In Vivo Observation of Articular Surface Contact in Knee Joints

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This paper was submitted for publication to the Journal of Biomechanics 11/2005 and rejected for publication. The story behind the article is that I (Levin) needed arthroscopic knee surgery for a torn cartilage and I persuaded my surgeon (Madden) to perform the surgery under local anesthesia and weould try a few things under my direction. Madden had no idea what I was up to as he was unaware of my work in biotensegrity.

Abstract

Background

Arthroscopic knee surgery is a common orthopedic procedure that provides the opportunity to observe the articular surfaces of the joint in vivo.

Methods

Arthroscopic knee surgery was performed local anesthesia with the patient fully awake and cooperative. Maneuvers were performed to simulate loading the joint and weight bearing.

Findings

No maneuver could coapt the surfaces of the knee joint and “contact surfaces” of the joint were always separated by a minimum of 1mm of space. Hydrostatic forces are insufficient to keep the surfaces separated.

The concept that joints transmit loads by compressing across articular surfaces must be reassessed. Trusses may be suitable alternative models as they may be constructed without joints loaded in compression.

Introduction

Clinical observations during surgery provide insights into biomechanical models not available in the laboratory. It has long been known that we see what we are trained to see, and that laboratory models and experiments are influenced by preconceived concepts. Arthroscopic joint surgery has been popular and common since the early 1980s, and several hundred thousand arthroscopic surgical procedures are performed in the United States each year, and probably an additional equal number worldwide. There have, therefore, been millions of missed opportunities for scholars and students of biomechanics to directly observe live tissue in a clinical situation. Surgeons are rarely trained as biomechanics and, even when they are, their interest at the time of surgery is focused on the task at hand, and not on biomechanical modeling. "Experiments" on patients can invite challenge on ethical grounds, and great care is necessary to avoid exploiting patients during surgery. However, in vivo, intraoperative observation of the patient's mechanics is often an integral part of the process during joint surgery. The clinician, however, usually is busy viewing the mechanics from the perspective of practical function rather than scientific understanding. Recently, an opportunity arose to do both.

An Orthopedic Surgeon (SML) with a background in biomechanics required knee surgery. Surgery was performed under local anesthesia with the patient fully awake and with muscle function intact. The operating surgeon performed several biomechanical evaluations at the patient's/biomechanic's request. A real-time video projection of the internal workings of the knee joint was visible to the operating surgeon and the patient/surgeon/biomechanic. The operating surgeon (MM) had no prior knowledge of the biomechanic's theoretical models and focused on the surgical evaluation with the added ability to look through the biomechanic's eyes and introduce a maneuver or two, adding nothing to the risks involved, trivially to the operating time, and considerably to the elucidation of some significant biomechanical points.

Every joint surgeon knows that there is a space, filled with joint fluid or surgical irrigating solution, between the articular surfaces of the joints. Joints are 'loosely packed', and the spaces between the articular surfaces are readily entered with operating instruments. In the knee, the space is easily opened to 5 mm and more. The patello-femoral joint may be a bit tighter but is also clearly visible and can be entered with instruments. It is assumed that this space exists only when the joint is not weight bearing and that when muscles contract and/or the joint is weight bearing, the space closes and there is direct contact of adjacent articulating surfaces. Hydrostatic pressure in the joint is insufficient to keep the surfaces apart when the joint is loaded in compression. Thin fluid lubrication is possible, but that would not alter the compression across the joint. It would just smooth out the surfaces and make them more slippery.

Procedure

Patello-femoral tracking is routinely evaluated during surgery. In the mind's eye of the operating surgeon, the articular surfaces of the patella and femur compress one another, particularly at full flexion of the knee (Figure 1).

