Robotic Assessment of Patella Tracking in Total Knee Arthroplasty

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Abstract

Objectives
Robotic-tools have been developed to improve planning, accuracy and outcomes in total knee arthroplasty (TKA). The purpose of this study was to describe and illustrate a novel technique for assessing the patellofemoral (PFJ) in TKA using an imageless robotic platform.

Methods
A consecutive series of 30 R-TKA were undertaken by a single-surgeon utilising the described technique. A technique to dynamically assess the PFJ intra-operatively, pre and post implantation was developed. A full set of data from 9 cases was then collected and reviewed for analysis. A series of dynamic PFJ tracks collected intra-operatively pre and post implantation are presented. Furthermore, a full assessment of PFJ over and under-stuffing through a 90° arc of flexion is illustrated. Finally, a pre and post centre of rotation for the PFJ was defined and measured.

Results
The described technique was defined over a series of 30 R-TKA using the described robotic platform. Nine cases were analysed to determine what data could be measured using the robotic platform. Intra-operative real-time data allowed a visual assessment of PFJ tracking through a range of motion of 0° to 90° flexion pre and post-implantation. PFJ over and under-stuffing was also assessed intra-operatively through a range of motion of 0° to 90° flexion. Post operative analysis allowed a more detailed study to be performed, including defining a pre and post implantation centre of rotation (COR) for the patella. Defining the COR allowed the definition of a patella plane. Furthermore, patella mediolateral shift in full extension, and end flexion could be measured.

Conclusion
Intra-operative assessment of the PFJ in TKA is challenging. Robotic tools have been developed to improve measurement, accuracy of delivery and outcomes in TKA. These tools can be adapted in novel ways to assess the PFJ, which may lead to further refinements in TKA techniques.

What are the new findings:
- Robotic-assisted patella tracking is possible with the simple adaptation of a currently available system
The concept of patellofemoral balancing can be refined with the additional information provided by robotically-assisted patella tracking. The new data provided by this technique will allow new insights into understanding patellofemoral biomechanics and their relevance to clinical outcomes following total knee arthroplasty.

Keywords: Robotic surgery, robotically-assisted total knee arthroplasty, patella, patella tracking, patellofemoral joint, patellofemoral joint balancing.
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**Introduction**

Robotically-assisted technology is increasingly being utilised in total knee arthroplasty (TKA) to improve surgical planning, accuracy and ultimately outcomes. To date, all commercially available systems have focussed on the tibiofemoral compartment, with little attention being directed to the patellofemoral space [31]. Modern arthroplasty data demonstrate between 10 to 30% of patients suffer from clinically significant patellofemoral joint (PFJ) dysfunction following TKA even when the patella is resurfaced [9, 11, 12, 25].

Patella tracking describes the pathway of the patella through an arc of flexion. An important surgical goal of TKA is to avoid patella maltracking intra-operatively [19]. This goal is underpinned by the rationale that physiological patellar tracking optimizes the position of the patella and improves the mechanical advantage and thus function of the extensor mechanism [23]. However defining maltracking remains difficult as the patella has six degrees of freedom of movement and it’s position changes throughout flexion. Furthermore, the clinical significance of maltracking of the patella in TKA remains uncertain.

Intra-operative assessment of PFJ tracking in TKA has evolved little since it was first defined. The rule of no thumb was originally described by Scott [26] in 1979. Extensor mechanism balance was said to be achieved if the patella did not tilt, subluxate, or dislocate during flexion [26]. In practical terms, this has resulted in surgeons typically assessing patella tracking by observing if the patella dislocates, subluxes or tilts when the knee is passively flexed intra-operatively with either trial or definitive prosthetic components. This method remains the predominant manner by which PFJ tracking is assessed in modern TKA despite significant advancement in surgical tools and techniques.

Robotic tools may be able to provide a method for surgeons to measure and manipulate patellofemoral tracking in TKA. The use of robotic tools to assess dynamic patella motion has been described previously in cadaveric models [1, 20], however due to practical challenges, their use in clinical practice has not yet followed. Previously, imageless robotic tools have been used to map the anatomy of the trochlea groove in patients undergoing TKA [13]. A working solution for recording and measuring the movement of the patella intra-operatively however remains elusive.

