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Review article

Intraoperative load-sensing drives the level of constraint in primary total knee arthroplasty: Surgical technique and review of the literature

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ABSTRACT

Total knee arthroplasty is a traditional surgical procedure aimed to restore function and relief pain in patients with severe knee osteoarthritis. Recently, many medial pivot knee systems were deigned to replicate the normal knee kinematic: a highly congruent medial compartment and a less conforming lateral tibial plateau characterize these devices. A slightly asymmetric soft tissue balancing is mandatory using medial pivot designs to obtain a correct and physiological knee biomechanics leading good outcomes and long survival rates. This article describes a new surgical technique using a modern third generation TKA design combined with wireless load–sensor tibial trials to improve the correct knee load balancing with a minimal conformity of the polyethylene insert. The use of wireless load–sensing tibial trials has several benefits: it is an intraoperative, objective and dynamic tool allowing surgeons to optimize in real time soft tissue balancing. The meaning of a "truly balanced knee" is still a controversial issue in the current literature.

1. Introduction

Soft tissue imbalance in total knee arthroplasty (TKA) has been estimated to cause up to 35% of early TKA revisions in the United States.[1] Soft tissue balancing, however, remains entirely subjective and extremely operator dependent. Historically, two surgical techniques have been utilized by surgeons to create the "perfectly balanced" TKA: a "measured resection technique" and a "gap balancing technique."

In the measured resection technique, the femoral component is rotated parallel to the surgical trans-epicondylar axis of the femur.[2] In contrast, the determination of rotation using the gap balancing technique relies on the tension of the medial and lateral soft tissue sleeves with the knee at 90° of flexion.[3] Independent of either technique used to determine proper femoral component rotation, manual stress testing, laminar spreaders, spacer blocks, and tensiometers are all used to assess intra-operative symmetry of the extension and flexion gaps.[4] However, despite these tools, balancing the knee remains an inexact art with no standardized protocol to optimize tissue tension in TKA. The reason for this is bifactorial: it is extremely operator dependent and the relationship between soft tissue balance with regard to tibiofemoral contact stress during physiologic range of motion (ROM) remains unclear. Recent reports, including those from the author's institution, have shown that the use of modern, third-generation TKA designs and instrumentation did not improve satisfaction rates in the TKA patient population.[5,6] Given this, studies show that using the minimum level of constraint to maintain stability has been related to a higher survivorship and patient satisfaction.[7] Many surgeons, however, fearing mid-flexion instability as a cause for early revision,[8] tend to over-constrain the knee resulting in loss of active ROM, point loading on the polyethylene insert, premature insert wear, and inferior implant survivorship.[9] A more quantitative, and therefore more standardized, method of intra-operative detection of global soft tissue balancing and proper component alignment may help surgeons to optimize function and increase survivorship of TKA. Recently, intraoperative sensing technology (VERASENSE, Orthosensor, Dania, FL) (Fig. 1) has been presented as a way to give dynamic, real-time feedback regarding tibio-femoral position and quantitative pressure at peak contact points in the medial and lateral compartments during TKA trialing and final implant positioning. Using this sensor-derived data, the surgeon can intra-operatively track and evaluate inter-compartmental loading pressures during ROM and correct soft-tissue imbalance in real time. Using recently published literature measuring patient outcomes against sensor-derived data and existing biomechanical studies describing normal physiologic tibiofemoral loading in the native knee,[10] there is now an objective means by which the operator can assess soft tissue balance in TKA.

The purpose of this technical note is to review the current literature on the use of intraoperative digital sensor technology and to propose a surgical technique, which might help surgeons in choosing the ideal level of polyethylene constraint in their primary TKAs.

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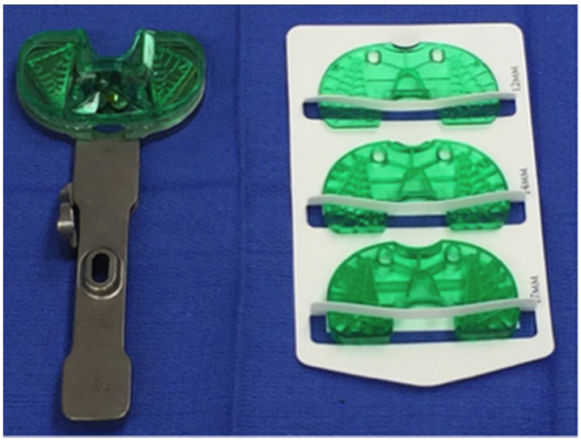

Fig. 1. VERASENSE, Orthosensor, Dania, FL, USA. Four different thickness are available (10 mm, 12 mm, 14 mm, 17 mm) for TKA intraoperative load sensing testing.

1.1. Literature review

The use of a radiofrequency-based electronic load sensor for soft tissue balancing in primary TKA was first proposed by Gustke et al.[11] in a multicenter study in 2014. The authors reported on 176 knees that received a PCL retaining or sacrificing Triathlon Knee System (Stryker, Mahwah, NJ) using the VERSASENSE sensor. Once the appropriate tibial size insert was determined with the trial components in place, the corresponding VERASENSE sensor was activated and implanted. Data was recorded with the knee in full-extension, mid-flexion and at 90° of flexion. All patients were evaluated 6 months postoperatively using two patient-reported outcomes measurement systems (PROMs): the American Knee Society Score (KSS)[12] and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).[13] These authors demonstrated that balanced knees (87%/176), with an intraoperative mediolateral intercompartmental loading difference of ≤15 lbs measured with the sensor through ROM, showed greater improvements in KSS and WOMAC scores than in unbalanced knees (13%/176). It is important to note that this study had several limitations, including the lack of a control group, a significantly smaller "unbalanced" group with respect to the "balanced" group, eight different operating surgeons resulting in a lack of a homogeneous surgical technique, and the use of different levels of TKA constraint (PCL retaining versus PCL substituting).