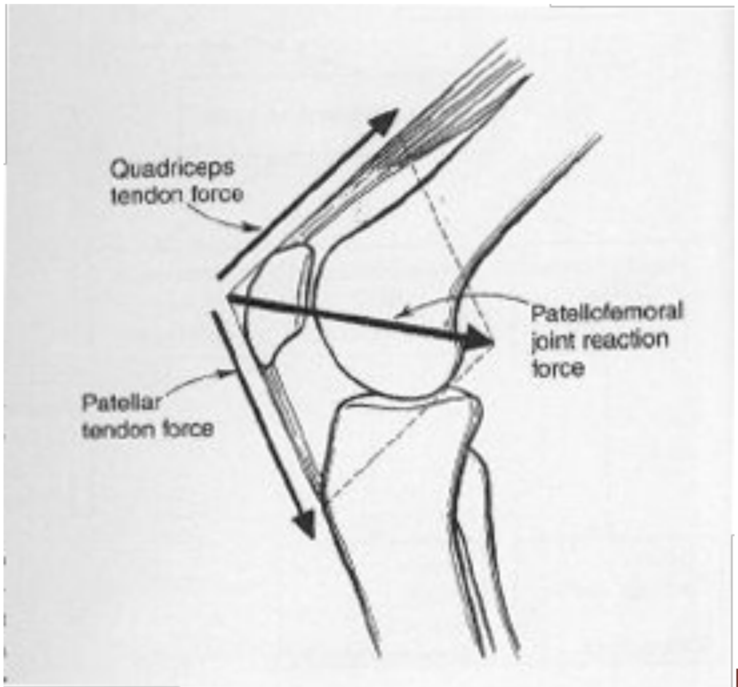

Figure 1. Theoretical forces compressing the patello-femoral joint with contraction of the quad muscles.

When observed under the direction of the bio-mechanic, the space remained open by two to three millimeters. The patient then contracted the quadriceps mechanism and the space remained (Figure 2).

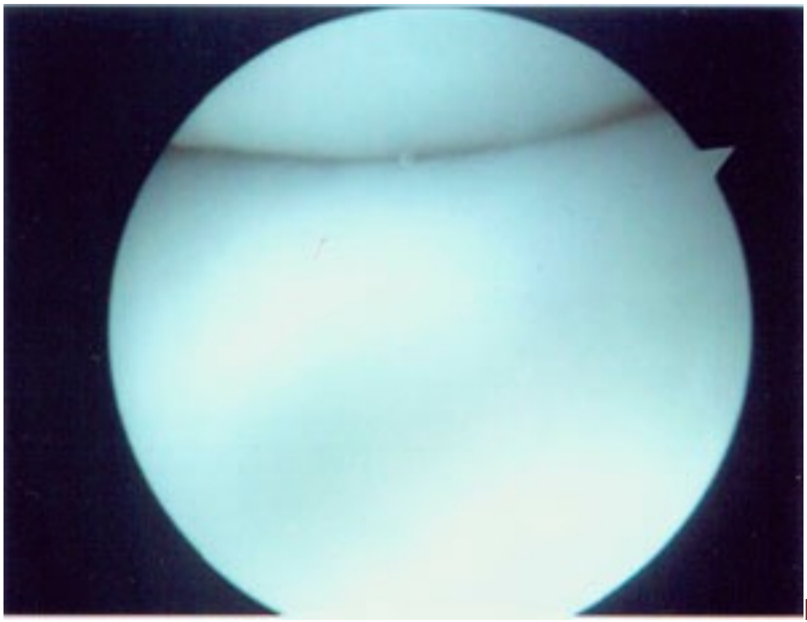

Figure 2. Patella loaded as per figure I.

Even when the surgeon compressed the patella directly against the femur, the space remained. In turn, the articulating surfaces of the medial and lateral femoral-tibial joint articulations and the femoral-meniscal articulation were evaluated. The patient, fully awake, pressed the sole of his foot against the abdomen of the surgeon, with the surgeon (MM) pushing back with full body weight to simulate weight bearing. The articular surfaces within the joint were under direct observation during these maneuvers. At no time did any of the articular surfaces ever touch; the patella seemed to be floating above the femur, and the femur seemed to float above the tibia. A visible and enterable space of 1-3 mm remained at all times (Figure 3-6).

