



## Surgical technique

## Use of Fulcrum Positioning as a Balancing Tool During Total Knee Arthroplasty on a Robotic Platform

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## ABSTRACT

Total knee arthroplasty is a common procedure performed to improve pain and dysfunction attributed to arthritis, yet postoperative patient dissatisfaction rates remain relatively high. Patient satisfaction and outcomes have been linked to successful joint gap balancing in the coronal and sagittal planes intraoperatively. In previously described balancing techniques, the fulcrum used for alignment changes is customarily centered on the intramedullary axis generating symmetric changes in medial and lateral gaps. We propose a novel technique in the literature that, with the use of robotic-arm assisted technology or similar systems, allows manipulation of the fulcrum center of rotation during pre-resection planning and intraoperative gap establishment before bony cuts to asymmetrically influence medial and lateral, flexion and extension gaps to aid in balancing during total knee arthroplasty.

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## Introduction

Total knee arthroplasty (TKA) is one of the most common orthopedic procedures performed to improve pain and function as a result of arthritis [1,2] with a documented survivorship of 82% at 25 years [3]. Utilization of TKA is projected to grow 85% from 2015 to 2030 [4].

Patient-reported outcome measures are variable after TKA with studies demonstrating good-to-excellent satisfaction in 85% of patients at 6 months and only 84% of patients at 12 months [5,6]. Patient satisfaction and outcomes have been linked to successful balancing in the coronal and sagittal planes intraoperatively [7].

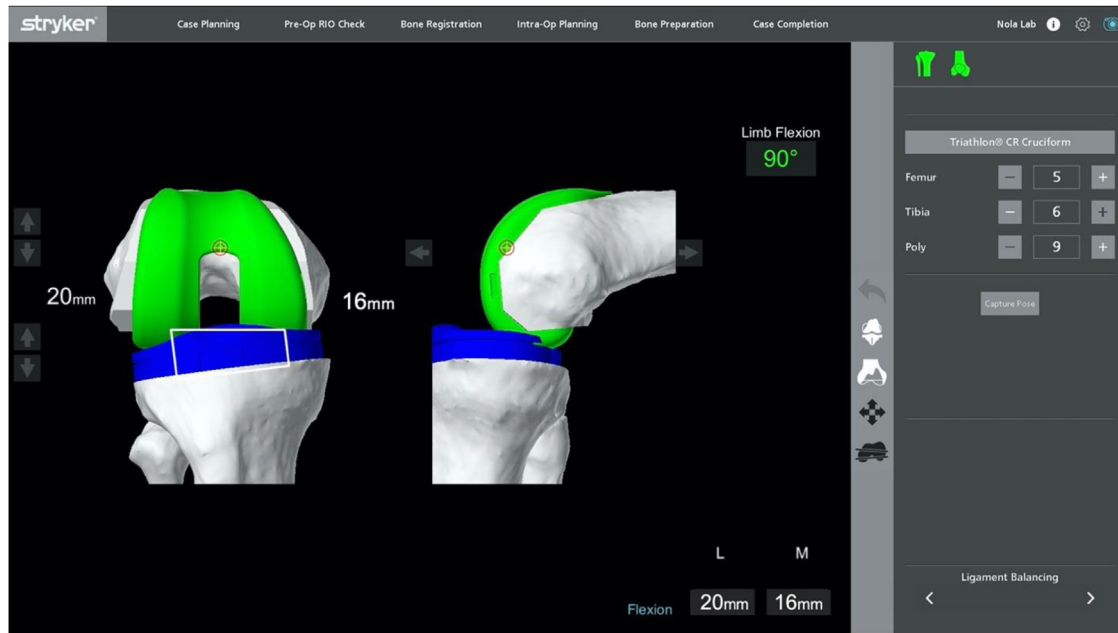
In an attempt to reconcile the influence of knee imbalance on postoperative TKA dissatisfaction, newer methodical approaches have been developed to replace surgeon subjective judgment on intraoperative tissue balancing [8]. Measured resection technique relies on bony landmarks for component positioning and adapts soft tissue to the implant placement. In this technique, bony cuts are made before soft tissue tensioning, which may introduce laxity and asymmetry within the joint that is addressed with ligament

