ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

THE 3D BODY CENTRE OF MASS TRAJECTORY BEFORE AND AFTER TOTAL KNEE ARTHROPLASTY: SYMMETRY AND MECHANICAL WORK

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SUMMARY

The kinematics of walking on treadmill were collected and the 3D trajectory of the body centre of mass was computed in subjects suffering from mono-lateral knee osteoarthritis, before and after total knee arthroplasty. Experimental data showed after 6 months from surgery significant improvements in many biomechanical parameters as gait symmetry indices and total work done.

INTRODUCTION

Osteoarthritis (OA) is one of the most common degenerative joint disease causing morbidity in elderly people and knee is one of the most injured joint, with 6% of prevalence in the global adult population. Degenerative processes on the bones surfaces cause pain and compromise patient's life quality permanently [2]. For this reason total knee arthroplasty (TKA) is considered an established and effective treatment for end-stage osteoarthritis [1].

Common qualitative examinations, both for diagnosis and monitoring of OA progression are radiology, questionnaires and functional outcome measures. Quantitative measures should be identified to guide the optimal timing of TKA and to promote maximal functional benefit [7], but references reporting biomechanical analysis of knee OA, with TKA are just a few [3,5,8,9].

The main aim of this project is the quantitative evaluation of the biomechanical variables of walking in OA patients that undergo to the TKA. In particular we are interested in the three dimensional (3D) Body Centre of Mass (BCoM) trajectory modifications before and after total knee replacement.

METHODS

Seven subjects with mono-lateral knee OA took part to the study (age 68.9 ± 4.8 years, body mass 69.1 ± 9.1 kg, height 1.60 ± 0.07 m). In order to compare biomechanical locomotion features in walking, the described experimental protocol was applied in four different phases: before surgery (1 or 2 days before), after 2 months and after 6 months from TKA. The brand and model of prostheses was always the same (PFC-Sigma, DePuy, J&J), as well as the surgery procedure and the surgeon.

Each patient compiled a questionnaire regarding pain, stiffness and disability caused by the OA (WOMAC evaluation scale). Subjects walked on a 5-force platforms corridor (Bertec, OH USA), in order to estimate spontaneous velocity v_s (f=1000 Hz). Froude Number (*Fr*) was calculated in order to compare different size subjects and two velocities, lower than v_s, were calculated (v_1 = -30% *Fr* and v_2 = -15% *Fr*, respectively). 18 reflective markers were located on anatomical landmarks of the relevant joints in order to be detected from the 8-camera optoelectronic system (VICON, Oxford UK) [4]. Each subject performed on treadmill (Ergo LG; Woodway) a 1-minute walking trial for each estimated velocity (v_s, v_1, and v_2).

3D coordinates from 12 body segments were recorded (f=100 Hz). A recent mathematical method for the 3D BCoM trajectory description [6] was used, which simultaneously incorporates spatial and dynamical features of the BCoM. Symmetry dynamical indices for the three Cartesian axis (SIx, SIy, SIz) were calculated, together with stride frequency (SF), double contact (DC) time, right and left duty factor, mechanical external and internal work (Wext and Wint respectively), total work (Wtot=Wext +Wint) and energy recovery (RE).

Two-way ANOVA for repeated measured with velocity and time (from the day of surgery) as factors, while a one-way ANOVA for repeated measured compared the spontaneous velocities and WOMAC indices. The null hypothesis was rejected when $p<0.05$.

RESULTS AND DISCUSSION

Biomechanical variables evaluated in this study showed values akin to physiological reference in the period subsequent to the replacement. Spontaneous velocity increased from 0.87 ± 0.12 m/s (pre-surgery) to 0.94 ± 0.10 m/s after 2 months and 1.06 ± 0.07 m/s after 6 months. Significantly differences were found between pre-surgery and post-6-months velocities, and between post-2-months and post-6-months velocities (p<0.01). WOMAC questionnaire indices regarding pain, stiffness and disability improved significantly after surgery. These results, together with the increased spontaneous velocity indicate an increment of patient's comfort, as confirmed also by a concomitant decrease of SF. Patients performed longer steps, with higher confidence and stability, showing DC time and duty factor values very similar to the physiological one (20% and 60%, respectively).

Symmetry indices of the BCoM trajectory for progression axis x and vertical axis z, are presented in Figure 1a and 1b (they are expected to be equal to 1 in case of perfect symmetry between right and left steps). Indices get closer to the physiological values reported by Minetti and collaborators in 2011 [6]. Higher values of symmetry indices, in particularly for the vertical axis, witness lameness reduction in subjects after TKA. These results are also visible in Figure 2, where BCoM 3D profiles for the three different conditions are shown.

