the ‘C’ shape metallic frame so as to keep the lower limb in the vertical position. One end of an aluminum link is attached to the feet with the help of screw while other end is attached to another aluminum link. The links are drilled with equidistance hole. The circular link is fixed with the 100 rpm motor and powered by 12 V, 7A battery. Speed of the motor can be regulated by using the knob provided. The cyclic reciprocating action to the feet is given via circular link segment. Thus entire structure follows to and fro motion.

C. Working of mechanism

The mechanism initially is in the static condition, at this stage ligaments are not stretch and therefore no strain is induced in the ligament. As motor rotates it gives rotary motion to the circular link fixed with it. Because of the rotary motion of the circular link a series of aluminum link also rotates and gives forward and backward motion to the feet. Thus the lower limb moves to and fro. This motion causes the ligaments to stretch and therefore strain is developed. The induced strain can be measured using strain gauges or sensors. Thus the mechanism is capable of measuring the strain in artificial ligaments and in bones also. Different mechanical properties such as fatigue, tensile strength etc can be measured by including auxiliary’s equipments or accessories in the mechanism. Moreover, the result can be extrapolated to predict the different properties using advance techniques.

D. Benefits of model

Assessments of proposed mechanism will give the effect of stretching on artificial ligaments and will also give the mechanism for strength testing. Since the mechanism is useful for measuring the strength of the ligaments it can be use for testing the other properties of ligaments. Artificial ligaments can also be replaced by the ligaments of rat, goat or other animal to test different properties.

III. COMPUTER AIDED MODELING OF HUMAN SYSTEM

The developed mechanism includes all the essential real time features of lower extremities of human system which has to be explored in order to accomplish the real time data. It is difficult to generate conducive environment to keep live hard and soft tissues in the experimentations. Hence the aide of computer aided modeling technique is explored. To accomplish this task a commercial available ADAMS 2012 is used. In the current study cylindrical links are used to represents hard tissues like Bones and soft tissues like Ligaments. The arrangement of anatomical structure is represented in the Fig. 5.

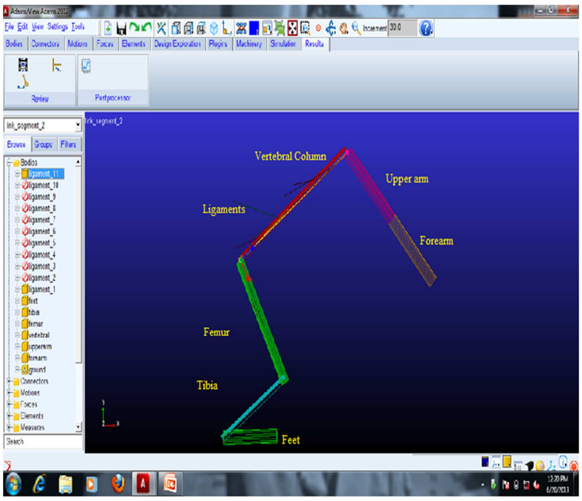

Fig. 5 Anatomical Structures in ADAMS Software

For the analysis of human skeletal system various assumptions and fairly accurate data from the standard anatomy atlas is considered. A cylindrical link of 25 cm length and 2 cm radius is taken as forearm it is at an angle of 300º with respect to the upper arm. Similarly a cylinder of 27 cm length and 2 cm radius is assumed as an upper arm it makes an angle of 330º with vertebral column. A cylinder of 55 cm length and 2 cm radius is taken as a vertebral column it makes an angle of 60º with femur. Similarly a cylinder of 40 cm length and 2 cm radius is taken as a femur making an angle of 130º with tibia. Tibia is taken as a cylinder of 33 cm length and 2 cm radius making an angle of 60º with feet. A foot is taken as a cylinder of 23 cm length and 2 cm radius making an angle of 150º. With the help of connector function of revolute joint each of the body part is connected together. The system is articulated in the software and its structure is represented in Fig.5. It is initially analyzed with hard tissue configuration and further extended for the ligament tissues by considering flexible link segment. A weight of 5 kg is assumed to be held in the forearm which is equivalent to a force of 49 N acts in a vertical plane and simulation is carried out for 0.045 s and 1000 steps to investigate the joint forces. The results are obtained in the form of plots for different anatomical parts.

When the bone and the ligament configuration are considered as rigid and simulation is carried out for the above assumptions. The results obtained on the different body segments and the joint force variations are shown in Fig.6 (a) and (b) respectively. Further the simulation is extended for flexible bone and ligament tissues variations. The Force v/s Time variations on different body segment and joint force are shown in Fig.7 (a) and (b) respectively.

