ENGINEERING

McMaster University

Project 2 – Independent Research Summary

Total Knee Replacement

ENGINEER 1P13 – Integrated Cornerstone Design Projects

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Tutorial 1

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Executive Summary

A total knee replacement is a procedure that involves the full replacement of a person's entire knee joint [1]. The geometric design of a total knee joint implant limits both translational and rotational motion in one or more directions [1]. The implant's femoral component is often metallic and typically made using cobalt-chromium alloys, titanium, or titanium alloys [1]. However, the tibial and patellar components are usually comprised of a polymer such as polymethyl Methacrylate or ultra-high molecular weight polyethylene [1].

References

[1] Ansys Granta EduPack software, Granta design Limited, Cambridge, UK, 2020 (www.grantadesign.com).

Annotated Bibliography

[1] M. R. Ayatollahi, M. H. Davari, H. A. Shirazi, and A. Asnafi, "To Improve Total Knee Prostheses Performance Using Three-Phase Ceramic-Based Functionally Graded Biomaterials," *Frontiers in Materials*, vol. 6, p. 107, May 2019, doi: 10.3389/fmats.2019.00107.

The purpose of this study is to investigate the advantages of implementing three-phase ceramic-based functionally graded biomaterials (FGBM) in total knee joint implants. The proposed FGBM utilize hydroxyapatite at the site of bone bonding to maximize biocompatibility, alumina or zirconia ceramics at bearing surfaces to maximize wear resistance, and finally titanium in between to provide the required strength while having a lower elastic modulus to decrease the effect of stress shielding. The Von Mises stress values were determined in 12 directions on a 3D model of the prosthesis using COMSOL Multiphysics5.2 software. The results of comparing both a three-phase alumina based and zirconia based FGBM to a cobalt-chromium one, was an increase in average stresses on all paths, which significantly reduces stress shielding. In conclusion, the zirconia based FGBM showed the greater increase and is therefore the most favourable, though both will increase long term success.

[2] R. Shafaghi *et al.*, "A review of materials for managing bone loss in revision total knee arthroplasty," *Materials Science and Engineering C*, vol. 104. Elsevier Ltd, p. 109941, Nov. 01, 2019, doi: 10.1016/j.msec.2019.109941.

This study investigates the current materials used to manage bone loss in revision total knee arthroplasties (rTKA) and proposes new ones to better treat this. Traditionally, bone grafts or bone graft substitutes, which can include both natural and synthetic grafts, are used to treat this. Other treatments for bone loss in rTKA that were

investigated are bone cements, metallic scaffolds, megaprostheses, metal augments, block and wedge-shaped augments, porous tantalum metaphyseal cones, titanium metaphyseal sleeves, and bioactive augments. After this conclusive review, it was determined that there is currently no suitable alternate for augments in rTKA, which is why developing bioactive augments that will overcome the limitations of metal ones is the future. Bioactive glasses are encouraging candidates for this since they are both osteoconductive and osteoinductive, as well as have a low material cost.

[3] P. Chatterjee, D. Panchal, and S. Chakraborty, "A Developed Meta-model for Biomaterials Selection.," *Trends in Biomaterials and Artificial Organs*, vol. 34, no. 1, pp. 20–33, Jan. 2020, Accessed: Dec. 08, 2020. [Online]. Available: https://go-gale-com.libaccess.lib.mcmaster.ca/ps/i.do?p=AONE&sw=w&issn=09711198&v=2.1&it=r&id=GALE%7CA627689554&sid=googleScholar&linkaccess=fulltext

The purpose of this study is to develop a new model for biomaterials selection of the femoral component in both total knee and hip replacements. The proposed newly developed model integrates two material selection techniques, design of experiments (DoE) and evaluation based on distance from average solution (EDAS) in order to identify the most significant biomaterial selection criteria and therefore find the best material. To test the validity of the new method, the resulting selection is then compared to the results of currently used selection methods. The results showed that the proposed technique is in fact a less strenuous, yet equally accurate method for the biomaterials selection of total knee and hip replacement prostheses. In conclusion, the new system was successful and has the potential to be applied to a much wider range of biomaterials selection problems.

Additional References

[1] Y. Chang *et al.*, "A novel injectable whitlockite-containing borosilicate bioactive glass cement for bone repair," *Journal of Non-Crystalline Solids*, vol. 547, p. 120291, Nov. 2020, doi: 10.1016/j.jnoncrysol.2020.120291.

[2] R. Yu, H. Wang, Y. Zhuo, D. Liu, C. Wu, and Y. Zhang, "Continuous adductor canal block provides better performance after total knee arthroplasty compared with the single-shot adductor canal block?: An updated meta-analysis of randomized controlled trials," *Medicine*, vol. 99, no. 43, p. e22762, Oct. 2020, doi: 10.1097/MD.0000000000022762.

[3] J. Kubicek, F. Tomanec, M. Cerny, D. Vilimek, M. Kalova, and D. Oczka, "Recent trends, technical concepts and components of computer-assisted orthopedic surgery systems: A comprehensive review," *Sensors (Switzerland)*, vol. 19, no. 23. MDPI AG, p. 5199, Dec. 01, 2019, doi: 10.3390/s19235199.