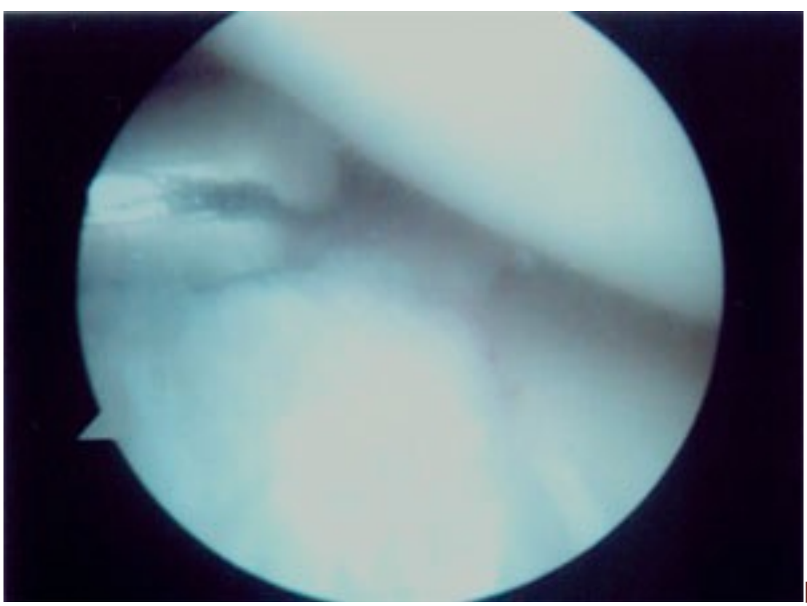

Figure 3. Medial meniscus, unloaded. Note surgical instrument in joint space.

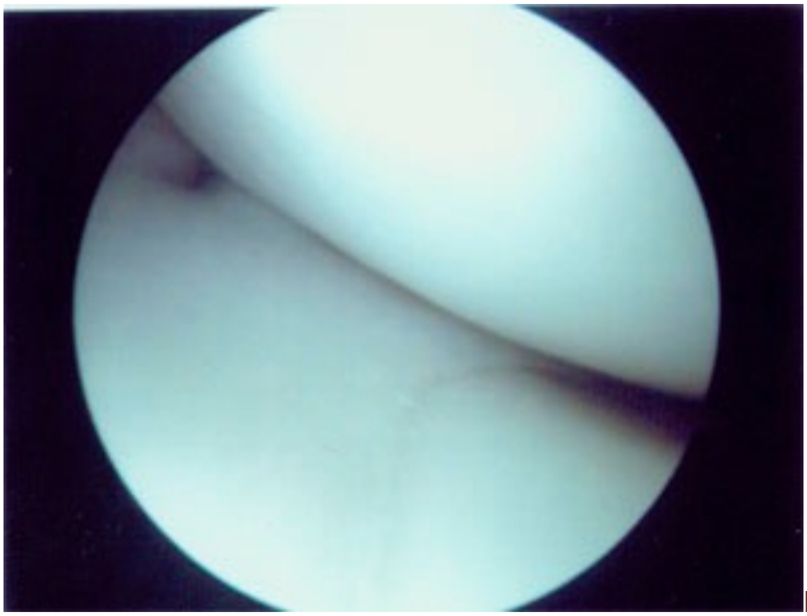

Figure 4. Medial meniscus, loaded.

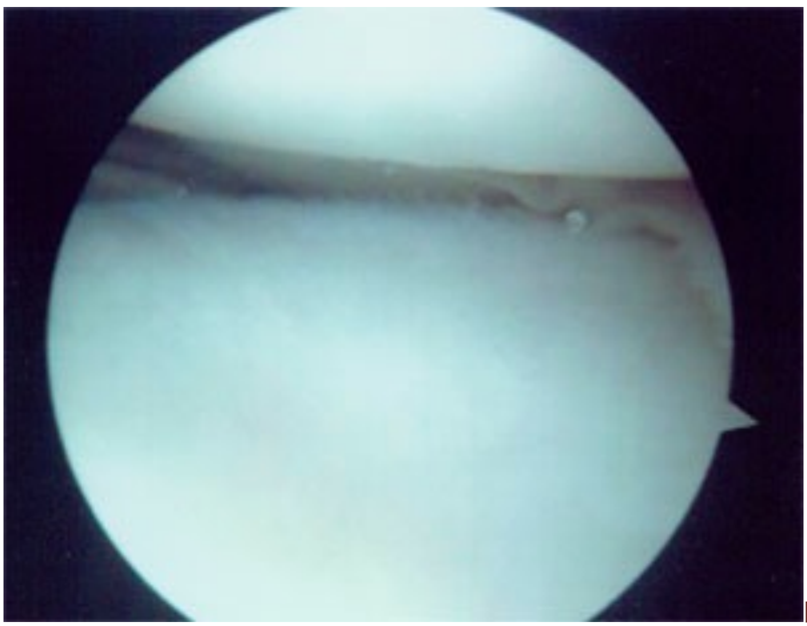

Figure 5. Lateral meniscus, no load.