Schnaser et al.[14] reviewed the influence of the position of the patella on the sensor detected load distribution at the tibio-femoral compartment during gap assessment. The authors evaluated 57 patients (60 knees) who underwent primary posterior-stabilized (PS) TKA utilizing the Triathlon Knee System (Stryker, Mahwah, NJ). Intraoperatively, once the knee was considered well balanced with the trial components in, the sensor device was inserted and medial and lateral compartments loads were obtained during gravity assisted full extension, 45° of flexion, 90° of flexion, and gravity-assisted full flexion. Measurements were recorded with the patella relocated in the femoral groove with the medial retinaculum both open and closed, with the patella lateralized but not everted, and with the patella lateralized and everted. The authors of this study demonstrated that the dislocation of the patella, with and without eversion, alters the load distribution during sensor testing on the medial and lateral compartment of the knee. Mean loads registered in the medial compartment with the patella relocated in the femoral groove were 30 lbs in full extension, 17 lbs at 45°, and 15 lbs at 90°; the mean loads registered in the lateral compartment were 26 lbs in full extension, 21 lbs at 45°, and 16 lb at 90°. Of note, the medial and lateral compartments were found to exhibit a significantly different load pattern during ROM. A progressive shift of load from the medial to the lateral compartment was detected with progressive knee flexion regardless of the patellar position. This last finding contrasts with the physiologic greater lateral laxity and postero-lateral rollback of the knee during flexion demonstrated by many radiological and fluoroscopic studies.[15,16]

Meere et al.[17] conducted a multi-surgeon blinded cadaveric study to investigate differences in gapping of the medial and lateral compartments and to evaluate the medial and lateral compartment compressive forces through ROM using the same load-sensing technology while performing a PCL retaining TKA. This study showed significantly reduced medial, lateral, and total mediolateral gapping in sensor assisted TKA. Additionally, TKA performed without load-sensing technology resulted in greater lateral compartment compressive force in comparison to those performed with the sensor, which had greater medial compartment forces as the knee was flexed. Having slightly greater compressive forces in the medial compartment with greater lateral laxity during active ROM might reproduce the medial pivot and lateral femoral rollback characteristic of the normal knee.[18] The "in vitro" results by Meere et al. reflect the "clinical" results reported by Liebs et al.[19] in a study demonstrating that patients with a larger lateral extension gap in their replaced knee had significantly better WOMAC pain scores than patients with an increased medial gap. In another study, Meere et al.[20] demonstrated that using wireless load-sensing tibial components allows surgeons to reproduce the normal[21] medial-to-lateral force ratio when using PCL-retaining TKA implants via progressive, stepwise, surgical soft-tissue and bone corrections.

Recently, Meneghini et al.[22] reviewed 189 consecutive TKAs (cruciate-retaining, posterior-stabilized, and high congruent) at a minimum of 4 months from surgery. All knees were intra-operatively balanced using tibial insert sensor trials (VERASENSE, Orthosensor, Dania, FL). The authors recorded intraoperative compartment forces and related those to the PROMs obtained at 4 months from surgery. This paper confirmed that mean medial compartment forces (70.7 lbs) were higher than mean lateral compartment forces (44.0 lbs) during trial sensor testing at 0°, 45° and 90° of flexion. Surprisingly, the authors demonstrated that PROM outcomes were unrelated to mediolateral balance of the knee as determined by medial and lateral compartment pressures.

1.2. Surgical technique for primary TKA using load sensors

At the author's institution, we routinely use the Persona (Zimmer Biomet, Warsaw, USA) total knee system to treat advanced knee osteoarthritis. The proposed surgical technique, further described below, was implemented by the author beginning in 2015. It is targeted for patients with a mild, moderate, or severe varus alignment often requiring some amount of medial release. This TKA system has an extreme modularity allowing for an intraoperative shift between different levels of constraint: two femoral designs (PS – posterior stabilized and CR – cruciate retaining), one anatomic tibial baseplate, and four different polyethylene inserts (PS, CR, UC-Ultra Congruent and MC-Medially Congruent) are routinely available. The current authors advocate that the contemporary use of a modern and extremely modular total knee system, combined with a wireless load sensing device, provides a customized knee implant allowing for reduction in the level of constraint.

At the author's institution, prior to TKA, all knees undergo standard antero-posterior, lateral, Merchant et al.[23], and long leg alignment radiographic evaluation in order to detect the degree of deformity, bone loss, and the overall alignment. Intraoperatively, a median parapatellar approach is routinely used. Standard bone cuts are made using traditional instrumentation for the Persona knee system, including an extramedullary tibial jig for the tibial cut and intramedullary instrumentation for the distal femoral cut. The chosen surgical technique is a combination of the "balanced gaps technique"[24] and the "measured resection technique."[25] First, a rectangular extension gap is created and checked using standard blocks. Then, the femoral sizing guide is oriented on the axial plane according to the surgical trans-epicondylar (sTEA) axis. Particular attention is paid to avoid excessive external rotation of the femoral component to prevent opening of the medial compartment in flexion. As such, 3° of external rotation of the femoral component is routinely, but not always, used in the varus knee. All implants are tentatively aligned in the coronal plane reproducing patient's

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