first peaks appeared at 32.3% (±9.9%) of the stance phase. The amounts of thrust in subjects with K-L grade 2 (25 knees), 3 (13 knees), and 4 (6 knees) were 2.4°(±1.3°), 2.8°(±1.4°), and 7.2°(±5.3°), respectively and the knee adduction moments were 3.6(±1.5) %BW*Ht, 3.9(±1.2) % BW*Ht and 6.9(±2.2%) BW*Ht, respectively. The amount of varus thrust increased in higher K-L grade knees and was significantly related to K-L grade ($p = 0.015$). The amount of thrust exhibited significant correlation to static radiographic alignment (R = 0.47: 95% confidence interval 0.67-0.21, $p = 0.0038$) and showed greater correlation to the knee adduction moment (R = 0.73: 95% confidence interval 0.84-0.55, $p<0.001$), which has been identified as an important dynamic index of the disease (Fig. 3).
**Conclusions**: The amount of thrust correlated to static and dynamic parameters. Among the parameters we investigated, the amount of thrust closely related to knee adduction moment which has been used as an important index in assessing for knee OA since it is a dynamic evaluation during motion when patients feel pain or discomfort and it is related to the disease's progression and prognosis. The equipment to measure the moment usually requires certain costs and space and it is difficult to apply in daily use at clinics. On the other hand, a simple projection of the marker angle could be recorded by digital video or camera. The amount of varus thrust might become a simple dynamic assessment of knee OA severity in clinics. In conclusion, the amount of thrust, which can be measured by simple inexpensive equipment, was correlated to knee adduction moment, coronal limb alignment, and X-ray joint degeneration and appears to offer an important index for knee OA disease severity.

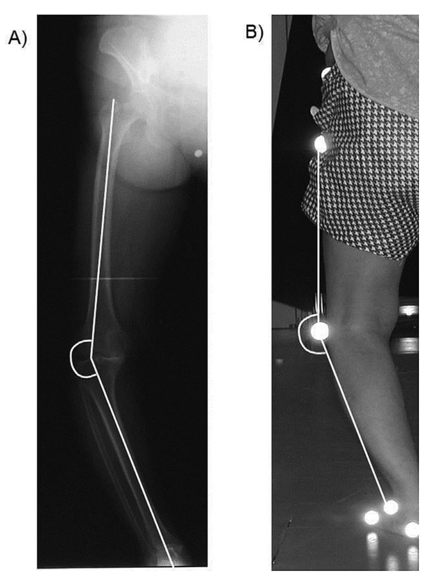


Figure 1. A) Femoro-tibial angle (FTA) and B) marker MKA angle.

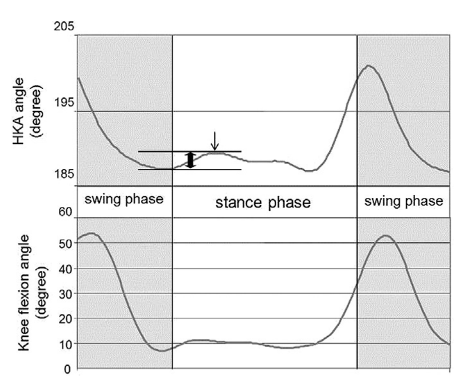


Figure 2. Changes in HKA angle and knee flexion angle. The difference between the angle at heel strike and the first peak (shown as a thin arrow) was defined as “the amount of varus thrust” (thick arrow).

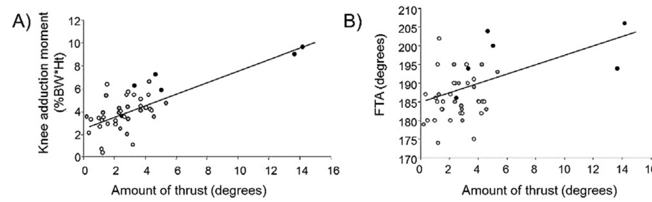


Figure 3. The relationship between the amount of thrust and knee adduction moment (A), between the amount of thrust and FTA (B) White, gray, and black dots represent subjects in K-L grade 2, 3, and 4, respectively.