The CORI imageless robotic system is a diverse platform that allows the surgeon to collect unique landmarks determined by the operator. This coupled with its rapid motion capture system may provide a means for measuring the movement of a landmark through a movement of the knee, such as the patella through an arc of flexion. The purpose of this study was to describe and illustrate a novel technique for assessing PFJ motion in TKA using an imageless robotic platform.

**Methods**

*Ethics*

Data collection and analysis were carried out in accordance with the human ethics approval - Human Research Ethics Committee of Northern Sydney Local Health District HREC/17/HAWKE/140.

This was a consecutive case series of patients undergoing primary TKA using the CORI, Robotic System, manufactured by Smith and Nephew Robotic system and a cruciate retaining Legion II implant with an asymmetric patella button. Cases of post traumatic arthritis, grade
IV Iwano patellofemoral arthritis or cases utilising a posterior stabilised implant were excluded from the final analysis. The patella was resurfaced in all cases and all components were cemented. All TKA were performed using a functional alignment technique according to previously described implant and balancing boundaries [28, 29].

Data Acquisition

Anatomic data were acquired intraoperatively using an imageless robotic system (CORI; Smith and Nephew), which also allows verification of bone resections, extension and flexion gaps, ligament balance through an arc of 120° flexion and implant position. This system’s protocol and accuracy have previously been reported, and nominal accuracy of the system is 0.5°/mm[5].

A feature of the system allows the surgeon to capture anatomical points of their choosing. This system can be utilised to allow PFJ kinematics to be tracked and can provide a pre implant and post implant comparison.

Surgery

Positioning, Setup and Exposure

The patient is setup with an adjustable side support, a foot bolster with the knee flexed to 100° and a tourniquet is placed but not inflated. Having a side support that allows slight hip abduction and external rotation is critical to being able to achieve a correct hip centre of rotation (COR) without the patient’s pelvis moving during registration. The hip COR is collected kinematically, with a required accuracy to proceed.

All surgeries were performed using a medial parapatellar approach. Such an approach allows the femoral arrays to be placed within the incision and underneath the quadriceps muscle.

Prior to the arthrotomy being performed, a marking pen is used to mark the extensor mechanism at 45° to the superomedial border of the patella. This allows for accurate closure and tension to be placed in the capsule both for definitive closure but also will mark the location of the single stitch that is placed when patella tracking is assessed. Following performance of the arthrotomy, a standard soft tissue clearance is performed. Tibial and femoral check-point screws are installed onto the femur and tibia, and the hip centre of rotation as well as the malleoli positions are mapped by the surgeon.

Femur and Patella Registration

The femoral anatomy is fully mapped using a probe that measures the surfaces of the native anatomy. Following this, the ‘free point’ or ‘special point’ collection mode is utilised to define the position of the patella and the trochlea groove. The deepest point of the trochlea groove, frequently referred to as ‘Whiteside’s line’ is mapped first, allowing for assessment of trochlea depth pre and post implantation. The patella is reduced into the trochlea and a single stitch is placed into the capsule. Such a technique is similar to that previously described by Lewonowski et al[19].

Next, diathermy is used to etch a mark on the patella that will serve as the ‘constant’ point on the patella during movement. The surgeon prefers the most central location of the patella for this described technique. Once this point has been defined, the knee with the patella in the reduced position and with a single stitch in the capsule is taken through a range of 0° to 90° flexion. The knee flexion is performed with the assistant standing on the operators side (on the patients right side for a right knee) placing their hands underneath the thigh and flexing the
knee up. During this movement it is important to avoid any lateral movement of the knee. Also, flexing the knee by grasping the tibia may introduce error as this may create a false position that alters the position and vector of the patella tendon. The operator stands in the usual position and holds the probe in place and takes continuous measurements during this movement. Any error created by the probe losing position on the patella is visually obvious to the operator and the points are re-collected.

