

Patellofemoral Joint Instability: A Biomechanical Study

Wongwit Senavongse* and Suchada Tantisatirapong,

ABSTRACT

Patellofemoral joint instability is a complex clinical problem. It may be a consequence of pre-existing anatomical abnormality or trauma. The objectives of this study were to use experimental mechanics to measure patellar stability and to quantify the effects of pathological abnormalities on patellar stability in vitro. Eight fresh-frozen cadaver knees were studied. The patellar stability was measured using an Instron material testing machine. A total load of 175N was applied to the quadriceps muscles. Patellar force-displacement was tested at different knee flexion angles as the patella was cyclically displaced 10mm laterally and medially. Three pathological abnormalities were applied: VMO malfunction, flat lateral trochlea, and medial retinacular structure rupturing. For the first time, this study has shown comparative and quantitative influence of pathological abnormalities on patellar stability. It was found that a flat lateral trochlea has greater effect than the medial retinacular rupturing whereas the medial retinacular rupturing has greater effect than VMO malfunction on patellar lateral stability. The results are important for future investigations on the treatment of patellofemoral instability.

Keywords: Patella; Patellar stability; Biomechanics; Knee joint

1. INTRODUCTION

Patellofemoral disorders are a common cause of knee pain and disability. One of the most common patellofemoral disorders is patellar instability due to subluxation and dislocation. The terms instability and stability are commonly used clinically to describe the presence or absence of a patient's functional symptoms. Instability encompasses giving way as a result of the patella partially slipping out of the femoral trochlea and dislocation which is a complete displacement of the patella out of the femoral trochlea. Stability of the patellofemoral joint depends on several factors such as the balance of

the quadriceps muscle force, the articular geometry of the patella and femur, the retinacular structures, etc. The complex interaction between these factors maintains the stability and normal function of the patellofemoral joint during knee flexion. However, abnormalities in these factors cause some changes away from normal knee behavior which are not well understood. Also, the role and the relative contribution of these factors, patellar stabilising mechanisms, are still unclear. It is essential to define the term 'stability' quantitatively for comparative studies. Stability can be described quantitatively as: the displacement induced due to an applied load, patellar laxity; or the resultant 'restraining force', the tendency of the patella to return to the position of stable equilibrium from a chosen displacement, due to an applied displacement, patellar stability. Quantitatively, laxity or stability is usually employed when reporting force-displacement or 'stiffness' tests. Quantitative stability characteristics can be presented as laxity at a given displacing force, or as restraining force at a given displacement. The objectives of this study were to quantify medial and lateral patellar force-displacement behavior in the normal human cadaver knee across a range of knee flexion angles and to comparatively study the effects of various simulated pathologies.

2. METHODS

2.1 Specimen and specimen preparation

Eight fresh-frozen knee specimens were used in this study. The skin, underlying fat, iliotibial tract, and all the muscles, except the distal portion of the quadriceps components, were removed. Care was taken to preserve the retinaculæ and the fascia of the quadriceps muscles intact. The quadriceps components were then separated as accurately as possible, using the indications of aponeuroses and fascia. The muscles' distal tendinous fibers, which merge together, were left intact to ensure that the actions of the muscles were close to the physiological ones as much as possible. The quadriceps components were separated into six components: the rectus femoris (RF), vastus intermedius (VI), vastus lateralis longus (VLL), vastus lateralis obliquus (VLO), vastus medialis longus (VML), and vastus medialis obliquus (VMO) as shown in Fig. 1.

Manuscript received on July 26, 2008 ; revised on August 14, 2008.

* Corresponding author.

W. Senavongse and S. Tantisatirapong are with Biomedical Engineering Programme, Faculty of Engineering, Srinakharinwirot University, Nakonnayok 26120 Thailand, Phone +66 9485-0965; fax +66 2931-8675

E-mail addresses: wongwit@swu.ac.th (W. Senavongse)