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## A NOVEL APPROACH OF THE STOKES' SECOND PROBLEM FOR THE SYNOVIAL FLUID IN KNEE OSTEOARTHROSIS

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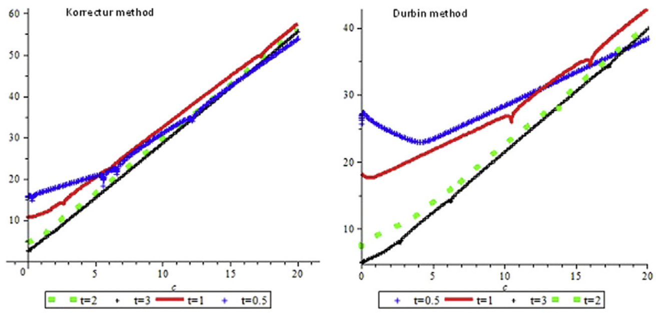
**Purpose**: In this paper we are focused on the understanding of the physiology and mechanisms concerning human movable joints, more precisely, the mathematical description of the synovial fluid rheology.
To this date, there have not been fully understood the conditions and origins of some pathological diseases, the mechanics of human joint lubrication or shock load absorbing, for which the synovial fluid is an essential medium. These features could be, nevertheless, a great enhancement in the engineering of designing the life-long functional joint prostheses or in the disease treatment.
There are several models describing the synovial fluid, see for example Rudraiah et al. (1991), Lai et al. (1978), Morris et al. (1981). Nevertheless, they are great simplifications of the otherwise complex rheology of synovial fluid, usually based on simple experiments adapted for the linear theories, both viscoelastic and viscous. In this we see the main obstacle in development of reliable models capturing the most important non-Newtonian features of synovial fluid. To be more specific, the synovial fluid has been modeled as either viscous shear-thinning fluid or linear viscoelastic fluid-like material. Our aim is to study such rheological behavior of synovial fluid, based on the existing experimental literature, and create novel viscous and viscoelastic models. Mainly, we focus on the description of viscous responses of synovial fluid, as a fluid thinning the shear.
**Methods**: Recently Devakar and Iyengar (2009) studied Stokes' first problem for a micropolar fluid, i.e. the fluid flow through a half space delimited flat plate. Initially both the plate and the fluid are at rest. At time $t = 0+$ the plate suddenly starts to slide slowly in its plane with the constant velocity U. Stokes' second problem refers to the case when the velocity of the wall is time-dependent.
Here we will refer to the Stokes' second problem, when the wall is driven in an oscillatory shearing motion. Ibahem et al. (2006) solved a Stokes' second problem for a micropolar fluid, embedded into a thermal analysis. We take into account a slip between the velocity of the synovial fluid at the wall and the speed of the wall uw. Moreover, we will allow a temporal variation of uw either in cosine or sine form, inspired by the paper by Khaled and Vafai (2004), who were able to obtain exact solutions for micropolar fluids.
The basic equations for an incompressible micropolar fluid with initial and boundary conditions depend on the wall velocity and on the frequency of the vibration. Regarding the boundary condition of the velocity at the wall, we remark that there is a discontinuity of the velocity at the fluid-wall interface.
The few studies in fluid mechanics and convective heat transfer, where the numerical inversion is used, are rather silent with respect to the choice of the parameter c, as well as the choice of time in [0,2t]. For the determination of the optimal parameter c = c{opt} in this paper are analyzed, modeled and simulated two methods: the method of Durbin and the Korrektur method.
**Results**: Besides velocity $u = u(y)$ and micro-rotation $N = N(y)$ profiles, we are also interested in computing the quantities of physical interest, which are the wall shear-stress and the local couple stress at the wall, written in the dimensionless form, in report with the skin friction coefficient and the local couple stress at the wall.




A remark on the frequency parameter, that cannot be eliminated unfortunately from the analysis as did Khaled and Vafai (2004) in their study on Newtonian fluids (by an appropriate choice of dimensionless quantities): we have another parameter, which will be set to 1 for the rest of the analysis.

**Conclusions**: A very important point to pay attention is about the (dimensionless) times considered by Devakar and Iyengar (2009), but also by Helmy (2000) and Helmy et al. (2002), that are not very large. In their numerical runs, Devakar and Iyengar (2009) took dimensionless times less than a value of 6. Certainly, the problem resolution for larger values of time will require an optimization of the numerical scheme. The apparent viscosity of hyaluronan solution is increasing with decreasing rate of shear while at higher rates of movement the viscosity drops. This entails that the joint is "dynamically" stabilized and well lubricated during slower motions but at higher rates of movement the drag of the bones faced against each other in synovial joint is significantly reduced.

