An analytical model of the patello-femoral joint
by Jack Stephen Hagelin

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
* in Mechanical Engineering
Montana State University

Abstract:
The intent of this research was to develop an analytical model of the human knee joint for the purpose of aiding orthopedic surgeons in determining the optimum corrective operation to alleviate the condition of recurrent patellar dislocation.

A kinematic model was developed defining the relative positions of the femur, tibia, and patella for all angles of flexion. The patellar - surface was approximated by a cosine curve rotated through a specified arc length and the patella was modeled as a cylinder. The assumption was made that the quadriceps muscle group could be approximated by a single muscle in which the resultant force acting on the patella was equivalent to the total muscle group. The accuracy of this model is contingent upon the accurate determination of the proximal attachment for the effective quadriceps muscle.

Nineteen nonlinear simultaneous equations were developed to relate the nineteen unknown kinematic parameters and were solved using Newton-Raphson's Method on the computer. The computer output is in the form of a video display indicating the position of the patella in the patellar groove. Surgeons may simulate operations on the computer model and determine visually the path of the Datella throughout flexion. Trial operations are simulated until the desired patellar path is reached.

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Date 27 Oct 1978

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ABSTRACT

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CHAPTER 1

INTRODUCTION

The intent of this research was to develop an analytical model of the human knee joint for the purpose of aiding orthopedic surgeons in determining the optimum remedial operation for recurrent patellar subluxation.

Recurrent dislocation of the patella is primarily due to an irregular geometrical configuration in the leg anatomy. Since there are a number of different abnormalities possible, there are also a number of operative techniques available to surgeons. This results in a degree of uncertainty in their decisions, which in turn results in an undesirable failure rate.

To reduce this failure rate, a model was desired which could predict the effect of each of the different operations performed. Surgeons could then select the operation which would result in a desirable force pattern and acceptable patellar path.

To accomplish this, a kinematic model was developed which included parameters for ligament directions and a description of the relative positions of the femur, tibia, and patella. The assumption was made that at any given angle of flexion, there is only one point on the patella which is in contact with the femur. The result is a computer model which outputs a video display indicating the path of the patella in the patellar groove through flexion.

CHAPTER 2

ANALYTICAL MODEL

2.1 Introduction

The purpose of this research was to develop an analytical model of the patello-femoral joint, accurately defining the position of the patella in the joint for all angles of flexion.

The kinematic model developed incorporates the use of vectors in defining all bone and ligament positions. A force analysis is included requiring the patella to be in static equilibrium throughout flexion.

2.2 Definition of Kinematic Model

Figure 1 depicts the model used in this study. Listed below is a description of the coordinate system and all points in the model.

A rectangular coordinate system is used in this model as defined in Figure 1-a. Both the left and right knees incorporate a left-handed coordinate system. The Y-axis is the axis of rotation of the tibia about the femur. The X-axis is parallel to the femoral shaft and is located laterally in the same plane as the tibial tuberosity. This axis is positive in the distal direction. The Z-axis is positive anteriorly.

Point '0' is the origin of the coordinate system. Point '1' is the point of contact between the patella and the patellar surface. (The gap shown in Figure 1-b is due to the fact that there is a layer of cartiledge between the femur and the patella.) The patellar surface will hereafter be referred to as the cam. Point '2' is the tibial tuberosity,

