CONTACT AREA AND CONTACT PRESSURE IN KNEE IMPLANTS: COMPARISON OF DIFFERENT TESTING AND FE METHODS

Josef-B. Weiß (1), Hanna Bächle (1), Sven Krüger (1), Thomas M. Grupp (1,2)

1. Aesculap AG, Research & Development, Germany; 2. Department of Orthopaedic and Trauma Surgery, Musculoskeletal University Center Munich (MUM), Campus Grosshadern, LMU Munich, Munich, Germany

Introduction

The mechanical environment of articulating surfaces has a strong effect on the long-term survival of knee implants. Therefore, the analysis of the contact area and contact pressure between the articulating components is of particular interest. The FDA [1] and ASTM F2083-21 request an investigation of the contact area and stress in the tibiofemoral and patellofemoral articulating surfaces at different flexion angles. Finite element (FE) simulations are widely used to calculate these quantities. Their credibility requires assessment in accordance to ASME V&V40-2018. The Gold standard for *in vitro* measurements of these quantities are pressure sensitive films (e.g., FujiFilm®) or sensors (e.g., Tekscan®). However, the contact may be affected by these films, and therefore an optical measurement can be advantageous. The aim of this study is to evaluate the variability in both *in silico* and *in vitro* methods using a ball indentation test.

Methods

Mechanical problem:
MXE (0.1 % vitamin E blended polyethylene, 30 kGy gamma sterilized) plates are idented using a Ø 32 mm CoCr hip ball at a constant velocity of 5.0 mm/min until 1 000 N is reached at room temperature (see Figure 1).
*In vivo:*3 methods are used to measure the contact area and pressure: FujiFilm Prescale LLLW, FujiFilm Prescale MS and a digital-image-correlation system DIC (GOM Aramis (12M sensor configuration)) based on the assumption of rigid body displacement. Six measurements were made for each method.
In silico: The numerical code verification of ANSYS Mechanical 2022R1 was performed using the ASME V&V 40 framework. Sensitivity studies were performed for key model parameters, which were given contact formulation, friction coefficient μ and UHMWPE material model based on literature (Three Network Model (TNM) [2] and two Two-segment elastic-plastic material models (TS) (based on the data of GUR 1020 VE and GUR 1020 50kGy VE [3]).

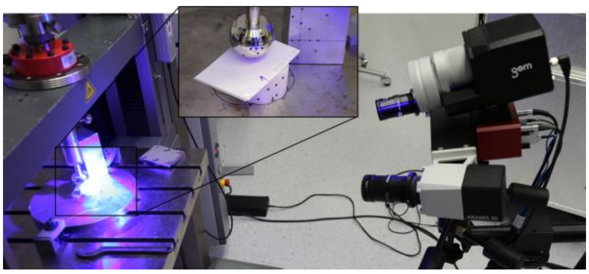

Figure 1: Test setup with LLLW film and DIC.

Results

The measured and simulated contact areas and pressures are listed in Table 1. Mesh convergence of 1% was achieved with a final mesh density of 0.05 mm in the contact area.

In vitro, n=6 for each method

Method	*Contact Area ± SD in mm²*	*Max. Contact Pressure ± SD in MPa*
Prescale LLLW	31.7 ± 5.4	N/A
Prescale MS	20.8 ± 0.3	N/A
DIC	27.7 ± 1.2	N/A

In silico

μ	*Material model*	*Contact Area in mm²*	*Max. Contact Pressure in MPa*
0.025	TNM	25.8	45.1
	TS GUR 1020 VE	22.6	53.7
	TS GUR 1020 50kGy VE	22.6	52.3
0.05	TNM	25.8	45.0
	TS GUR 1020 VE	22.6	53.6
	TS GUR 1020 50kGy VE	22.6	52.3

Table 1: Result summary

Discussion

The measured contact areas are strongly influenced by the method used. The contact areas measured by DIC are in the same range as those measured with pressure sensitive films. The choice of material model used has little effect on the calculated contact areas generated by FE simulations. Although material models from the literature were used, a good agreement with the experimental data was found. The contact areas and pressures are not sensitive to variations in the coefficient of friction.
Fujifilm Prescale LLLW tends to overestimates the contact area because small gaps are closed, as observed by Sarwar et al. 2017 [4]. To access the credibility of FE models, DIC-based methods should be considered as they do not interfere with the contact situation. Furthermore, they also allow continuous measurements during dynamic loading scenarios.

References

1. FDA Guidance 1418, 2016.
2. Bergstrom et al., Int J StructChang Solids 2(1):31–39, 2010.
3. Malito et al., Journal of the mech. behavior of biomed. Mat. 83, 9, 2018.
4. Sawar et al., BioMed Int., vol. 2017, p. 4310314, 2017.