Effect of body mass index on the mechanical response of knee joint with damaged femoral cartilage

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***Abstract* — Everyday activities can lead to damage in our cartilage. Focal cartilage lesions have been associated with the progressive degeneration of the surrounding cartilage tissue which could lead to additional health problems such as early-onset osteoarthritis. Our aim was to compare the mechanical response of the knee joint with damaged femoral cartilage for normal and high body mass index (BMI) values during the stance phase of the gait cycle, using the finite element method. The location of the hypothesized lesion was above the anterior section of the lateral meniscus. Comparison of the obtained results has shown a significant influence of BMI on the Von Mises stress values, even in the case of simplified material properties.**

***Keywords* — knee joint, femoral cartilage, focal lesion, finite element methods, stress distribution**

I. INTRODUCTION

During everyday activities, articular cartilage experiences high loads, stresses, and deformations [1]. Sometimes those activities can lead to cartilage damage and in some situations this damage can lead to permanent impairment. Focal cartilage lesions are often the result of some traumatic injury or degeneration process [2]. The lesions could lead to the development of early-onset osteoarthritis [3].

Treatment options for focal cartilage lesions are among the main clinical challenges. The aim of any type of treatment is to help patients with pain relief and joint function improvement [4]. The treatment depends on the defect size, location, and age of a patient. When it comes to defect sizes to decide treatment indications, several thresholds exist. However, the most used threshold value is that of 2 cm^2 [5].

The objective of this paper was to compare the mechanical response of the knee joint with femoral cartilage lesion using finite element models during the stance phase of the gait cycle. Two cases were analyzed:

1) *normal BMI value (BMI = 21) and*
2) *high BMI value (BMI = 32).*

The lesion of the femoral cartilage had a surface area of 2 cm^2. This value is commonly used by clinicians to decide on lesion treatment.

Our aim with this paper was to analyze the damaged femoral cartilage in order to assess the effect that BMI has on the stress values and to investigate the effect that the cartilage damage and different BMI values have on the stress distribution in the meniscus. Also, the idea was to compare the stress results for these two cases in order to better understand if, besides the threshold value of 2 cm^2 lesion size, other factors like BMI can influence the stress values on the articular surface at the damaged area and should be therefore considered for the clinical management.

II. MATERIALS AND METHODS

A. Knee joint model

In this paper, we have analyzed the knee joint with a femoral cartilage lesion. The knee joint model was developed from MRI DICOM images belonging to a healthy female aged 40. Bones (femur and tibia), menisci (medial and lateral meniscus), and articular cartilage (femoral cartilage, medial tibial cartilage, and lateral tibial cartilage) were segmented from the DICOM images. Patella and ligament were omitted from this model in order to reduce the time needed for the numerical simulation. Considering that the scans belonged to a healthy person, the femoral cartilage lesion was created manually.

The created model is presented in Fig. 1. The lesion was located above the anterior section of the lateral meniscus. The surface area of the lesion was 2 cm^2, as described in the section above.

The number of nodes and tetrahedral elements in the volumetric mesh of the knee joint model was 30083 and 123869, respectively.

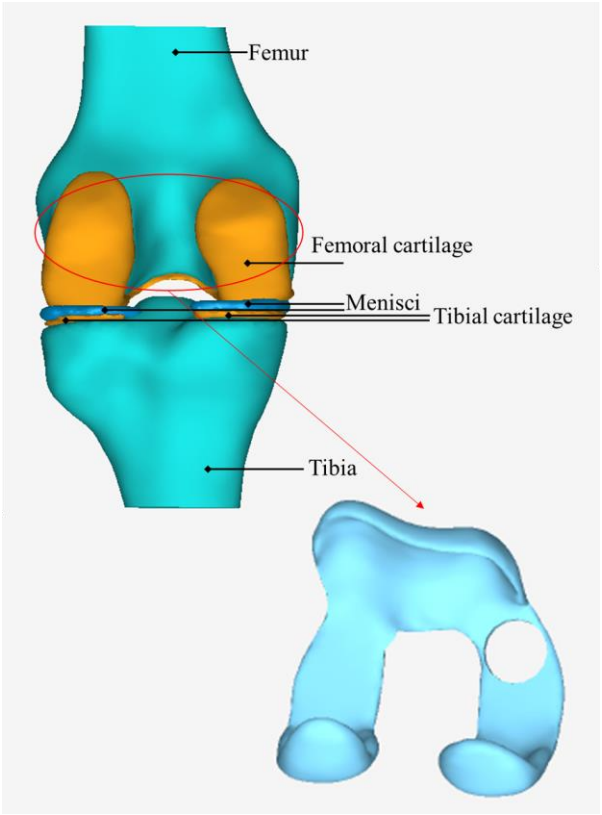

Figure 1. Knee joint model with femoral cartilage lesion

Special attention was given to the femoral cartilage mesh near the created lesion. The mesh of the femoral cartilage was manually refined close to the lesion, in order to increase the mesh densityand it is presented in Fig. 2.

