3D MOTION ANALYSIS OF THE HUMAN KNEE JOINT: COMPARISON BETWEEN INTRA- AND POST-OPERATIVE MEASUREMENTS

Claudio Belvedere, Andrea Ensini, Domenico P. Notarangelo, Silvia Tamarri, Alessandro Feliciangeli, and Alberto Leardini

1 Movement Analysis Laboratory; 2 II Division of Orthopaedic Surgery, Istituto Ortopedico Rizzoli, Bologna, Italy

Email belvedere@ior.it; web: www.ior.it/en/laboratori/lab-analisi-movimento/movement-analysis-laboratory

INTRODUCTION

During total knee replacement operation, a number of different computer assisted technologies nowadays allow accurate assessment of joint kinematics before and after prosthesis component implantation. This is meant to support the surgeon for achieving the best possible replication of natural knee motion, compatible with the prosthesis design and the status of the joint, in the hope that this kinematics will be then the same during the daily living activities of the patient. Particularly, surgical navigation systems report and store in real time relative motion between the tibia and the femur, necessarily in passive conditions, i.e. from the patient under anaesthesia, in order to identify best possible locations for the corresponding prosthesis components, according to the morphology and the lower limb mechanical axis [1]. By means of these systems, knee kinematics is tracked in the original arthritic joint at the beginning of the operation, during the various tests after bone cuts implanted with trial components, and after final components implantation and cementation. Rarely the extent to which the kinematics in the latter condition is then replicated during activity is analyzed.

The most accurate technique for the in-vivo measurements of joint kinematics of the replaced joint is three-dimensional video-fluoroscopy [2], utilised frequently for assessment of the motion performance at the replaced joint. Despite the motor tasks analyzed are limited by the small field of measurement, this allows tracking joint motion in-vivo, and under typical movements and loads of daily living.

The general aim of this study is assessing the capability of the current surgical navigation systems to foresee replaced joint motion after surgery. Particularly, the specific objective is to compare, for a number of total knee replacement patients with two different prosthesis component designs, knee kinematics obtained intra-operatively after final component implantation with that post-operatively at the follow-up, measured respectively with surgical navigation and three-dimensional video-fluoroscopy. A good super-imposition between these two measurements would strengthen further the navigation-based technique for knee replacement, because it would be also able to predict intra-operatively the final kinematics performance of the replaced joint.

METHODS

31 patients affected by primary gonarthrosis were treated by total knee replacement between July 2005 and August 2006, and included in the study. These were implanted with a fixed bearing posterior-stabilized (PS) prosthesis design, either the Journey® (JOU; Smith&Nephew, London-UK) or the NRG® (NRG, Stryker Orthopaedics, Mahwah, NJ-USA). All implant operations were performed by means of a knee navigation system (Stryker®-Leibinger, Freiburg, Germany; nominal accuracy of 0.5 mm for translations and 0.5° for rotations), utilized to track and store joint kinematics intra-operatively immediately after final component implantation (INTRA-OP).

Six months after operation, the patients were followed for the control, which implied clinical assessment and three-dimensional video fluoroscopy (POST-OP). Fifteen of these gave informed consent, 8 patients with the JOU, 7 patients with the NRG, and these were analyzed.

At surgery (INTRA-OP; Fig. 1), all knees were treated through the standard anterior longitudinal exposure. A spatial tracker, i.e. a cluster compound of active markers, of the navigation system was attached through two bi-cortical 3 mm thick Kirschner wires to the distal femur and another to the proximal tibia. The conventional navigation procedure recommended in the system manual was performed to calculate the preoperative deformity including the preoperative lower limb alignment, i.e. the mechanical axis to execute the femoral and tibial bone cuts, and to measure the final lower limb alignment [1]. Static alignments and joint kinematics were calculated based on the initial anatomical survey, which implies calibration, by an instrumented pointer, of anatomical landmarks and axes.

Patients were then analyzed (POST-OP) by three-dimensional video-fluoroscopy (digital remote-controlled diagnostic

![Figure 1: Diagrammatic representation of the INTRA-OP measurements: the two standard trackers with five light-emitting diodes, pinned onto the femur and the tibia, together with the pointer-like tracker used for bony landmark (depicted) and axis digitization, tracked by the localizer with three cameras at the workstation.](image-url)
Alpha90SX16; CAT Medical System, Rome, IT) at 10 frames per second during chair rising-sitting, stair climbing, and step up-down. Attention was paid to position the fluoroscopic 32-cm-wide field of view to enable collection of the largest number of images of the replaced knee during the motor task. By means of static images of a plexiglas cage with nine 0.3 mm-diameter tantalum beads on its faces and of a 40x40 cm grid with same dimensional tantalum beads with 5 mm step on both directions, a technique for obtaining three-dimensional positions and orientations of the prosthesis components was utilized [2,3]. This technique was based on CAD-model shape matching. Relative motion between the tibial and femoral components was represented using a standard joint convention [4]. The contact line rotation was also calculated, defined as the rotation on the tibial baseplate of the projection of the line connecting the medial and lateral condylar contact points with respect to the medio-lateral axis of the baseplate. These points were assumed to be where the minimum distance between the femoral condyles and the tibial baseplate is observed.

Between the two techniques, the kinematics variables analyzed for the comparison were the three anatomical components of the joint rotation, the translation of the line through the medial and lateral contact points on the tibial baseplate and corresponding pivot point, and the location of the instantaneous helical axes with corresponding mean helical axis and pivot point.

RESULTS AND DISCUSSION
In all patients and in both conditions, physiological ranges of flexion (from -5° to 120°), and ab-adduction (±5°) were observed. Internal-external rotation patterns are different between the two prostheses, with a more central pivoting in NRG and medial pivoting in JOU, as expected by the design. Restoration of knee joint normal kinematics was demonstrated also by the coupling of the internal rotation with flexion, as well as by the roll-back and screw-home mechanisms observed.

Location of the mean helical axis and pivot point, both from the contact lines and helical axes, were very consistent over time, i.e. after six months from intervention and in fully different conditions (Fig. 2 and 3). Only one JOU and one NRG patient had the pivot point location at follow-up different from that INTRA-OP, despite cases of paradoxical translation.

![Figure 2: Graphical representation from a typical patient (JOU); INTRA-OP measurements for the location of the contact lines (yellow), with the pivot point depicted, found in the medial compartment.](image)

![Figure 3: Similar graphical representation from the same patient (JOU) of Figure 2; POST-OP measurements for the location of the contact lines (various colours according to the range within the flexion arc), with the pivot point depicted, found nearly in the same position in the medial compartment.](image)

CONCLUSIONS
First of all, in all the replaced knees analyzed, a good restoration of normal joint motion was observed, both during operation and at the follow-up. This supports the general efficacy of the treatment, i.e. quality of the surgery and of both prosthesis designs, and the selection of successful knee replacements. But these results also show a good consistency of the measurements over time, no matter these were taken in very different joint conditions and by means of very different techniques. In particular, the pivot point of the contact lines POST-OP replicated that at INTRA-OP.

Intra-operative kinematics therefore does matter, and must be taken into careful consideration for the implantation of the prosthesis components. Therefore joint kinematics should be tracked accurately during surgery, and for this purpose current surgical navigation systems seem to offer a very good support. In other words, surgical navigation systems not only supports in real time the best possible alignment of the prosthesis components, but also make a reliable prediction of the motion performance of the replaced joint. Additional analyses will be necessary to support this with a statistical power, and to identify the most predicting parameters among the many kinematics variables here analyzed preliminarily.

REFERENCES