MiKneeSoTA - Minimizing Knee Soft-Tissue Artefacts During Kinematic Analytics

Eike Jakubowitz[1], Leon Budde[1], Ariana Ortigas Vásquez[2,3], Adrian Sauer[2,3], Michael Utz[2], Ann-Kathrin Einfeldt[1]

[1]Laboratory for Biomechanics and Biomaterials, Department of Orthopedic Surgery, Hannover Medical School, Germany
[2]Research and Development, Aesculap AG, Tuttlingen, Germany
[3]Musculoskeletal University Center Munich, Department of Orthopaedic and Trauma Surgery, Ludwig Maximilians University, Munich, Germany

Email of Presenting Author: Jakubowitz.Eike@mh-hannover.de

Disclosures: Eike Jakubowitz (N), Leon Budde (N), Ariana Ortigas Vásquez (N), Adrian Sauer (N), Michael Utz (N), Ann-Kathrin Einfeldt (N).

INTRODUCTION: The most frequently used method measuring and describing human joint movements is optoelectronic marker-based motion capture [1]. This approach involves attaching retroreflective markers to anatomical landmarks and capturing their three-dimensional coordinates over time using infrared cameras. Due to well-known challenges introduced by soft tissue induced motion artefacts (STIMA), and also imprecise positioning of markers relative to the underlying anatomical landmarks such marker-based methods are highly susceptible to systematic errors [2]. These errors affect especially the frontal and transversal motion planes [3]. As a result, different and sometimes even contradictory dynamic angle profiles for knee joint movements are still reported in the orthopaedic literature [1]. In the present paper, we address the need for a more accurate approach for the calculation of tibiofemoral joint kinematics, by describing the theoretical foundation and detailed implementation of an alternative marker set and computational method. The proposed new marker set leverages an over-determination of the two joint segments (femur and tibia) as well as a complementary optimization approach to ultimately **Mi**nimize **Knee** **So**ft-**T**issue induced motion **A**rtefacts (MiKneeSoTA) during in vivo motion analysis. The resulting kinematics are compared to the classical Helen-Hayes approach [3] as well as to established knee motion analyses [4,5] during normal level walking.

METHODS: The mathematical implementation of the MiKneeSoTA method is based on an extended Helen-Hayes marker model [3] using 30 markers. The algorithm essentially generates and positions a best fit virtual cylinder into each of the marker-based reconstructions of the four segments of the lower extremities based on three reference planes. Each plane contains of 12 virtual points, derived from the static trials of motion analysis. The relative position and orientation of the cylinders with respect to each segment are then optimized frame by frame throughout the dynamic trials to match their original position in the static trial as much as possible. The relative rotations and translations of these cylinders are then calculated along the corresponding anatomical axes. Fifteen healthy subjects were equipped with the marker set, and then underwent gait analysis while walking with a standardized gait speed on a treadmill (4 km/h). After a familiarization phase (2 min), kinematic data of nine consecutive gait cycles was acquired, preprocessed for event detection, and joint angle calculations according to the Helen-Hayes method [3]. All marker trajectories were then optimized with the MiKneeSoTA algorithm.

RESULTS: Exemplarily shown knee kinematics (Fig. 1a) in the sagittal plane indicate similar angular profiles (MiKneeSoTA = yellow; Helen-Hayes method [3] = blue), whereas in the other two planes they differ significantly. The Helen-Hayes method [3] shows greater signal variations and standard deviations than the MiKneeSoTA method for all subjects especially during the swing phase. Deviation of profiles in the frontal plane always starts and ends during initial and terminal swing phase with knee flexion of around 25-30° (green dashed lines). In frontal plane, angle profiles always show maximum variations during knee flexion of around 40° (red dashed lines). Deviations in the knee rotation were nearly at the same time but lasted significantly longer up to the next loading response. When comparing the average MiKneeSoTA dataset with a bonepin dataset [4] (red) and a dynamic x-ray dataset [5] (blue), there are similar joint angle profiles in all three planes (Fig. 1b). Subjects tracked with the MiKneeSoTA method show slightly higher knee flexion angles at the beginning and end of the gait cycle and reached peak knee flexion slightly later than both other datasets.