A map of the pathway of the patella is recorded and visually represented on the robotic software and be viewed in the coronal plane to obtain a representation of the patella pathway, so called ‘tracking’ and in the sagittal plane to view the patella offset. The stitch is then removed, and the surgeon continues by registering the tibia and completing the bony cuts and trialling of implants according to their preferences for this system. The patella points are later recollected using the same steps as described above, utilising the single stitch in the same marked location of the arthrotomy. Re-collecting the patella points once trial or definitive components have been placed creates a comparison to the native state, and so called ‘over’ or ‘under-stuffing’ through the full arc of flexion can be viewed (figure 1.) In this series, measurements were taken after implantation of the definitive components, however collection of the patella movement at the trialling stage can allow the surgeon to make adjustments such as altering polyethylene thickness, tibial rotation, implant constraint, soft tissue releases or bone re-cuts. (figure 2)

**Data Output**

**Intra-Operative Data**

By creating a map of the patella movement in two planes, patella tracking and over or under-stuffing can be evaluated by the surgeon. However owing to it’s relative infancy, the software does not currently provide numerical data to indicate the distances between the special points, ie. How much the patella may be over or under-stuffed by. To obtain this information still requires a post operative analysis.

**Post Operative Data**

Utilising the data points captured, a more detailed analysis of the PFJ is possible post operatively. All patella special points, both pre- and post-implantation, are recorded in a single text file without any divisions that separate the groups. The distances between each set of two consecutive points was calculated. When a significant jump occurs in the distance between two consecutive points, it indicates the transition from pre-implant points to post-implant points. This resulted in two distinct sets of points: one for pre-implant and one for post-implant.

For each set of patella points (pre- and post-implant), the position at full extension and 90° of flexion is recorded. Next, a plane was fitted to the point cloud using a 3D least squares plane fitting algorithm. The plane was defined by a point on the plane (in this case, the centroid of the points) and a normal vector perpendicular to the direction of the points. Once the plane was defined, the points were projected onto it. Using a linear least squares method [6] a circle was fitted to the points. The centre of this circle was considered the patella centre of rotation (PCOR), and the axis passing through this point in the direction of the plane’s normal vector represents the patella flexion axis relative to the femur trochlea (Figure 3). Such an axis has previously been described [14, 17] in the laboratory setting using cadaveric knees.

By comparing data between pre-op and post-implantation the radius of the circle, the centre of the PCOR, shift in planes and location of extension and flexion points of the trajectory can be visually presented and also analysed (figure 4).
Results
A total of 9 CR TKA’s underwent analysis. The pre-implant and post-implant patella tracking data are presented in Table 1. The patella rotation radius was increased in 5/9 cases. The change in the PCOR axis rotation demonstrated a heterogeneous alteration across the 9 cases. Similarly, the patella track was altered heterogeneously in all planes (anterior/posterior, superior/inferior and medial/lateral) across all cases.

Discussion
Intra-operative assessment of the PFJ in TKA has evolved little since first being described. Robotically-assisted TKA to date has focussed on the tibiofemoral joint. This paper describes a method for measuring the PFJ in TKA using an imageless based robotic system. The data obtained from this technique demonstrated a wide variety in the alteration of the patella track from the pre to post implantation state. This methodology may provide the basis for future research and development of software that allows the surgeons to more precisely measure the PFJ in TKA. Furthermore, this technique describes a method by which more objective data can be obtained and may allow for the concept of PFJ balancing to be precisely defined in the future.

Assessment of Patella Tracking
Intra-operative assessment of PFJ tracking in TKA has proven difficult and remains vague [7, 10]. The rule of no thumb [26] described in 1979 remains the predominant method of assessment for many surgeons in TKA. A similar method but with the addition of a single stitch to the medial arthrotomy and no medial force being applied to the patella was later described by Lewonowski et al [19]. This is similar to the described technique in this paper. However, measuring tracking has remained imprecise, with assessment intra-operatively being largely descriptive and terms such as dislocated, subluxed or tilted being used to describe tracking. Efforts to develop a more precise method of assessing patella tracking have been explored but have been hampered by practical considerations such as attaching bulky arrays [1] to the patella or inserting tracking pins or screws [20] which may interfere with patella button placement or lead to patella fracture. The current technique offers a relatively simple and efficient solution whilst allowing a more detailed assessment of patella tracking, with a pre and post implantation visual map being provided in real time for immediate feedback to the surgeon. Furthermore, with a post operative analysis, defining and measuring changes to the PCOR are possible and represent an advancement in assessing patella tracking, paving the way for future research in an area that remains poorly understood.