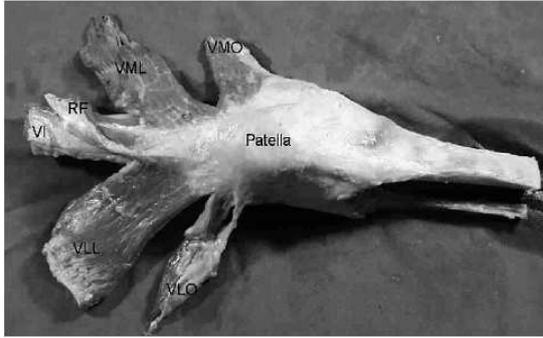


Fig.1: Specimen preparation

2.2 Experimental Setup

The apparatus for the experiment consisted of the stability rig mounted in an Instron 1122 materials testing machine (Instron Ltd., Buckinghamshire, England). In Fig. 2, the knee was oriented with the lateral aspect uppermost, and with the tibia flexing in a horizontal plane. The quadriceps components were each loaded by cables routed via pulleys to hanging weights. A total load of 175N was applied to the muscle groups according to the directions and physiological cross-sectional areas (PCSA's) of the muscles [1] relative to the femoral axis: VLL 14° lateral and 0° anterior; VLO 35° lateral and 33° posterior; VML 15° medial and 0° anterior; VMO 47° medial and 44° posterior; RF+VI 0° lateral and 0° anterior. The quadriceps tension distribution among the muscles was: RF+VI 35%, VLL 33%, VLO 9%, VML 14%, VMO 9%.

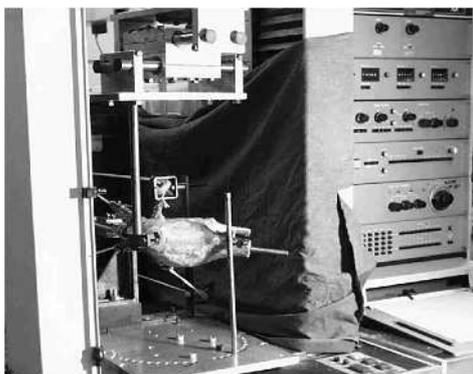


Fig.2: Setup of the experiments

The patella was connected via a patellar mounting and the three-degree-of-freedom linkage to a load cell on the moving crosshead of the Instron. At the patella, a ball-bearing inside the patella, centred 10mm deep to the anterior surface, allowed natural tilt and other rotations of the patella (three-degree-of-freedom) when it was displaced laterally and medially. This arrangement allowed five-degrees-of-freedom while controlling the medial-lateral translation.

2.3 Experimental Procedure

Patellar force-displacement behavior was tested at 0, 10, 20, 30, 45, 60, and 90° knee flexion. The patella was cyclically displaced 10 mm laterally and 10 mm medially from its stable position at 100 mm/min. Farahmand and coworkers [2] found that 12.7 mm displacements did not damage the tissues, and 10 mm displacement cycles gave reproducible force-displacement curves. The fourth load versus displacement cycle was recorded at each knee flexion angle. Three pathological abnormalities were simulated: VMO malfunction by relaxing the VMO muscle, flattened lateral trochlear groove by cutting a wedge out, and ruptured medial retinacular structure by displacing the patella laterally as shown in Fig. 3 and Fig. 4.



Fig.3: Cutting a wedge from lateral trochlea



Fig.4: Flattened lateral trochlea

3. RESULTS

The mean lateral and medial force-displacement curves are shown in Fig. 5. A graph of percentage reduction of lateral displacing force caused by each of the pathologies versus knee flexion angles was plotted in order to clearly compare the contribution of each pathology as shown in Fig. 6.

