Effects of Soft Tissue Artifacts on the Calculated Biomechanical Variables in Patients with Total Knee Replacements During Stair-Ascent

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SUMMARY
Total knee replacement (TKR) has been the main choice of treatment for advanced knee osteoarthritis (OA). Biomechanics of the knee during stair-ascent has mostly been studied using skin marker-based motion analysis techniques, but no study has reported a complete assessment of the soft tissue artifacts (STA) and their effects on the calculated joint center translation, angles and moments at the knee in TKR patients during this activity. Quantification of the effects of the STA on calculated knee kinematics and kinetics will help for the understanding of the measurement errors on target activities. The purposes of this study were to integrate a model-based 3D fluoroscopy method, skin marker-based stereophotogrammetry, and a forceplate to quantify the movement of the markers relative to the underlying bones, and to assess its effects on the calculated kinematic and kinetic variables at the knee in six patients with total knee replacements (TKR) during stair-ascent. Considerable STA during stair-ascent were found, leading to significantly underestimated flexion and extensor moments, but overestimated joint center translations.

INTRODUCTION
Total knee replacement (TKR) has been the main choice of treatment for advanced degenerative osteoarthritis (OA) of the knee over the last few decades. With a good long-term survival rate, improvement of functional recovery has received much attention [1]. Therefore, in evaluating TKR designs, it is essential to assess the functional performance of patients during activities of daily living, such as level walking and stair-ascent. It is well-recognized that stair-ascent places higher loads on the knee joint than level walking does, with larger ranges of motion, joint moments and muscle efforts. Therefore, accurate measurement of the relevant biomechanical variables during stair-ascent is necessary. Biomechanics of the knee during stair-ascent has mostly been studied using skin marker-based motion analysis techniques, giving three-dimensional (3D), non-invasive and in vivo estimates of knee kinematics and kinetics. It has been noted that these techniques are prone to soft tissue artifacts (STA) that are difficult to eliminate non-invasively [2]. Knowledge of the STA and their effects on the calculated kinematics and kinetics of TKR during stair-ascent would be helpful for a better interpretation of the results obtained. It may also help with the development of STA error-compensation methods for reducing their effects.

However, data on the STA and their effects on the calculated kinematic and kinetic variables at the TKR knee during stair-ascent have not been available in the literature. Therefore, the current study aimed to integrate a model-based 3D fluoroscopy method, skin marker-based stereophotogrammetry, and a forceplate to quantify the STA of skin markers on the thigh and shank, and to assess the effects of STA on the calculated knee kinematic and kinetic variables in patients with TKR during stair-ascent.

METHODS
Six patients with mobile posterior cruciate ligament-retaining TKR participated in this study with written informed consent, as approved by the Institutional Ethics Committee. Retro-reflective markers were attached to the pelvis (ASISs and PSISs), the tested thigh (greater trochanter, four technical marker at mid-thigh, medial and lateral epicondyles), the tested shank (head of fibula, tibial tuberosity, medial and lateral malleolus), and the tested foot (navicular tuberosity, fifth metatarsal base and heel). The subject was asked to walk up a three-step stair while the ground reaction forces were measured by a force-plate, the marker trajectories by a 7-camera motion capture system, and the motions of the TKR components around the knee joint by a single plane fluoroscopy (Fig. 1). The “gold standard” of the spatial positions and orientations of the femoral and tibial prosthesis components during movement were then determined using a model-based 3D fluoroscopy method [3].

During quiet standing without skin movements, TKR coordinate systems were also defined for the thigh and shank based on the registered poses of the femoral and tibial components to coincide with the segment-embedded coordinate systems defined by the skin markers. The STA of the markers around the knee joint including the medial and lateral femoral epicondyles (MFC and LFC), thigh markers (T1, T2, T3, and T4), tibial tuberosity (TT), and fibular head (FH) were calculated as their displacements in the relevant TKR coordinate systems. For inverse dynamics analysis, the pelvis, thigh, shank and foot were modeled as a 4-link system. The angles of the knee
joint were obtained following a z-x-y cardanic rotation sequence, corresponding to flexion/extension (Flex/Ext), adduction/abduction (Add/Abd) and internal/external rotation (IR/ER), using both skin marker and prosthesis poses. The internal moments about the knee joint center were also calculated using the marker and prosthesis data with the measured ground reaction forces. For comparisons between the variables obtained from skin markers and prosthesis poses, a paired t-test was used with a significance level of 0.05.

RESULTS AND DISCUSSION
The current study aimed to assess in vivo the STA on the thigh and shank, and its effects on the calculated kinematics and kinetics of the TKR during stair-ascent. Considerable STA during stair-ascent were found, in agreement with the literature [4]. The movement of markers relative to the underlying TKR components resulted in an underestimated flexion and internal rotation (Fig. 2). For the translation components, the over-estimated displacements in posterior and distal components were found (Fig. 2). Skin marker data led to significantly underestimated knee joint moments, particularly the extensor component (Fig. 3). Knee extensor moments calculated from the skin markers were significantly smaller than those from the 3-D fluoroscopy at 10%, 20%, 30% and 40% of stance phase. In general, STA affected mainly the results of the kinematics and the kinetics of the knee during the first half of stance phase.

It appears that clinical studies of TKR with a normal control group may benefit from these STA data when interpreting the results obtained. Taking STA into account in the analysis of the knee will be helpful for a more accurate estimation, and thus a better understanding, of its pathological biomechanics during stair-ascent for TKR patients.

Figure 1: Schematic diagram showing the integration of the stereophotogrammetry, a forceplate and a single-plane fluoroscopy system.

Figure 2: Means of the angular motions of the knee, calculated with a skin marker-based method (gray thick dashed lines) and with 3-D fluoroscopy (black solid thin lines). Standard deviations are represented as upper and lower error bars. Means and standard deviations of knee joint translations in the tibial coordinate system are also shown. Stars mark statistically significant differences.

Figure 3: Knee Ext/Flex, Abd/Add and IR/ER moments measured by skin marker-based method and a 3-D fluoroscopy method, respectively, were calculated from 10% to 90% of the stance phase during stair ascent at 10% intervals. Stars mark statistically significant differences.

CONCLUSIONS
A complete quantitative, in vivo assessment of the STA effects on joint center translations, angles and moments of TKR during stair-ascent was performed for the first time in the literature. The STA of the markers were considerable, leading to significantly underestimated flexion and extensor moments, but overestimated joint center translations during the first half of the stance phase. The current results will be useful for a better understanding of the biomechanics of the TKR during stair-ascent, serving as a baseline for future clinical applications and for developing a compensation method to correct for the effects of STA.

REFERENCES