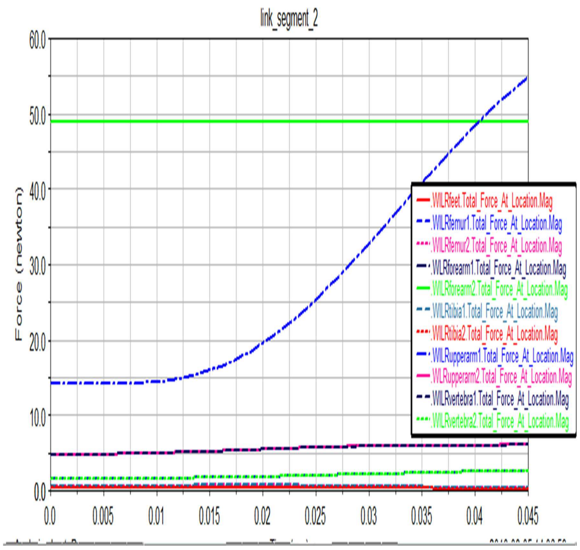

Fig. 6 (a) Body Segment

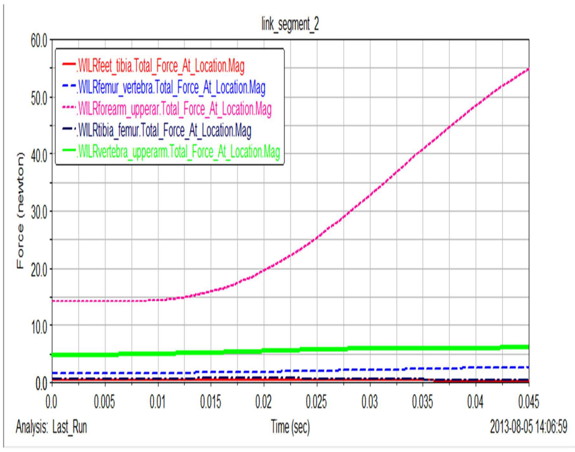

Fig. 6 (b) Joint Force

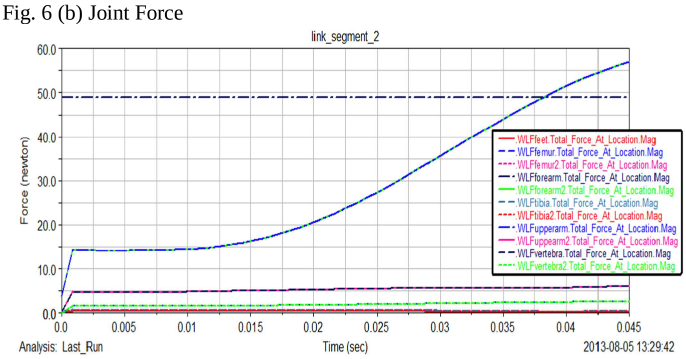

Fig. 7 (a) Body Segment

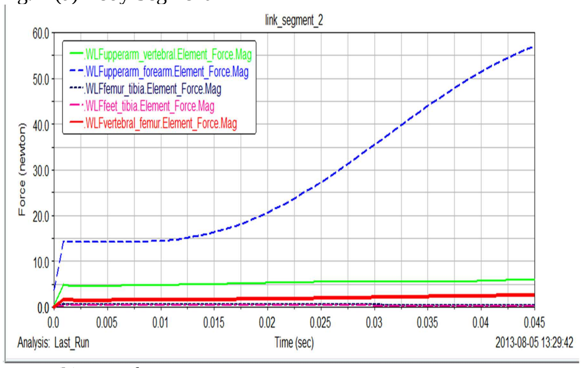

Fig. 7 (b) Joint force

IV. Discussion

In the current study, proposed mechanism can predicts the strength of artificial ligaments at various section of the lower limb region. The advantage of such mechanism is to obtain required result without applying it on the human being. This mechanism can be successfully used for investigation purposes and provides better understanding of lower limb and lower limb ligaments. The mechanism created in the ADAMS facilitates to perform simulation for different configurations of skeletal systems for different static and dynamic considerations. The need of in-vitro study can be minimized and such Computer Aided Model provides a guideline for the better convergence of the result.

V. Conclusion

Although significant advances have been made in the biology, biochemistry, and biomechanics, there is still much work to be done in the field of tissues and ligaments. Presented in this paper is the mechanism related to strength testing of artificial ligament. Ligaments play a significant role in stabilizing joints and specifying joint motion. They are commonly injured in various activities and, therefore, injured ligaments are replaced by artificial ligaments. The mechanism in the article gives the strength testing mechanism to test its properties. Such a mechanism will help in understanding the properties of artificial ligaments.

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