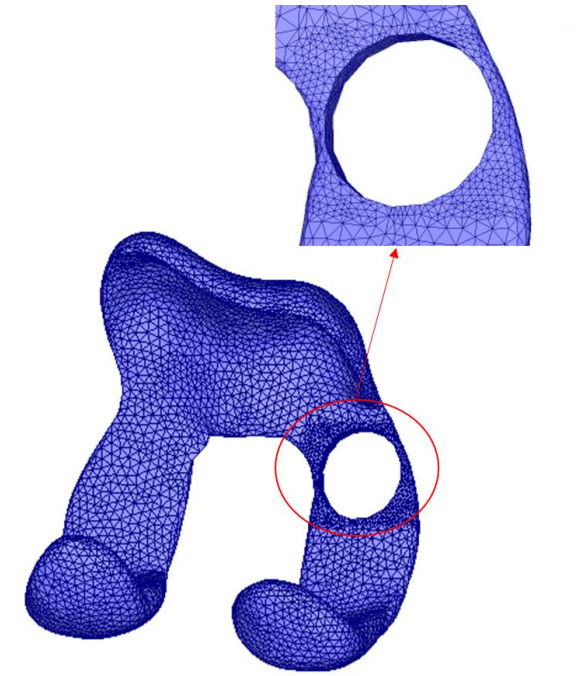

Figure 2. Femoral cartilage mesh

B. *Material Properties and Boundary Conditions*

Material properties of bones, cartilages, and menisci were simplified and considered to be linear elastic, homogeneous, and isotropic. Young's modulus and Poisson's ratio for each material are listed in Table 1.

TABLE I. MATERIAL PROPERTIES

Material	***Young's modulus [MPa]***	***Poisson's ratio***	***Reference***
Femur	16700	0.3	[6]
Tibia	14317	0.315	[6]
Cartilage	12	0.45	[7]
Menisci	80	0.3	[7]

Applied boundary conditions corresponded to the physiological conditions when a person is standing on a fully extended leg (Fig. 3). The force was perpendicular to the femur's upper surface and corresponded to the highest force during the stance phase of the gait cycle [8]. The applied values were distributed among the surface nodes.

The nodes located on the lower tibia surface were fixed, while all other nodes were allowed to move only along the z-axis (perpendicular to the femur's upper surface).

Contact was defined between all the knee joint elements. The majority of the contacts were considered glued: tibia – tibial cartilage, tibial cartilage – menisci, and femoral cartilage – femur. The contact between femoral cartilage and menisci was considered frictionless. For this analysis, the friction between femoral cartilage and menisci was not considered.

Numerical analysis was performed using solver NX Nastran 11.4.1.

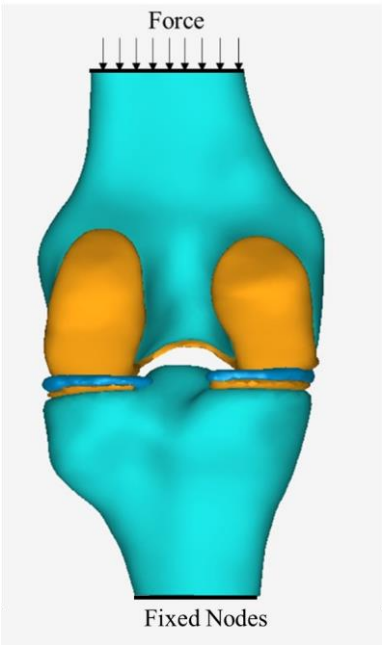

Figure 3. Boundary Conditions

III. Results and Discussion

Based on the obtained results, it is noticeable that BMI is an important factor for the stress values in the knee joint. Von Mises stress distribution for the femoral cartilage is presented in Fig. 4.

