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## IN-VIVO ANATOMY-BASED PATELLAR TRACKING IN NAVIGATED TOTAL KNEE REPLACEMENT

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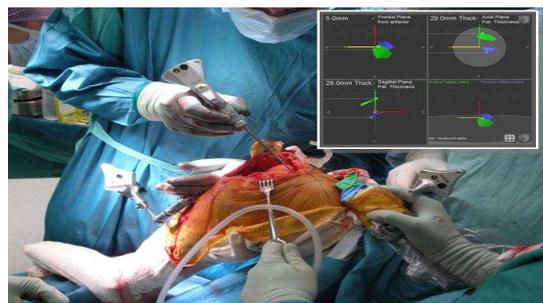
### SUMMARY

Despite a large percentage of failures in total knee replacement occurs for problems at the patello-femoral joint, current navigation systems assess tibio-femoral joint kinematics only, not the patello-femoral. A new technique for tracking patellar morphology and motion has been developed as an extension of a standard knee navigation system. This includes new relevant surgical instrumentation and software/hardware tools, which provides important intra-operative measurements. The aim of this study was to report on early performance of this technique, in-vivo during real total knee replacement in 15 patients. These were implanted using navigated techniques; the patella was resurfaced, whose resection level and orientation were assessed intra-operatively, together with tibio- and patello-femoral joint kinematics. All these real-time patellar-based measurements were found feasible, despite the cumbersome instrumentation in this prototype. Final misalignment of the patellar osteotomy was found as small as  $0.4^\circ$  and  $1.4^\circ$  in the sagittal and transverse planes on average. The mean discrepancy in thickness between the original and resurfaced patella was as small as 0.4 mm. With the support of the new patellar tracker, a thorough kinematic assessment of both joints, before and after each surgical action, was offered to the surgeon. Discrepancies in thickness were also revealed between the traditional manual and the new computer-aided measurements. These findings support the relevance, feasibility and efficacy of patellar tracking in navigated total knee replacement, even in case of not resurfacing.

### INTRODUCTION

In the human knee, patellar maltracking may result in patello-femoral joint (PFJ) disorders after total knee replacement (TKR) [1]. This is generally accounted to prosthesis component misalignment in both tibio-femoral joint (TFJ) and PFJ, i.e. in patellar resurfacing, and this may result frequently in knee pain, a number of joint disorders, and, ultimately, in TKR failure. Particularly, whereas in TKR without patellar resurfacing the physiological patellar motion depends on the femoral/tibial component implantation only, in case of resurfacing this is further influenced by the patellar preparation, i.e. bone resection level and orientation, and relevant component positioning. Surgical navigation systems (SNS) for TKR allow accurate prosthesis component implantation, though on the femur and tibia only. These systems guide intra-operatively the

surgeon in bone cut executions after the collection of a number of bony landmarks, and provide information about TFJ kinematics after each surgical action [2]. Currently, the standard technique for patellar resurfacing is based only on the visual inspection of patellar articular aspect for clamping the patellar cutting jig, and on a simple caliper to check for patellar thickness before/after bone resection, i.e. without any computer aid, and no quantitative patellar motion data is available. The introduction in in-vivo traditional navigated TKR of a procedure for tracking also the patella based on patient-specific patellar morphology and robust biomechanical conventions is, therefore, fundamental for a thorough anatomical and kinematic assessment of the whole knee, before and after each surgical action. The efficacy of such a procedure has been experienced in-vitro [1], and also in-vivo in a pilot study [3], for which the main surgical instrumentation and software/hardware tools were realized. The aim of this study was to report the developments of such experiences in-vivo. Particularly the novel procedure was here applied more extensively in two patient cohorts, each implanted with a specific TKR prosthesis design with patellar resurfacing using a suitably adapted SNS.



**Figure 1:** Landmark digitization during TKR. Femoral, tibial and patellar trackers are fixed on corresponding bones and detected by the localizer (not visible). Patellar morphological data are shown on PSNS screen (small box).

### METHODS

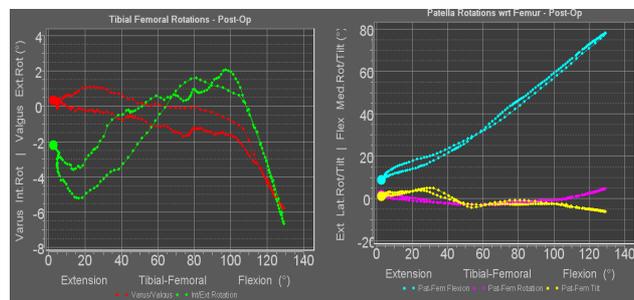
Fifteen patients affected by primary gonarthrosis were recruited to be implanted with a fixed bearing posterior-stabilized prosthesis (NRG® and Triathlon® in ten and five patients, respectively, Stryker®-Orthopaedics, Mahwah, NJ-USA) with patellar resurfacing. All TKR were performed using two SNS (Stryker®-Leibinger, Freiburg, Germany) equipped each with a workstation embedding the localizer with three camera sensors, the standard pointer and the

