Knee Kinematics Following Total Joint Arthroplasty versus ISO Standard Profiles

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Introduction: During the past several decades, increases in life expectancy, body weight and activity level of total knee replacement (TKR) candidates have been documented, thereby implicating the necessity for implant endurance and durability[1]. Knee wear simulators are an essential assessment tool for pre-clinical evaluation of prosthesis performance, particularly since wear is the most prevalent implant failure mechanism[2]. Simulators today are operated under standardized protocols for either force (ISO14243-1) or displacement control (ISO14243-3). Both standards input identically defined flexion-extension (FE) patterns, however, the force controlled simulation controls the anteroposterior (AP) translation and internal-external (IE) rotation by dictating the load and moment, whereas, the displacement controlled simulation defines the actual movement of these two motions. In order to allow viable assessment of implants, the testing input should be as realistic as possible. The purpose of the current study was to assess the validity of the motion profiles defined by both force and displacement controlled simulator protocols with in vivo kinematics of a sample TKR population for an entire gait cycle.

Materials and Methods: Ten TKR patients (6M/4F, 76.0±4.9yrs), implanted with well-functioning Miller-Galante II (MGII) type prostheses (affected side L/R=4/6) with an average in-situ time of 12.0±0.5yrs, were recruited. To obtain the primary knee motion, FE, and secondary knee motions, AP translation and IE rotation of the tibia with respect to the femur, the sample TKR population was gait tested using the point cluster technique (PCT)[3]. An optoelectronic camera system (CFTC, US) was used to record the 3-dimensional knee motions for 8 separate walking trials per subject. Inter- and intra-patient variability was calculated through a coefficient of variation analysis[4]. These results indicated that intra-patient variability was significantly smaller than inter-patient variability and it was, therefore, feasible to use 1 representative walking trial from each subject for comparison with the standard profiles. The motions obtained from the walking trials were directly compared with the motion based input data of ISO14243-3 for an entire gait cycle. To allow comparison with the motion output of the force driven ISO14243-1 simulation, a wear test was conducted with the same implant type using a 3-test/1-loadsoak station knee joint simulator (Endolab, Germany). FE, AP and IE motion data was recorded at 1 station for 4 complete walking cycles at an acquisition rate of 120Hz. This acquisition was repeated 8 separate times over the duration of the test and subsequently averaged.

Results: The output FE motion pattern from the load controlled test conformed almost perfectly to the defined displacement control input (Fig.1a). Since both standards implement the same FE motion pattern, this conformation verified the ability of the simulator to represent the defined input. Similarly, this agreement was seen between the specified input and resulting output axial force. The TKR subjects also exhibited a similar FE pattern; however, the subjects did not reach full knee extension during midstance (11° flexion vs. ISO specified 5°flexion, p<0.05) and displayed a time delay in the gait cycle (peak knee flexion≈76% gait for subjects vs. 72% gait for ISO, p<0.001). For AP translation, differences in the pattern of motion between the two ISO curves were apparent (Fig.1b), with ISO14243-3 displaying a more defined pattern of movement. Both standard profiles had smaller magnitudes of AP translation (ISO maximum AP travel of 5.6mm vs. 24mm for TKR subjects, p<0.001) and had an opposite pattern of motion from midstance and swing. The IE rotation pattern also reflected the AP translation findings (Fig.1c), showing non-conformation between both ISO curves to each other and individually to that of the TKR subjects. Though the total range of IE rotation of the subjects was not significantly different from that of the ISO curves, the patterning was exactly opposite from midstance to the end of swing.

Discussion: Resulting motion profiles for the load control standard are highly dependent upon the prostheses design and therefore, may not necessarily mirror those of the displacement control standard input. The larger AP translation observed in the subjects are reflected, and thereby supported, in postmortem wear scar analyses where 24.3±5.3mm medial and 23.7±5.2mm lateral AP wear scar lengths were measured on MGII tibial liners[5]. The rotational pattern specified by the standards represented the well-known “screw-home mechanism”, which was opposed by the subjects during midstance and swing.

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