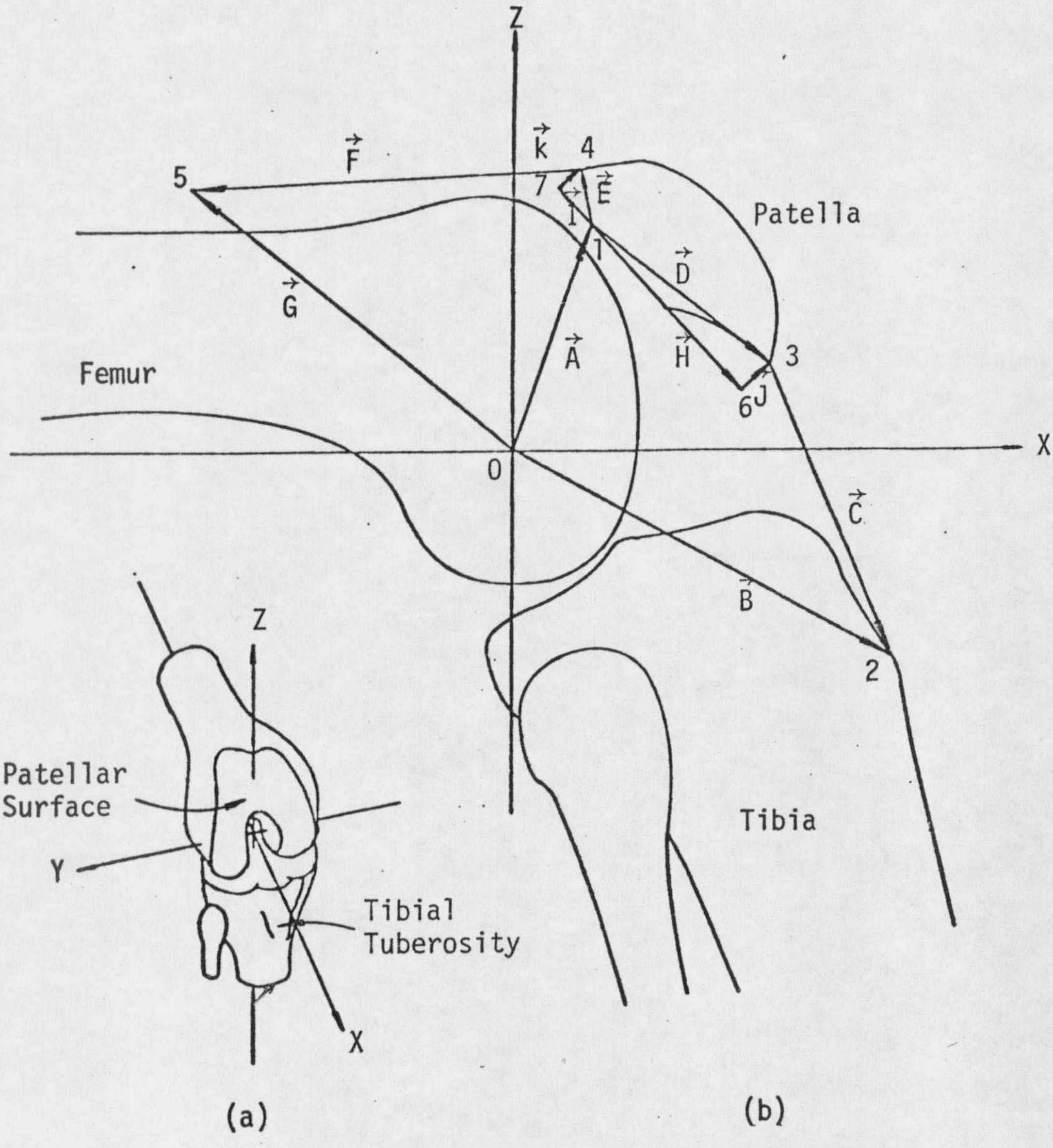

Figure 1.--Analytical model parameter definition

the point of insertion of the Ligament Patellae; and point '3' is the point of origin for this ligament, located on the distal end of the patella. Point '4' is the point of insertion of the quadriceps group, located on the proximal end of the patella; and point '5' is the effective point of origin for this muscle group, which is to be determined by the surgeon. Points '6' and '7' represent the extreme points on the inferior surface of the patella and are colinear with point '1'.

All vectors are defined in terms of the points listed above. Note that vectors $\vec{C}$ and $\vec{F}$ represent the directions of the patellar ligament and the quadriceps group respectively.

A number of assumptions are inherent in this model and will be discussed in the following section.

2.3 Assumptions

The quadriceps group is made up of four muscles: the rectus femoris, the vastus lateralis, the vastus intermedius, and the vastus medialis (see Figure 2-a). All of these have as their insertion the proximal end of the patella, but their origins differ greatly, ranging from the anterior inferior iliac spine for the rectus femoris, to points all along the shaft of the femur for the vastus group. Figures 3-a through 3-c illustrate these proximal points of attachment. The assumption was made that the quadriceps group could be approximated by a single muscle with its proximal attachment at the appropriate position, as shown in

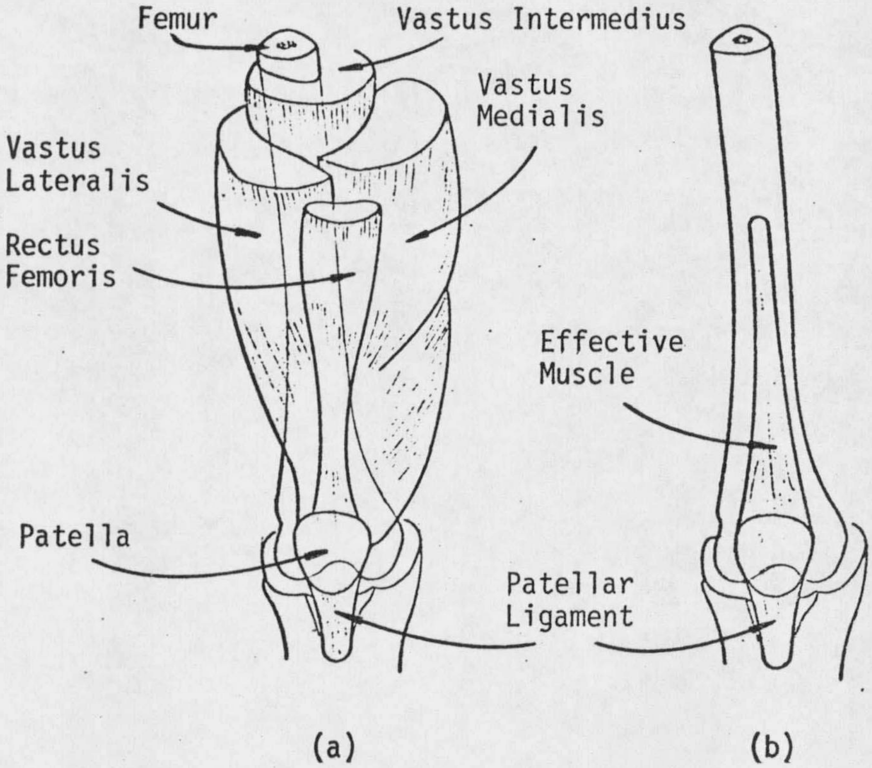

Figure 2.--Quadriceps muscle group
(a) actual
(b) modelled