femoral and tibial trackers. An innovative specially-designed patellar tracker, lighter and smaller than the others, was designed and manufactured to offer small gravitational and inertia effects. Trackers and pointer incorporate 3-to-5 light emitting diodes; the former were fixed onto bones for relevant motion tracking and the latter was used for bony landmark digitations (Fig. 1) to define anatomical reference frames. The novel procedure for patellar tracking implies the use of a second SNS, i.e. the patellar SNS (PSNS), with dedicated software, also for supporting patellar resurfacing, and relevant data processing, in addition to the traditional knee SNS (KSNS). Tibial and femoral anatomical references were defined by KSNS according to standard navigation [2] and shared between the two systems. The patellar reference frame was based on the digitization of the patellar apex and the medial and lateral prominences, the origin being in the prominences mid point, the antero-posterior axis is orthogonal to the plane of these three landmarks, the proximo-distal axis along the vector from the apex to the origin, and the medio-lateral axis as normal to the previous axes. TFJ and PFJ kinematics were calculated according to recommendations and a recent proposal [1]. The procedure was approved by the local ethical committee; all patients gave informed consent prior to surgery. Before TKR, both SNS were initialized; additional probes, used in patellar resurfacing for bone cut level setting/verification, were instrumented with a tracker and a reference frame was defined on them by digitization with PSNS. With the knee still intact, femoral and tibial anatomical data were collected by KSNS; patellar reference frame definition and TFJ/PFJ kinematics assessment were performed by PSNS. Subsequently, standard navigated TKR was performed using KSNS for femoral/tibial component implantation [2]. Afterwards, the procedure for patellar resection was executed: the surgeon clamped the patella with the cutting jig suitably instrumented with a probe; PSNS captured relevant probe data to the desired patellar cut level and orientation. After cut execution, corresponding accuracy was assessed using a verification probe. With all three trial components in place, TFJ and PFJ kinematics were captured. Adjustments in component positioning could still be performed until both joint kinematics were satisfactory. At last, the final components were cemented, and final TFJ and PFJ kinematics were acquired. A sterile calliper and pre/post-implantation lower limb X-rays were used to check for patellar thickness and final alignments.

## RESULTS AND DISCUSSION

The full surgical procedure was performed successfully in all TKR without complications, resulting in about 30 min longer operations, on average over the patients, with respect to standard TKA. The final lower limb alignment was  $0.5^{\circ} \pm 1.6^{\circ}$ ; resurfaced patella was  $0.4 \pm 1.2$  mm thinner than the native, and patellar cut was  $0.4^{\circ} \pm 4.1^{\circ}$  laterally tilted and  $1.4^{\circ} \pm 4.8^{\circ}$  flexed with respect to the defined patellar reference frame. Final PFJ kinematics (Fig. 2 and 3), i.e. with final component implantation and the patella resurfaced, was taken within the reference normality [4]. This showed a range of flexion, tilt and medio-lateral shift of  $66.9^{\circ} \pm 8.5^{\circ}$  (mean of minimum  $\div$  maximum values,  $15.6^{\circ} \div 82.5^{\circ}$ ),  $8.0^{\circ} \pm 3.1^{\circ}$  ( $-5.3^{\circ} \div 2.8^{\circ}$ ), and  $5.3 \pm 2.0$  mm ( $-5.5 \div 0.2$  mm), respectively. Significant correlations were

found between the internal/external rotation of the implanted femoral component and the range of PFJ tilt ( $p=0.05$ ;  $R^2=0.41$ ), and between the mechanical axis on the sagittal plane and the range of PFJ flexion-extension ( $p=0.05$ ;  $R^2=0.44$ ) and of antero-posterior shift ( $p=0.04$ ;  $R^2=0.45$ ). Patellar implantation parameters were confirmed by X-ray examinations; discrepancies in thickness up to 5 mm were observed between SNS- and calliper-based measurements.



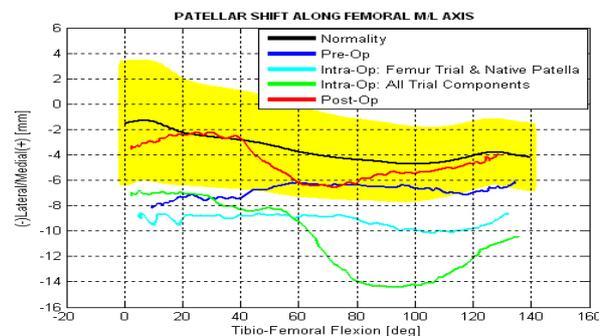
**Figure 2:** Snapshot of PSNS reporting post-operative TFJ & PFJ kinematics variables from a well representative case.

## CONCLUSIONS

The results reported support the relevance, the feasibility and the efficacy of patellar motion tracking and patellar morphological data acquisition in navigated TKR using an extension of a standard knee navigation system. These encouraging in-vivo findings may lay ground for the design of a future clinical SNS the surgeon could use to perform a more comprehensive assessment of the biomechanical status of the whole knee, i.e. including also PFJ, both intact and after surgical actions. Patellar bone preparation would be supported for suitable component positioning in case of resurfacing but, conceptually, also in not resurfacing if patellar anatomy and PFJ kinematics assessment by SNS reveals no abnormality. In the future if the technique described above will be routinely applied in navigated TKR, TFJ and PFJ abnormalities can be detected and corrected intra-operatively by more cautious bone cut preparation and correct prosthetic component positioning on the femur, the tibia and also the patella, in case of resurfacing.

## REFERENCES

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**Figure 3:** PFJ shift after each surgical action from a well representative case. Abnormal intra-op shift with trial components (in green) was observed and taken within the normality (yellow band) after a lateral release (red line).