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Research Article

The Tibiofemoral Joint Gaps - An Arthroscopic Study

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Abstract: The articular surfaces of the tibiofemoral jointcommonly appear to have gaps in between during Arthroscopy operations. However, the same joint surfaces appear to be in contact inMR images. This discrepancy may be attributed to the pressure of the saline injected into the joint duringarthroscopy operations, insertion of cannulas, or anesthesia and the resulting absence of compressive force on the joint. This study examines the effect of these factors. Seven candidates of knee arthroscopysurgery participated in the study. The tibiofemoral joint space was observed with the arthroscope in different knee and hip flexion angles, with and without saline pressure, and with and without external compressive load. In the totally extended knee position, the joint was closed on both the lateral and medial sides. In the flexed knee positions, some of the joints showed a gap in either medial or lateral sides or both. Removing saline pressure and applying external compressive force on the knees did not affect the gaps. As this phenomenon cannot be explained with the conventional joint biomechanics, there is a need to revise the biomechanics of the knee joint, probably with the aid of the concepts laid in the theory of biotensegrity.

Key words: Joint gaps; Tibiofemoral joint; Arthroscopy; Saline pressure; Compression; Tensegrity

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Introduction

The tibiofemoral joint experience compressive loads equal to several body weights during normal daily activities.[1–3] According to the current biomechanical understanding, these loads are borne through compression of the cartilage surfaces on each other. However, certain computational and anatomical evidences suggest that non-contact load-bearing mechanisms may be active in the joint as well.[4–6] This forms the basis of the emerging "theory of biotensegrity",[6,7] which has received growing interest in the last decade.

The tibiofemoral joint surfaces appear to be in contact in MR images in both the extended and flexed knee positions.[8–15]Combination of MR imaging and double fluoroscopy on knees during motion and various flexion angles show similar results (in healthy subject[16–19] and in subjects with torn cruciate ligaments[19–21]). On the contrary, gaps among the joint surfaces are a common observation in knee arthroscopic operations. This discrepancy between the findings of in-vivo observations may be attributed to:

- The saline which is injected into the knee during knee arthroscopy operations pushes the joint surfaces apart.
- The cannulas used for inserting the arthroscope and the surgical tools into the joint, push the joint surfaces apart.
- Operations are performed under anesthesia. In this condition, passive muscle tensions are absent and therefore there is no compression on the joint caused by the muscles surrounding it. In addition, joints are normally not subjected to external compressive forces.

To the knowledge of the authors, till now only one study has been published in this regard, where the effect of external compressive load has been investigated. [5]This study reports the observations made during an arthroscopic knee surgery under local anesthesia. In this study, the gaps between the tibiofemoral and patellofemoral joint surfaces continued to exist even after application of considerable external compressive loads on the joint.

To find the real reason causing the gaps observed with the arthroscope, our paper examines the effect of saline pressure, cannula insertion, external compressive load, and flexion angle on the joint space.

Materials and methods

Seven subjects (6 males and 1 female, aged between 19 to 55 years) candidate of arthroscopy knee operation participated in our study. Written informed consent was signed by the subjects before the study. Ethical approval was obtained from the Ethics Committee of Tehran University of Medical Sciences and Health Services.

The experiments were performed while the subjects were under general anesthesia, and we could look into the joint space via the arthroscope. The joint space was continuously scanned to see the cartilaginous surfaces of tibial and femoral condyles, as well as the menisci, on both the medial and lateral sides. The video from the arthroscope was recorded on a laptop. Simultaneously, using a handheld camera, another video was made of the activities of the surgeons and the limb under operation. These two videos were afterwards synchronized into one video file using the software Wax 2. 0 (from http://www. debugmode. com/wax). This mixed video was used to study the effect of alteration of various parameters on the joint gaps. Sample frames of the videos are given in this paper.

Quantification of the distance between the three-dimensional joint surfaces needs simultaneous insertion of at least two arthroscopes, as well as insertion of calibration frame in the joint. Since, we only had one arthroscope in the joint and it was not possible to insert a calibration frame, the distances could not be evaluated quantitatively. Therefore, the spaces between the tibial and femoral surfaces were evaluated qualitatively in the form of "gap" or "contact" (Figs. 1 and 2).