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## ARTHROSCOPIC MEASUREMENT OF CARTILAGE STIFFNESS OF THE KNEE IN YOUNG PATIENTS USING A NOVEL INDENTATION SENSOR

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**Purpose**: Evaluation of mechanical properties of the articular cartilage is essential to identify physiological and pathological condition of the joint. Several devices have been developed and used to measure the stiffness of cartilage under arthroscopic control in adults. Uchio et al (2002) reported the cartilage stiffness of the femoral condyle and patella in 105 knees (74 patients) using an ultrasonic tactile sensor. They found that the cartilage with grade 1 and 2 degeneration showed lower stiffness, but the cartilage with grade 4 degeneration showed higher stiffness than normal cartilage. However, their patients age were between 9-72 years and there is no description about number of young patients. Thus, there have been limited data on the material properties of cartilage especially in children who are in growth period. In this pilot study, we have evaluated validation of an arthroscopic indentation sensor and applied it to the measurement of the cartilage stiffness of the children and adults.

**Methods**: A novel indentation sensor was developed; VENUSTRON system (Axiom, Sendai, Japan), which is an indentation sensor system to measure the stiffness of the cartilage under arthroscopy. The system consists of 4mm sensor with 8mm outer guide. (Fig 1)

1) Validation and repeatability of the system: Stiffness of a material with known material properties (PE light, Young's module 0.43 ± 0.:1MPa) was measured by the VENUSTRON system. The maximum displacement and pressure to calculate Young's module of the material were set at 1.0mm and 450gram. The stiffness of PE light was measured at thickness of 2mm to :10mm with a 2mm interval. The measurement were repeated for 3 times at each thickness, to evaluate repeatability.

2) Measurement of femoral cartilage stiffness in young and adult patients: After an IRB approval and informed consent from each patient, stiffness of articular cartilage of the medial femoral condyle were assessed in 11 knees in 10 patients (age from 6 to 37) who underwent arthroscopic surgery for knee disorders. Prior to the surgery, cartilage condition of the femoral condyle was assessed by MRI and we confirmed that no patients had damage or degeneration in the medial femoral condyle. Patients information was summarized in Table 1.

**Results**:

1) Young's module of the material (PE light) were 1.15-1.24 (mean 1.20) MPa. There were no difference in the measured Young's module with the material due to the difference of thickness between 2-10mm. Interclass correlation coefficients (ICCs) in repeated measurements using the material were 0.83-0.99.

2) Force-displacement curves of the medial femoral cartilage of young (9-15 years) and adult (16 and over) patients were shown in Fig 2 and 3. There were wide variations in cartilage stiffness among these patients (Table 1). The stiffness ranged from 0.088 to 0.156 N/mm.

**Discussion and Conclusions**: Since the VENUSTRON system is manually held during the measurement, there is a concern for validity and repeatability to assess material properties of the cartilage. Differences of the measured Young's module of the material from its specification value were 0.72 to 0.81 MPa. Regarding the difference and high repeatability (ICCs 0.83-0.99), the VENUSTRON system is an useful tool to measure material property of the articular cartilage under arthroscopy. Although the patients in this series have no damage or degeneration in their femoral cartilage, there were wide variations in the cartilage stiffness among the patients of 6-41 years, and we found no relationship between the cartilage stiffness and age. Previous reports also suggest that there are wide variations in the material property of the femoral cartilage. The Young's module of the femoral cartilage ranged from 100 kPa (Uchio, 2002) to 900kPa (Athanasiou,1991), however most of the data were from adult patients. In our series, it is possible that pre-existing disorder or trauma, rather than their age, affects the cartilage stiffness, but relationship between material property of the cartilage and age remains unclear.

Characteristics of the knee joint of the patients

| Age | Sex | Disorder | Total stiffness (N/mm) |
|---|---|---|---|
| 6 | Male | Right osteosarcoma | 0.154 |
| 9 | Male | Right discoid | 0.094 |
| 13 | Female | Right discoid | 0.146 |
| 13 | Male | Right discoid | 0.156 |
| 13 | Male | Left discoid | 0.114 |
| 14 | Male | Right ACL injury | 0.088 |
| 16 | Female | Right discoid | 0.111 |
| 19 | Male | Right meniscus injury | 0.102 |
| 26 | Male | Right PCL injury | 0.121 |
| 35 | Male | Right ACL injury | 0.120 |
| 37 | Male | Left Open fracture | 0.130 |