and soft tissue release to achieve balancing. In comparison, the gap balancing technique involves bony cuts after soft tissue tensioning. The surgeon can obtain near-equal medial and lateral gaps in this technique by applying tension to the joint in extension and flexion; however, the patella is subluxed in the tensioning process, offering potential for a wrong size or misbalanced gap and thus externally rotated femur [9,10]. Too much external rotation of a femoral component, especially in a valgus knee with hypoplasia, may alter patellofemoral kinematics as well, resulting in patella maltracking [11,12]. Conversely, kinematic alignment considers 3D visualization of the knee components to restore alignment to a prearthritic state, sparing the release of collateral ligaments [6]. Multiple studies have compared the functional outcomes of these various techniques, with a lack of consensus on technique superiority [13–15].

While the discovery and implementation of these techniques generated great improvement in TKA outcomes, the fulcrum used for these coronal and sagittal alignment changes is customarily centered on the intramedullary axis thus generating symmetric gap changes during balancing. Here we describe a novel technique in the literature that, with the use of robotic-arm assisted technology or similar systems, allows manipulation of the fulcrum center of rotation during pre-resection planning and during intraoperative establishment of gaps before bony cuts to asymmetrically influence medial and lateral, flexion and extension gaps to most precisely balance knees during arthroplasty.

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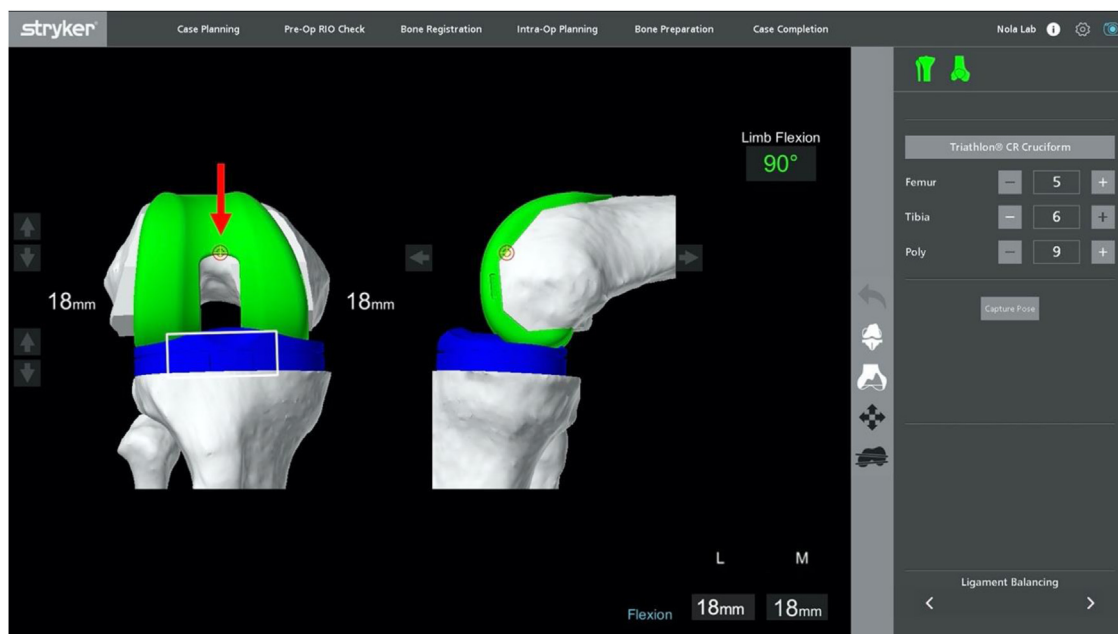
**Figure 1.** At 90° of flexion, this particular patient had a 4-mm mismatch between lateral (20 mm) and medial (16 mm) flexion gaps.