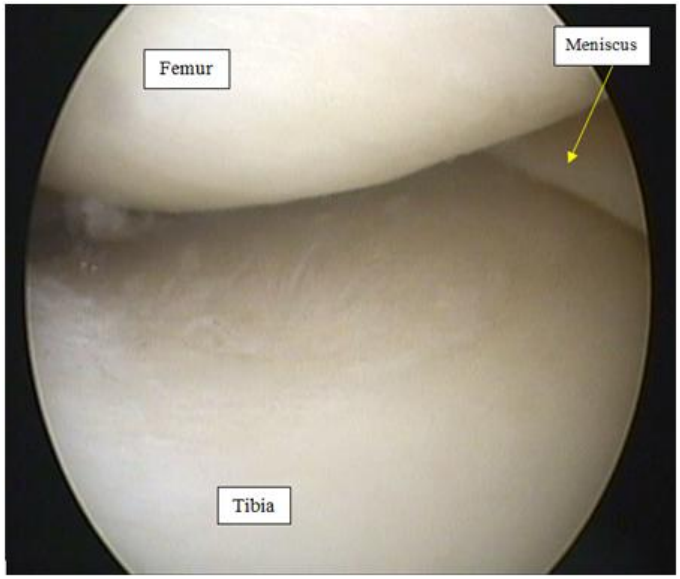

Figure 1 – An example of gap between the femur and the tibia

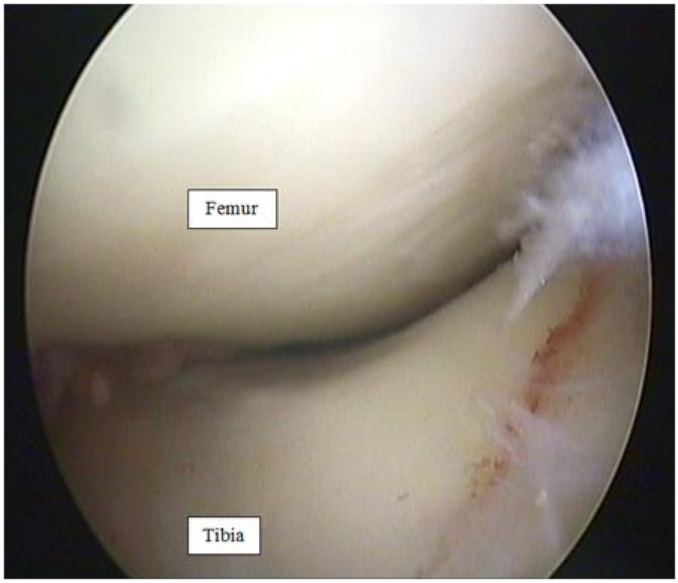

Figure 2 – An example of contact between the femur and the tibia

Various factors were altered during the experiments: 1- saline pressure, 2- external compressive force applied to the knee, 3- knee flexion angle, and 4- hip flexion angle. These factors were defined as follows:

- Saline pressure was present when the saline inlet was open and the outlet was closed. It was removed by closing the inlet and opening the outlet.
- To apply external compressive load in the position of full extension of the knee (Fig. 3 – bottom left), the foot of the patient was pushed by the surgeon towards the patient's knee. In the position of knee flexion (Fig. 3 – bottom right), the foot or shin

was held in place by the surgeon, and at the same time the thigh was pushed down by the co-surgeon. The amount of applied force was not measured during the tests. However, previous experiences during pilot studies using a force plate indicated that the forces applied in this manner by the surgeons are around 5 to 10 kgf.

- To have zero flexion angles in both the joints, the leg was horizontally put on the bed or held by the surgeon (Fig. 3 – Top right). For flexion in both the joints, the limb was held in the sagittal plane with the foot on the bed (Fig. 3 – bottom right). The joint angles were estimated from the external camera video pictures.

Figure 3 – Different positions of the lower limb (Top left: limb hanging from the bedside. Top right: limb lying on the bed with zero flexion angle in knee and hip. Bottom left: limb held horizontally by the surgeon with zero flexion angle in knee and hip. Bottom right: Limb in the sagittal plane, with foot on the bed, and flexion of the knee and hip)

Results

Table1 gives a summary of the effect of various parameters on the distance between femoral and tibial cartilaginous surfaces.

In all the cases, in the position of zero flexion angles in both knee and hip, the joint was closed on both the sides. In case 2, the joint opened on both the sides after flexing the knee about 10 degrees. A Similar observation was made in Case 4 at least on the medial side (in case 4, we did not see the lateral side).