DISCUSSION: Due to the acquisition methods, the effect of a STIMA can be excluded with regard to the data of Lafortune et al. [4] and Gray et al. [5]. Given the striking similarity between the knee joint angle profiles obtained through the newly designed MiKneeSoTA method and those from the aforementioned studies, we can confidently assert that the effective exclusion of such STIMA effects is achievable through the application of the established marker-based, optoelectronic, and additionally still non-invasive gait analysis. The comparison of knee kinematics resulting from different marker approaches revealed a noteworthy mitigation of STIMA effects when utilizing MiKneeSoTA, particularly during the swing phase. Notably, the relatively high signal variations observed with the conventional Helen-Hayes approach consistently coincided with comparable knee flexions. We attribute these STIMA effects to the movement of the Tensor Fasciae Latae tendon in response to knee flexion. This tendon runs over the femoral epicondylus lateralis, and as the knee flexes, it undergoes positional changes, consequently altering the position of the lateral knee marker. However, this disruptive effect can be effectively eliminated with the method presented here.

SIGNIFICANCE/CLINICAL RELEVANCE: Optoelectronic gait analysis remains the sole non-invasive method for diagnosing knee kinematics in orthopedics—whether for surgical planning in corrective osteotomies or for kinematic alignment in arthroplasty— For the first time, the herein presented method signifies, an unaffected and highly accurate approach to captureknee kinematics, unmarred by the presence of soft tissue artifacts.

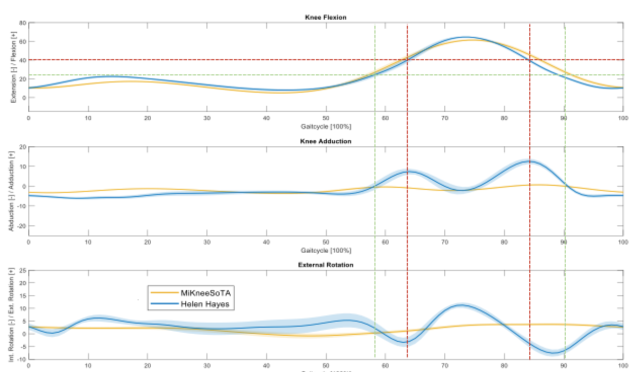

Fig. 1a: Knee kinematics from MiKneeSoTA (yellow) and Helen Hayes method (blue) of one subject. The green dashed horizontal line marks the initial and final knee flexion where both methods deviated in the frontal plane. The red dashed horizontal line marks the knee flexion, where both methods mostly deviated in the frontal plane during the beginning of the swing phase.

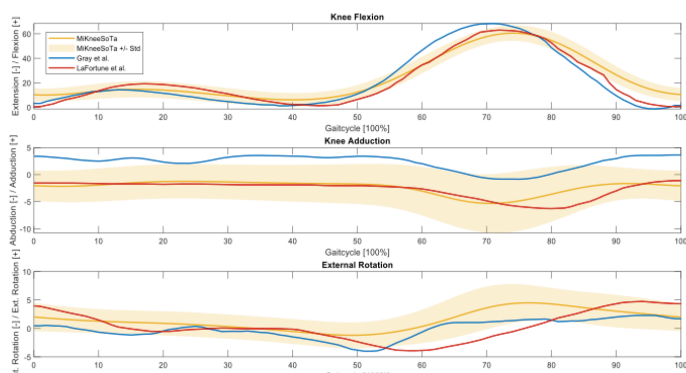

Fig. 1b: Comparison of knee kinematics as a result of the MiKneeSoTA dataset of all 15 participants (yellow), a bonepin dataset reported by Lafortune et al. [4] (red), and a dynamic x-ray dataset reported by Gray et al. [5] (blue) in all three planes.

REFERENCES: 1. Kerkhoff et al. 2020 *Curr Opin Biomed Eng.* 6(2); 2. Lahkar et al. 2021 *J Biomech.* 25(4); 3. Kadaba et al. 1990 *J Orthop Res.* 8(3); 4. Lafortune et al. 1992 *J Biomech.* 25(4); 5. Gray et al. 2019 *J Orthop Res.* 37(3).