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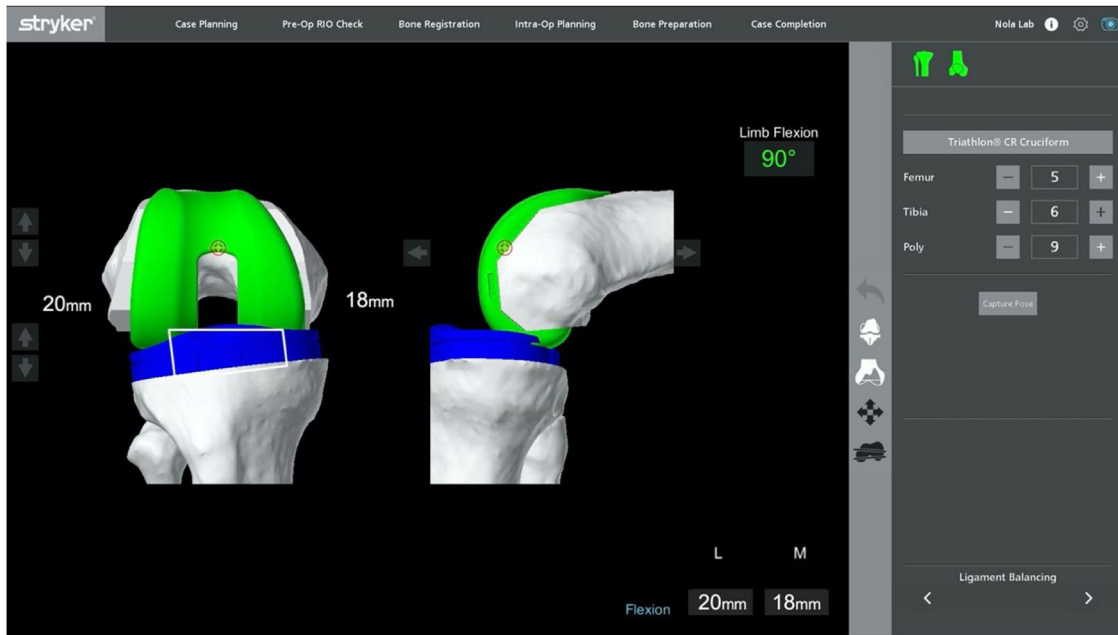
A common intraoperative finding while performing TKA in a varus knee is a tight medial flexion gap with undesired laxity of the lateral flexion gap. One method to address these discrepancies concurrently is to add external rotation to the femoral component during pre-resection planning. If the center of rotation is in the center of the femur, defined as the midpoint between the lateral-most portion of the lateral femoral condyle and the medial-most portion of the medial femoral condyle [16], additional external rotation would produce an increase in the medial flexion gap that is

numerically equivalent to a decrease in the lateral flexion gap (Fig. 1). A 1° change in coronal alignment of the distal femur or proximal tibia results in a 1-mm difference in the gap on each side of the fulcrum. In this situation shown here, the minimum thickness of the implant (femoral component plus tibial tray with minimum polyethylene thickness) is 18 mm such that the surgeon would want to not only decrease the lateral gap but also increase the medial gap, and thus the fulcrum is best positioned in the center of the knee (Fig. 2).

There are times, however, when the medial flexion gap is already balanced, and the lateral flexion gap remains larger than



**Figure 2.** In this instance, the center point of the femur (red arrow) would be used as the fulcrum such that with external rotation, the lateral compartment would decrease at the same rate the medial compartment would increase (2 mm) resulting in equal gaps (18 mm bilaterally).



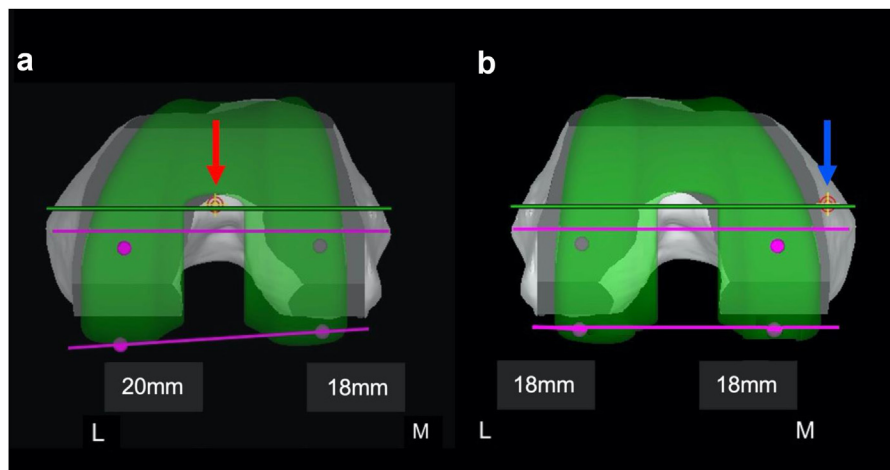
**Figure 3.** At 90° of flexion, this particular patient had a 2-mm mismatch between lateral (20 mm) and medial (18 mm) flexion gaps.

desired (Fig. 3). In this instance, external rotation of the femur during pre-resection planning would not achieve the surgeon’s goal if the center of rotation of the change was in the center of the knee (Fig. 4a). In this situation, we propose a simple method moving the fulcrum to the medial-most portion of the femoral condyle, such that the medial gap is less affected (Fig. 4b). The medialization of the fulcrum allows symmetric closure of the lateral flexion gap which, along with soft-tissue balancing, yields symmetric flexion gaps.