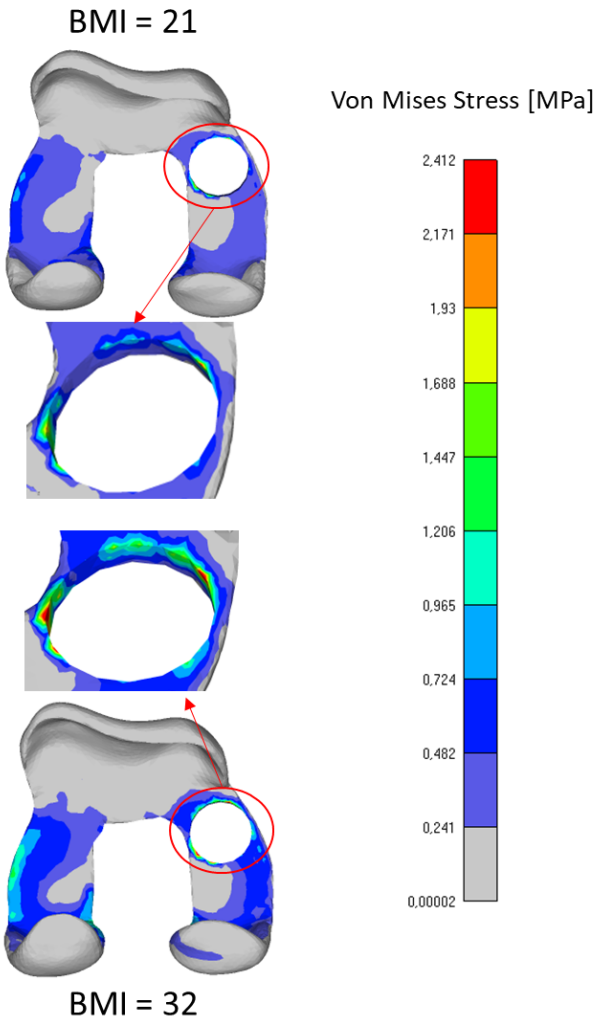

Figure 4. Von Mises stress distribution – femoral cartilage

As can be seen in Fig. 4, the maximum stress values for both cases (BMI = 21 or 32) were calculated on the rim of the lesion. The location of the maximum values was expected based on the data available in the literature.

A comparison of the maximum stress values for the healthy cartilage and cartilage with the focal lesion in the case of different BMI values is presented in Table 2.

TABLE II. Comparison of the stress results - cartilage

	Healthy cartilage [9]	*Cartilage with focal lesion (BMI = 21)*	*Cartilage with focal lesion (BMI = 32)*
Max cartilage stress value	0.798 MPa	2.412 MPa	3.718 MPa

For higher BMI values, the maximum stress was more than 50% higher for the cartilage stress values. Compared to the healthy cartilage with normal BMI, in the case of damaged cartilage with higher BMI, the values are higher more than 150%.

Von Mises stress distribution for the menisci is presented in Fig. 5.

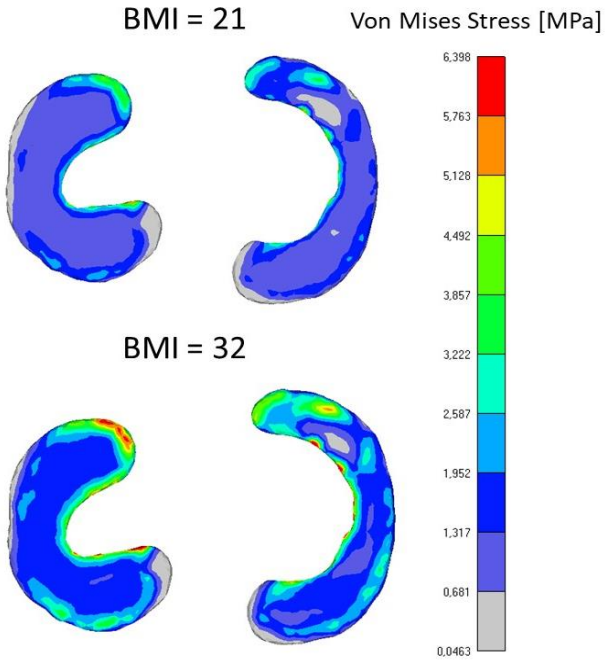

Figure 5. Von Mises stress distribution – menisci

The results for menisci indicate the same thing as the results for the cartilage - higher BMI values will lead to higher stress values.

A comparison of the maximum menisci stress value for the healthy cartilage and cartilage with focal lesion for both BMI values is presented in Table 3.

TABLE III. Comparison of the stress results - menisci

	Healthy cartilage	*Cartilage with focal lesion (BMI = 21)*	*Cartilage with focal lesion (BMI = 32)*
Max menisci stress value	5.99 MPa	6.398 MPa	9.863 MPa

The obtained results indicate that BMI should be considered as an important factor for managing patients with a cartilage lesion.

IV. Conclusion

The numerical analysis of a patient-specific cartilage lesion can be considered a very useful tool for clinicians to determine areas with higher stress values and help guide the treatment choices when managing these patients.

The presented work analyzed the mechanical response of the knee joint with damaged femoral cartilage for

normal and high BMI values. The response was analyzed for static loading conditions using the maximum force value during the stance phase of the gait cycle.

The results obtained using the finite element method include stress distribution for femoral cartilage and menisci.

We aimed to compare the mechanical response of the femoral cartilage affected by a focal lesion when a person has normal and high BMI values, in order to understand if this parameter has any significant effect on the stress values. Our future research will be focused on the use of dynamic loading conditions and more complex material properties for the cartilage.

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