In Case 2 with the limb hanging from the side of the bed, and in Case 4 with the knee and hip in flexion, the joint was open on both the sides. In some other situations, the joint was open on one side and closed on another side (See Table 1).

Case	Gender/Age/ Pathology	Knee flexion angle (°)	Hip flexion angle (°)	With saline pressure and without external compressive force		Effect of saline pressure removal (external force absent)		Effect of applying external compressive force (saline pressure present)	
				Med	Lat	Med	Lat	Med	Lat
1	F/55 Posterior horn of the medial meniscus totally torn. ACL and menisci have degenerated tissues	30	0	Gap	N/S	NE	N/S	N/S	N/S
2	M/24 Totally torn ACL	70	0	Gap	Gap	Gap reduced to half	NE	N/S	N/S
		0	0	Cont	Cont	N/S	N/S	N/S	N/S
3	M/36 Partial radial tear and a cyst in the medial meniscus	45	0	Cont	Gap	NE	NE	N/S	N/S
		0	0	Cont	Cont	NE	NE	NE	NE
4	M/22 Totally torn ACL	60	30	Gap	Gap	N/S	N/S	NE	NE
		60	0	Gap	Cont	NE	NE	N/S	N/S
		0	0	Cont	Cont	NE	NE	NE	NE
5	M/38 Lateral meniscus partially meniscectomied for partial radial tear; also torn on its outer periphery	80	40	Gap	Cont	N/S	N/S	NE	NE
		60	0	Gap	Cont	NE	NE	N/S	N/S
		0	0	Cont	Cont	NE	NE	NE	NE
6	M/32 Lateral meniscus partially meniscectomied for partial radial tear;	80	40	Cont	Cont	N/S	N/S	NE	NE
		60	0	Cont	Cont	NE	NE	N/S	N/S
		0	0	Cont	Cont	NE	NE	N/S	N/S

	also ACL totally torn								
7	M/19 Totally torn ACL	90	45	Cont	Cont	N/S	N/S	NE	NE
		70	0	Cont	Cont	NE	NE	N/S	N/S
		0	0	Cont	Cont	NE	NE	NE	NE
Cont: contact. NE: No effect. N/S: Not studied									

Table 1 - Summary of observations on the effects of knee and hip flexion angles, removing saline pressure, and applying external compressive force, on the space between femoral and tibial surfaces

As a common observation in all the cases, when there was a gap between the femur and tibia, there was also a gap between the meniscus and the femur (an example of this position is illustrated in Figure 4).

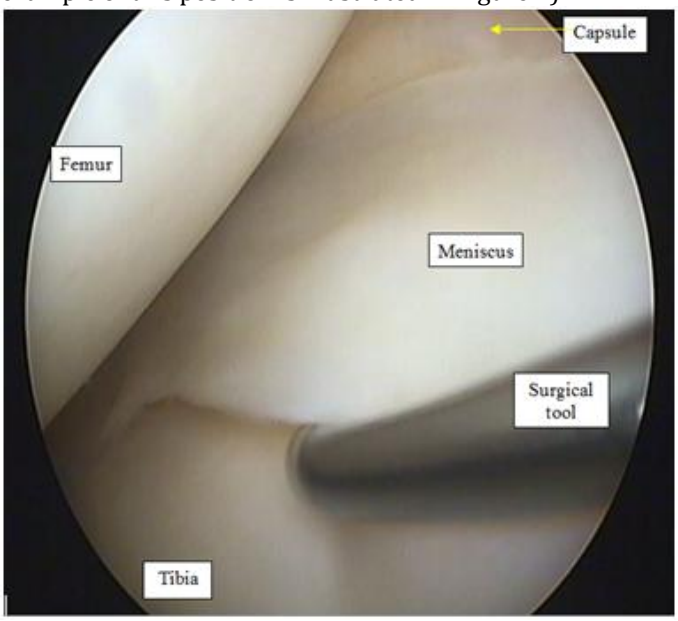

Figure 4 – An example of gap between the femur and the meniscus. In this figure, the joint capsule is visible.

Discussion

Effect of limb position and knee flexion angle

During the experiments, little abduction/adduction moments might have been applied to the knee. This can create a gap on one side of the knee. This increase in the distance between the femoral and tibial surfaces can reach several millimeters as observed in MR images, [22]greater in the lateral side compared to the medial side. [22, 23] When the knee is hanging from the bedside (Fig. 3 – top left), the little abduction moment is expected in the joint. This might help the joint to close to the lateral side and open on the medial side. Therefore, in cases where the gap is observed on the lateral side, it can be safely assumed not to be the result of the applied moment. This happened in Cases 2 and 3 (see Table 1). When the limb is kept in the sagittal plane on the bed (Fig. 3 – top right and bottom right), it seems no abduction/adduction moments are applied to the knee and observations cannot be confounded by this factor. With the limb in the sagittal plane and knee and hip in flexion, the joint was open on the both the sides in case 4, and on the medial side in case 5.