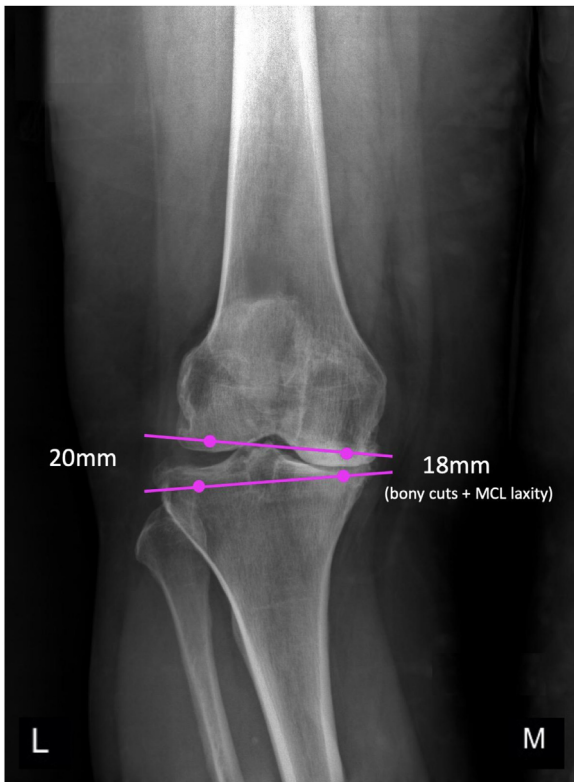
This same principle can be applied to the proximal tibia when the medial gap is tight both in flexion and in extension, as commonly seen in fixed varus deformities, by allowing additional varus during pre-resection planning and during intraoperative establishment of gaps before bony cuts. The joint surface in a normal proximal tibia is typically 3° of varus with respect to the anatomic axis of the tibia. Therefore, surgeons commonly allow the

proximal tibia to be cut in 1–2° of varus during gap balancing of a fixed varus knee deformity, as constitutional varus has been shown to be effective in this situation [6].

A preoperative radiograph along with physical examination may help guide surgical planning, as demonstrated in Figure 5 by a knee with a correctable varus deformity on examination with increased laxity of the lateral compartment in extension and flexion. In this case, the surgeon can intraoperatively use the robotic platform to move the fulcrum to the most medial side of the knee to asymmetrically influence the lateral gap more than the already balanced medial gap. If this were a fixed deformity with a tight medial gap and loose lateral gap in flexion and extension, the fulcrum would be left in the center of the knee to address both gaps equally with the addition of varus. The end result would be a medially and laterally balanced knee, confirmed with a post-operative radiograph (Fig. 6).



**Figure 4.** In this instance, if the center point of the femur is used as the fulcrum (a, red arrow) to balance the lateral flexion gap (20 mm to 18 mm), the medial gap becomes larger than desired (18 mm to 20 mm). Whereas if the most medial portion of the femur is used as the fulcrum (b, blue arrow), the medial flexion gap is relatively unchanged (18 mm), and the lateral flexion gap is asymmetrically influenced (20 mm to 18 mm) producing a balanced flexion gap (18 mm bilaterally).