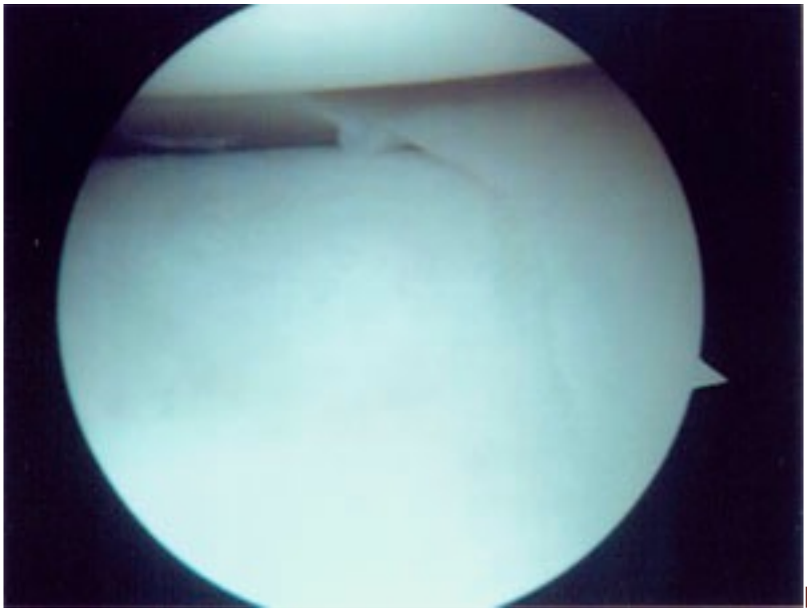
Figure 6. Lateral meniscus, loaded.

Discussion

It seems incredulous that there is a constant space present in even fully loaded joints. To be consistent with Newtonian mechanics and the linear post and lintel lever-fulcrum model that has been the paradigm since Borelli (1680), the femur during weight bearing should compress the tibia, and the tibia should deform under the load as the floor does beneath a foot. "A miss is as good as a mile' and even a 1mm space is nearly incomprehensible. Hydraulics cannot explain it, as there is insufficient hydrostatic pressure to support a load. Thin film lubrication is but a molecule thick and there would be no observable space.

The observation that the articular surfaces of the knee joint do not compress each other when the joint is loaded has since been reproduced several times, in different patients, and clearly is not an isolated finding. The joint space appears to be a function of the ligaments and geometry rather than the muscle forces. Additional evaluations of joints have yielded the same results under varying anesthesia and also in other joints, notably the gleno-humeral and talo-tibial. These findings have been predicted by theoretical models (Levin 1981; Levin 2000; Levin 2002), however, the operating surgeon (MM) had not been exposed to these theories prior to the initial surgical procedure and fully expected the joint surfaces to coapt under load. That they did not was, for him, totally unexpected, illogical, and inexplicable.

The theoretical model proposed is that joints in vertebrates function as part of a fully triangulated truss system. In triangles, the joints are loaded in tension rather than compression, and that could allow a space to exist between joint surfaces. Other models may exist. For now, the explanation is less important than the observable fact. Every interested scientist can enlist an orthopedic surgeon or an orthopedic veterinary surgeon to perform these assessments and make observations to confirm these findings. As a biomechanical evaluation of the joint being operated upon is standard procedure, no special permission is necessary and there are no ethical challenges. It is not the evaluation that changes, only the understanding of what is observed.

Conclusion

That the articular surfaces of the near intact knee joint do not touch each other is counterintuitive and awkward to comprehend. The finding seems to defy logic and appears contrary to the laws of Newtonian mechanics. A simple and readily reproducible in vivo observation challenges the long held belief that joints of vertebrates are compression loaded. The observed space between articular surfaces of the knee is not a space kept apart by hydrostatic pressure or a lubricating film, but a real space that is reproducible and can be readily verified in thousands of operating rooms around the world.

References

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