In Case 4, changing the hip angle without changing the knee flexion angle led to different results (see Table 1). But in Cases 5, 6 and 7, different hip angles with almost same flexion angles did not yield different results. The difference in Case 4 is probably the result of the abduction moment applied to the knee in the position of zero hip flexion (limb hanging from the bedside).

Effect of saline pressure

The saline packs are normally kept around 1 meter higher than the patient's knee. This creates a saline pressure of about 10kPa in the knee. Assuming an area of 20 cm^2 for the tibial surface, the saline can apply a force of 2 kgf to open the joint. This small force is probably not capable of opening the joint or changing the distance between the joint surfaces. This was confirmed in our experiments. Except for the medial side in Case 2, removing the saline pressure had no observable effect on the space between the joint surfaces (not even reducing the distance).

Effect of external compressive force

In almost all the experiments, the external compressive force did not have any observable effect on the joint gaps. The exception was seen in Case 7, for the lateral side in the position of zero flexion in knee and hip, which might have happened due to some abduction moment.

The applied forces were around 5 to 10 kgf. This small force did not cause any observable change in the distances between the joint surfaces. This probably means that a big force (of maybe 50 kgf or more) is required to close the joint gaps. Similar observation was reported by Levin and Madden, [5] where the surgeon applied a big force with his abdomen pressing on the foot of the subject without leading to any observable change in the joint surface distances.

Effect of arthroscope or tool insertion

In all the experiments, the anteromedial or anterolateral portals were used for inserting the arthroscope and tools. Inserting the arthroscope through these portals in the flexed knee can be done with little force, whereas the same is difficult in the extended knee and needs more force. This might be due to the necessity of pushing the joint bones open for inserting the arthroscope. But, in our experiments, the joint was closed in extended knees and was open in some of the flexed knees. This shows that the joint opening could not have been caused by insertion of the arthroscope or surgical tools.

Comparison with other studies

As per the knowledge of the authors, only one similar study is available. Levin and Madden[5] reported similar results from their experiment on one subject undergoing knee arthroscopic operation under local anesthesia. The surfaces of the femur, tibia, and menisci in both medial

and lateral compartments were observed. The patient, fully awake, pressed his foot against the abdomen of the surgeon, while the surgeon pushed back with full body weight to simulate weight bearing. At no time did any of the articular surfaces touch, and a visible and enterable space of 1-3 mm remained at all times. Flexion angles were not reported in this study.

Limitations of the study

In this study, small compressive forces were applied by hand, which were about 5 to 10 kgf in size. But since the compressive loads on the joint are normally higher than this amount, applying higher forces of at least 50-100 kg would create conditions better comparable to the condition of the knees not under the effect of anesthesia.

With the current number of subjects it was observed that in some cases there were gaps in the joint, which normally does not appear in MRI studies. However, increasing the number of cases and including various knee pathologies would help understand in what conditions such discrepancies happen.

We did not study the effect of anesthesia on the joint. The most direct method to do so is to take MR images of the knee of a subject before and after anesthesia, and see if the distances between the joint surfaces change.

Conclusions

This study showed that in the full extension of the knee, the tibiofemoral joint is closed on both sides. But, in some cases with the knee in a flexed position, gaps exist on one or both sides of the knee. This shows that the MRI and arthroscopy results agree in the fully extended knees and sometimes disagree in flexed knees.

The gaps that are seen with the arthroscope are not caused by insertion of arthroscopy cannulas, pressure of saline, or absence of compressive load on the knee. The possible contribution of anesthesia remains to be investigated.

The results of this study suggest that in some situations, the knee does not bear the force via touching and compressing of the surfaces on each other. This finding is not in accordance with the current understanding of joint biomechanics, whereas it is a core concept in the recently emerging biomechanical theory of biotensegrity. [6, 24] Thus, review of joint biomechanics, probably with the aid of the concepts suggested in the theory of biotensegrity, seems necessary.

Conflicts of interest

The authors have no conflicts of interest.

Acknowledgements

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