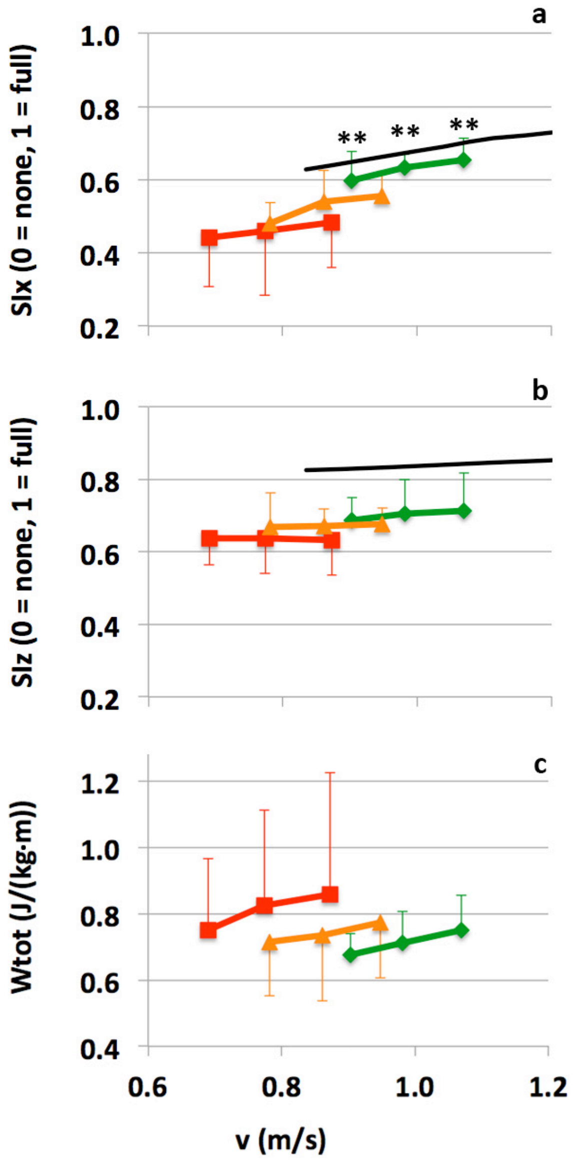

Figure 1: Mean values (± SD), analyzed pre-surgery (red lines), after 2 months (orange lines) and after 6 months (green lines), at the three different velocity levels, of a) SIx, b) SIz and c) Wtot. Asterisks denote the significant difference between velocities after two months and after 6 months from surgery. Black lines indicate reference physiological values for SI [6].

The upper boundary of BCoM trajectory reached a significantly higher vertical position compared to the before surgery condition. Walking with a lower BCoM position (due to more flexed knee) is likely the result of an antalgic strategy, with a less favorable moment arm for knee extensors. Also, straight knee walking is supposed to allow more energy saving via the pendulum-like motion of BCoM. Improvements are evident also for the sum of external and internal mechanical work. In Figure 1c we can observe the total mechanical work decreasing after surgery, for each velocity level recorded. Subjects with prosthesis seem to re-establish their natural locomotion pattern, with most of the relevant biomechanical parameters near to the physiological ones.

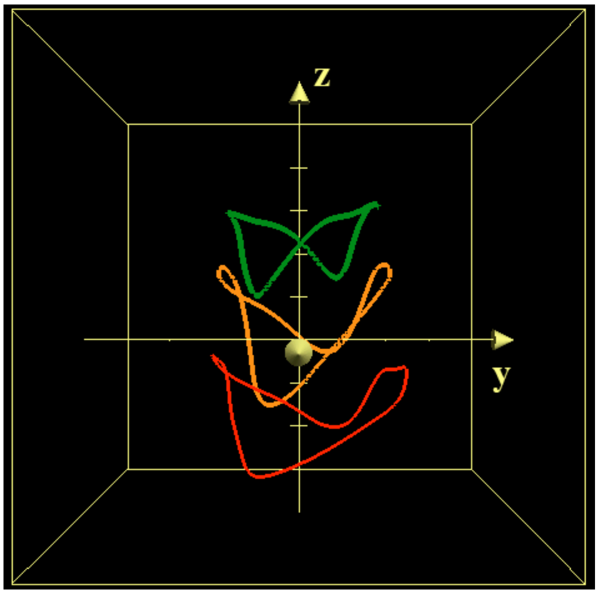

Figure 2: Example of the 3D BCoM trajectories pre-surgery (red), after 2 month (orange) and after 6 months (green), for a subject walking on a treadmill at 0.91m/s, as seen from the front.

CONCLUSION

The implemented procedure represents a novel method for quantitatively monitoring disease progression and normal gait restoration after surgery of Knee OA patients. Ongoing experiments are devoted to evaluate the same patients also after 12 months from TKA. The same protocol/methodology could be applicable subjects affected by orthopaedic pathologies affecting different other limb joints, like hip or ankle. Also, the effects of different prosthesis or surgical techniques on a single pathology/joint could be investigated.

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