Assessment of Patellofemoral Joint Over and Understuffing
A common surgical goal in TKA involves restoring patellofemoral offset, or so-called patella over or under stuffing. PFJ overstuffing occurs as the amount of bone and cartilage resected is less than the thickness of the prosthesis (+/- the cement mantle if it is used) replacing it [24, 27]. Clinical studies that have attempted to assess PFJ over or under-stuffing have done so by way of radiographic measurements that choose a single location in the anterior compartment of the knee and anterior flange of the prosthesis [2, 7, 8, 18, 21, 24, 33]. Such measurements consider one location in the trochlea and radiographic measurements are taken with the knee in anywhere from 0° to 30° flexion and are post operative. Intra-operative assessment relies on caliper measurements of the femoral and patellar bone cuts [15, 16], but does not actually measure the trochlea groove. The technique described allows for a visual presentation to be provided to the surgeon to clearly demonstrate if the PFJ has been over or understuffed. Furthermore, this data provides information regarding an arc of flexion of 90° rather than only considering one location on the trochlea for example. By assessing the restoration of the depth
of the trochlea groove after implantation of trial components, this method allows the surgeon to make adjustments to the thickness of the patella resection to more precisely restore the patellofemoral offset.

Patellofemoral over-stuffing has focussed on the ‘anterior compartment’ or avoiding anteriorising the trochlea or patella [3, 22, 30]. Previously it has been observed that knee flexion decreases an average 1.2° with each additional 2 mm of patellar thickness [4] and passive knee flexion decreases 3 degrees for every 2-mm increment of patellar thickness. Despite clear rationale and cadaveric evidence to support the dogma of avoiding ‘over-stuffing’ the PFJ, the clinical effects have not been so clear. By being able to visualise the change in depth of the native trochlea relative to the prosthesis through the entire arc of flexion, this technique will allow the clinical effects of changing trochlea depth and PFJ overstuffing throughout its full arc of flexion to be more thoroughly investigated.

Patella Plane
The concept of a patella flexion axis is not novel. The pioneering work of Hollister et al. [14] defined an axis of rotation about which the patella flexed. This concept was later explored and defined in more detail by Iranpour et al.[17] who defined a trochlear axis as the circular path around which the patella moved. However, such measurements have been limited to cadaveric testing laboratories, with no tools being made readily available to surgeons to use in clinical practice. This technique demonstrates that a visual representation of the trochlea axis is possible with robotic-assistance and can provide the surgeon with important data to illustrate if they have recreated the native trochlea axis. Due to its relative infancy, visual representation of the trochlea axis remain retrospective and can only occur after the case has been completed, meaning it is currently not available in a ‘live’ feedback form. Such a function will no doubt serve as a future avenue for technological advancements in this area.

Patellofemoral Balancing in Total Knee Arthroplasty
A common surgical goal in TKA is to produce a knee that is considered ‘balanced. Historically the patella was said to be balanced if did not tilt, subluxe, or dislocate during flexion[26]. The exact definition of what defines a balanced knee however remains controversial but is underpinned by the premise that the surrounding soft tissue of the knee should not be excessively altered from their native state[32]. Too tight, and stiffness, rapid component wear or loosening may occur and too loose, instability or in the case of the extensor mechanism, loss of efficiency of the quadriceps muscle may ensue[23]. Balancing the patellofemoral joint PFJ in TKA involves ensuring the pathway the patella will follow has not be excessively altered, but also requires recreation of patella offset to ensure the extensor mechanism length has not been excessively altered. Such a term is referred to ‘over’ or ‘under-stuffing’. Balancing the PFJ in TKA has been poorly defined with little advancements being made since it was first described in 1979. The current technique allows for more precise collection of data regarding the dynamic behaviour of the PFJ both pre and post implantation. Such information will allow the concept of PFJ balancing to be explored, and it’s relevance to outcomes understood in the future.