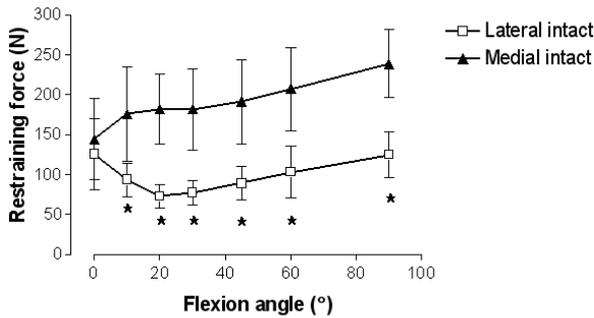


Fig.5: Mean restraining force of lateral and medial intact stability

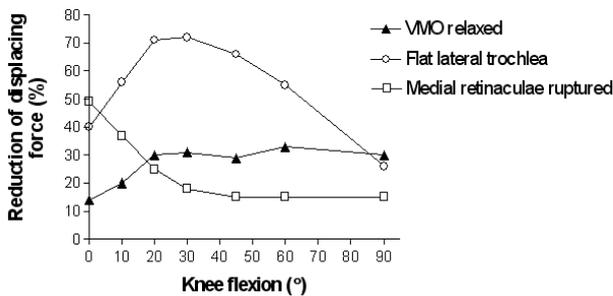


Fig.6: Percentage reduction of lateral displacing force

4. DISCUSSION

Patellar force-displacement behavior was of interest and critical near knee extension as knee flexion was expected to lead to greater patellar stability due to the closing angle between the quadriceps and patellar tendons in the sagittal plane, which caused a greater joint compression force vector. Laterally, it was found that 20° of knee flexion was the most vulnerable to patellar dislocation.

For the first time, both lateral and medial patellofemoral stability have been studied quantitatively over a range of knee flexion. Also, the relative contributions of the patellar stabilisers have been studied quantitatively under normal and simulated pathological conditions. Previous investigations concerning the quantitative description of the patellofemoral joint stability are limited [2-4]. They also used the concept of laxity or restraining force to describe the stability characteristics of the patellofemoral joint but they did not study under physiological conditions.

Lateral and medial patellar force-displacement behaviors have been described quantitatively in terms of restraining force under simulated physiological conditions. Unlike lateral force-displacement behavior, the medial force-displacement curves show that medial patellar stability increased with progressive knee flexion.

The findings of the present study suggest that the

lateral femoral trochlear articulation contributes significantly to prevent patellar dislocation while muscle imbalance has a small but consistent effect on the stability of the patella. The medial retinacular structure has a major role near knee extension. The present study adds more support against excessive and indiscriminate lateral release which may cause medial subluxation. It would be appropriate to make a study of lateral retinacular release using the methods described in this study. Also, medial patellar subluxation is a subtle problem that may be overlooked. It should be included in the differential diagnosis as something must go seriously wrong to create medial subluxation, since the present study has shown the naturally good resistance against it.

This study has some common limitations due to being based on cadaveric specimens, particularly the age (over 50 years old) and sample size of the specimens tested. Some limitations are based on experimental setup. The first limitation is the quadriceps muscle loading with tensions applied to the individual muscles in physiological magnitudes and directions. However, the tension ratio resulting from using the muscle PCSAs may not represent the ratio acting in non-maximal activation, and this may be the case in activities when patellar dislocation occurs in vivo. Nevertheless, the author was not aware of any better basis on which to assign muscle tensions. In the past, Goh used the mid-muscle cross sectional area of the quadriceps components in six specimens as an indication of the force ratios [5]. None of the literatures provides a complete force ratio of RF, VI, VLL, VLO, VML, and VMO as indicated by the anatomy of the quadriceps muscles. Also, the comparison between a dynamic clinical occurrence and a simulated cadaveric experiment must be interpreted with caution. However, it is believed that the results of this study adds support to the clinical findings and provides a first step towards an in vivo application. It is also believed that the results of this study are valuable because they provide quantitative data which can be used in studies of the effectiveness of surgical procedures for patellar dislocation.

References

- [1] F. Farahmand, W. Senavongse, and A. A. Amis, "Quantitative study of the quadriceps muscles and trochlear groove geometry related to instability of the patellofemoral joint," *J. Orthop Res*, 16, pp. 136-143, 1998.
- [2] F. Farahmand, M. N. Tahmasbi, and A. A. Amis, "Lateral force-displacement behavior of the human patella and its variation with knee flexion-a biomechanical study in vitro," *J. Biomech*, 31, pp. 1147-1152, 1998.
- [3] T. Conlan, W. P. Garth, and J. E. Lemons, "Evaluation of the medial soft-tissue restraints

of the extensor mechanism of the knee," *J. Bone Joint Surg Am*, 75, pp. 682-693, 1993.

- [4] S. M. Desio, R. T. Burks, and K. N. Bachus, "Soft tissue restraints to lateral patellar translation in the human knee," *Am J. Sports Med*, 26, pp. 59-65, 1998.
- [5] J.C.H. Goh, P.Y.C. Lee, and K. Bose, "A cadaver study of the function of the oblique part of vastus medialis," *J. Bone Joint Surg Br*, 77, pp. 225-231, 1995.

W. Senavongse photograph and biography not available at time of publication.

S. Tantisatirapong photograph and biography not available at time of publication.