Biomechanical Simulation & knee kinematic analysis integrated in intra-operative decision making towards a personalized knee arthroplasty surgery

Thomas M Grupp[1,2], William R Taylor[3], Ricardo Larrainzar-Garijo[4], Peter E Müller[1], Matthias Woiczinski[1,5], Björn Gunnar Ochs[6], Henning Windhagen[7], Gavin McHugh[8], Raphael Renaudot[2], Allan Maas[1,2]

[1]Ludwig Maximilians University Munich, Department of Orthopaedic and Trauma Surgery, Musculoskeletal University Center Munich (MUM), Campus Grosshadern, Munich, Germany

[2] Aesculap AG Research & Development, Tuttlingen & B.Braun New Ventures, Freiburg, Germany

[3] ETH Zurich, Institute for Biomechanics, Department of Health Sciences & Technology, Zurich

[4] Hospital Universitario Infanta Leonor, Orthopaedic & Trauma Department, Madrid

[5] Orthopaedic Department Waldkliniken Eisenberg, University Hospital Jena, Campus Waldkliniken Eisenberg

[6] Klinik für Unfallchirurgie, Handchirurgie & Orthopaedie, Orthopaedische Fachklinik Vincentius am Klinikum Konstanz, Konstanz

[7] Orthopaedische Klinik der Medizinischen Hochschule Hannover im Annastift, Hannover

[8] Sports Surgery Clinic & National Orthopaedic Hospital Cappagh, Dublin Ireland

Email: thomas.grupp@lmu.de

Summary

Primary total knee arthroplasty is today a successful clinical treatment over a 15 to 20 years period, but studies suggest that 15-20% of TKA patients were dissatisfied with their 1-year functional outcome [1].

In an innovative approach the integration of a biomechanical knee simulation considering individualized alignments and patient-specific parameters and an intra-operative tibio-femoral kinematic assessment as basis for an intra-operative decision making. Allowing for a patient personalized functional treatment in combination with up-coming primary TKA implant platforms, biomechanical evidence and surgical expert knowledge.

Introduction

In an empirical approach orthopaedic surgeons favour during the last years alternative knee alignment strategies, such as kinematic or restricted kinematic alignment [2], constitutional varus [3] or dynamic coronal plane limb alignment [4]. It has been found that only 15 % of TKA patients have a neutral limb alignment with a horizontal knee joint line, and that for varus knees with neutral or apex distal joint line obliquity patients benefit from kinematic instead of mechanical alignment [5]. Changing TKA patients pre-operative functional limb & femoral phenotype [6] by two or more categories significantly lowers clinical outcomes after 1-year [7]

Methods

In contrast to the empirical clinical development towards alternative alignment strategies, most of today's TKA knee systems are designed & clinically validated for mechanical axis alignment (180°±3°) and there is lack of clinical evidence, if a given TKA design is suitable for alternative knee alignment approaches in the long-term [8]. To allow for evidence based biomechanical thresholds for patient-individual anatomical, kinematic & musculoskeletal TKA treatment strategies, a dynamic FEA-based biomechanical knee model has been developed and validated [9] for intra-operative real-time usage in combination with orthopaedic knee navigation/robotics.

3915 navigated cases were included in this study (OrthoPilot®, Aesculap AG). After palpating the landmarks a neutral flexion of the knee joint was performed from full extension to full flexion. The position of the medial and lateral condyles at 0°, 30°,60° and 90° of flexion was computed using an implant fit algorithm defining functional-kinematic phenotypes.

Results and Discussion

During intra-operative surgical decision making the dynamic FEA-model predicts, if the given knee design in the chosen size combination, femur and tibia orientation, coronal and sagittal alignment is suitable considering implant fixation, contact mechanics and wear.

Half of the 3915 knees showed a medial pivoting pattern, with 49% having a posterior shift of the lateral condyle. 14% showed a lateral pivot, while 36% showed no pivoting or a central pivoting pattern.

Conclusions

In Conclusion this study proposes a method to integrate biomechanical simulation and intra-operative kinematics in the definition of functional phenotypes to better restore patient function after TKA, connecting for the first time musculoskeletal research, patient-related factors, implant design, articulating materials, surgical technique and intra-operative evaluation towards a personalized TKA clinical treatment.

References

[1] Gibon et al. 2017 Orth Clin NAm, 48:421-31.
[2] Rivière et al. 2018 EOR, 3:1-6.
[3] Bellemans et al. 2012 Clin Orth Rel Res 470:45–53.
[4] Larrainzar-Garijo et al. 2017 J Knee Surg 1598037.
[5] MacDessi et al. 2021 Bone Joint J 103:329-37.
[6] Hirschmann et al. 2019 KSSTA 27:1394-402.
[7] Rak et al. 2023 J Pers Med 13:778-87.
[8] Maas et al. 2024 Abstract 29. ESB Edinburgh
[9] Taylor et al. 2017 J Biomech, 65:32–39.