Typically, the assessment of PFJ over or under-stuffing has focussed on the anterior compartment of the knee, which corresponds to the anterior flange of the prosthesis and a patella position of full extension. The trochlea in the sagittal plane is a circular arc, and the
PFJ’s main function occurs during flexion. Assessment of PFJ over or understuffing that uses the anterior compartment may not reliably reflect restoration of the trochlea depth in flexion. The current technique allows for the surgeon to make adjustments to more precisely restore patellofemoral offset. Over-stuffing is thought to lead to lengthening of the extensor mechanism and has been proposed as a cause of knee stiffness, pain with deep flexion, the subjective feeling of tightness or a ‘vice like’ sensation and increased PFJ contact forces post TKA. Conversely, ‘under-stuffing’ may also cause extensor mechanism dysfunction. The current technique allows for a dynamic evaluation of the PFJ throughout an arc of 90° flexion, and can be used to manipulate the thickness of the patella resection in order to more precisely restore the PFJ offset.

Limitations
This is a descriptive study and is yet to be validated. However, the purpose of this paper is to explore the utility of robotic tools in addressing the PFJ in TKA. Measurement accuracy was not tested. Furthermore, no clinical outcomes were reported in this study, and the relevance of patella tracking to patient outcomes following TKA remains unclear[7]. Furthermore, measurements such as PCOR still require detailed data extraction and are not available in real time intra-operatively to the surgeon. Such a feature will no doubt serve the basis for future technological advancements.

Conclusion
Intra-operative assessment of the PFJ in TKA is challenging. Robotic tools have been developed to improve measurement, accuracy of delivery and outcomes of in TKA. This paper describes a novel use of a robotic tool to assist surgeons with the PFJ in TKA. Robotically assisted tracking of the PFJ appears possible. With the assistance of robotic tools understanding of PFJ tracking and balancing in TKA may be advanced, and its clinical relevance understood.

References:


Shatrov J, Battelier C, Sappey-Marinier E, Gunst S, Servien E, Lustig S (2022) Functional Alignment Philosophy in Total Knee Arthroplasty - Rationale and technique for the varus morphotype using a CT based robotic platform and individualized planning. SICOT J 8:11


Table 1. Trochlea axis change
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<th>Implant Type</th>
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ML: (+) Lateral, (-) Medial, AP: (+) Anterior, (-) Posterior SI: (+) Superior, (-) Inferior

Figure 1. Collection of Patella Special Points allows mapping of the patella throughout an arc of flexion

Figure 2. Adjustment of the Implant Positioning with Consideration of both the Tibiofemoral Compartments and Patella Tracking
Figure 3. Extraction of the patella tracking information using Special Points
Figure 4. Comparison between pre-implant (orange) and post-implant (blue) tracking data
Patella Centre of Rotation Pre and Post Implantation

A. Pre-implant

B. Post-implant

Robotically assisted patellofemoral joint balancing
Creation of the Patella Centre of Rotation using Special Points
A. Native

B. Native and implanted
Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Jobe Shatrov reports statistical analysis was provided by Smith and Nephew Inc. Jobe Shatrov reports a relationship with Smith and Nephew Inc that includes: board membership, consulting or advisory, and speaking and lecture fees. David Parker reports a relationship with Smith and Nephew Inc that includes: consulting or advisory, funding grants, and speaking and lecture fees. Tim Lording reports a relationship with Smith and Nephew that includes: consulting or advisory and speaking and lecture fees. Paul Monk reports a relationship with Smith and Nephew Inc that includes: consulting or advisory. Sebastien Lustig reports a relationship with Smith and Nephew Inc that includes: consulting or advisory. Milad Khasian reports a relationship with Smith and Nephew Inc that includes: employment. Jobe Shatrov: Consultancy: Smith and Nephew Board membership: Asia Pacific Advisory Committee (Smith and Nephew) Paid Presentations: Stryker, Smith and Nephew

Sébastien Lustig: Royalties: Stryker, Smith Nephew, Serf Consultancy: Stryker, Heraeus, Viatris, Serf Editorial Board: JBJS (Deputy Editor), SICOT J (Chief Editor), JISAKOS (associate editor, special issue on innovation and technology)

Tim Lording: Consultancy: smith and Nephew, Medacta Paid Presentations: Smith and Nephew, Arthrex

Paul Monk: Consultancy: Zimmer Biomet, Smith and Nephew

David Parker: Editorial Board member: JISAKOS, OJSM, AJSM, AP-SMART Journal Held shares: Personalised surgery, Ganymed Robotics Paid presentations: Smith and Nephew, Arthrex Institutional support: Smith and Nephew, Zimmer Biomet, Corin

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