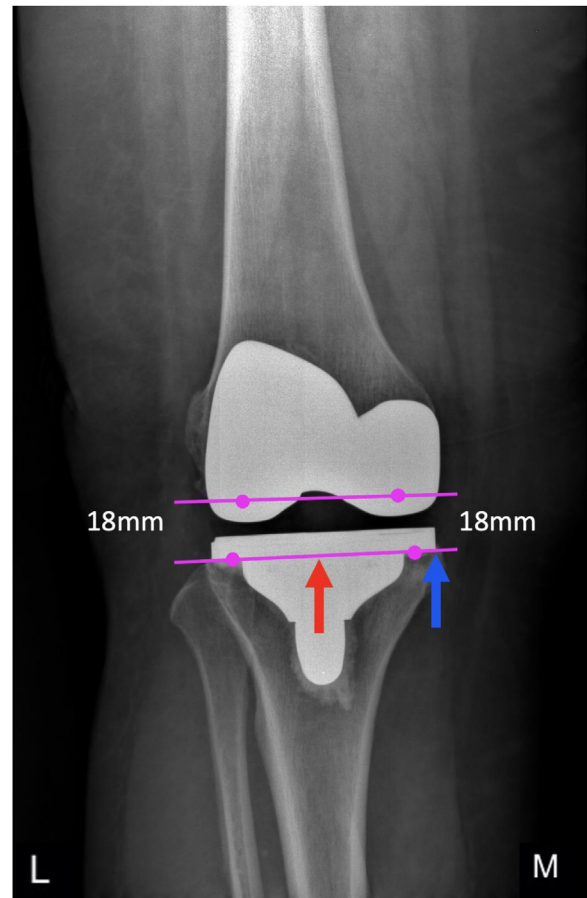
**Figure 5.** Preoperative standing anteroposterior radiograph demonstrating a knee with a correctable varus deformity on physical examination with increased laxity of the lateral compartment in extension and flexion, so the fulcrum should be placed on the most medial portion of the tibial plateau when introducing  $1^\circ$  of varus to decrease the lateral gap.

## Discussion

Advancements have been made in knee arthroplasty technology over the past few decades, yet the overall patient dissatisfaction after TKA remains relatively high at 19% [17]. This technique article demonstrates that TKA performed with a robotic-arm can be fine-tuned to enhance joint stability by altering the center of rotation on the femur or tibia to allow independent adjustments of medial and lateral flexion gaps. The end result of a medially and laterally balanced knee after TKA would improve postoperative patient satisfaction.

MAKO robotic arm–assisted surgery has demonstrated some advantages over conventional instrumentation, particularly in a reduction of soft tissue damage from the haptically bounded saw blade [18]. Early data have also demonstrated an improved accuracy of component placement and limb alignment compared with conventional techniques [19], although long-term data on survivorship have not yet been established.

As these robotic systems are progressively incorporated into more surgical centers, it is critical that surgeons work to fine-tune the suggested surgical algorithms to address lingering patient dissatisfaction with knee stability after TKA. Soft tissue imbalance leads to instability, as well as stiffness, and is a leading contributor to early revision surgery [20]. Gustke et al. found that at 1-year follow-up, patients with quantitatively balanced knees scored more favorably on knee outcome and osteoarthritic indices and reported higher average activity levels than their unbalanced counterparts [21]. In deciphering confounding variables, a balanced articulation contributed most significantly to postoperative outcomes [21]. Golladay et al. similarly reported that a quantitatively



**Figure 6.** Postoperative standing anteroposterior radiograph demonstrating a successful TKA with balanced medial and lateral extension gaps. The red arrow indicates where a conventional fulcrum center of rotation would be placed, while the blue arrow indicates a medialized fulcrum center of rotation. In this particular case, a medialized fulcrum was favorable to allow asymmetric influence of medial and lateral gaps.

balanced knee resulted in significantly higher Knee Society Score satisfaction, most influenced by the surgeon and occurrence of an adverse event, rather than by patient age, gender, body mass index, or randomly assigned balancing technique (sensor-guided or surgeon-guided) [22].

It is important to note that numerical joint gap values may or may not correlate in full with compartment loads or the behavior of the knee [23]. In addition, we limited our discussion to asymmetrical balancing of varus knees because similar rotational adjustments were made to a valgus knee. We have therefore endeavored to describe a mobile fulcrum technique that offers independent manipulation of medial and lateral flexion and extension gaps to help achieve optimal joint stability after TKA with the use of a robotic platform.

## Summary

Here we present a novel method to further fine-tune intraoperative knee balancing that can be applied to any system that allows the movement of the fulcrum intraoperatively while balancing from the center of the knee to the most medial and lateral points. This knowledge can also be used to mitigate limb lengthening on severely imbalanced knees due to large deformities.

## Conflicts of interest

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 article.

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