Level of constraint in revision knee arthroplasty

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Abstract Revision total knee arthroplasty (TKA) in the setting of major bone deficiency and/or soft tissue laxity might require increasing levels of constraint to restore knee stability. However, increasing the level of constraint not always correlates with mid-to-long-term satisfactory results. Recently, modular components as tantalum cones and titanium sleeves have been introduced to the market with the goal of obtaining better fixation where bone deficiency is an issue; theoretically, satisfactory meta-diaphyseal fixation can reduce the mechanical stress at the level of the joint line, reducing the need for high levels of constraint. This article reviews the recent literature on the surgical management of the unstable TKA with the goal to propose a modern surgical algorithm for adult reconstruction surgeons.

Keywords Total knee arthroplasty · Knee instability · Knee reconstruction · Flexion/extension balance

Introduction

The increasing number of patients undergoing primary total knee arthroplasty (TKA) (720,000 in the USA during 2010) has been accompanied by a similar increase in the number of revisions (70,000 in the USA during 2011). If common modes of early TKA failure are, in near equal numbers, infection and instability, instability alone is the leading cause (10 to 22 %) of late revision TKAs [1•].

Well-recognized causes of early instability after TKA include mismatch between the flexion/extension gaps, improper coronal and rotational component alignment, and intraoperative loss of ligamentous integrity. On the other hand, late instability is usually linked to loss of fixation with concomitant moderate-to-severe bone loss and polyethylene wear. Since the ultimate goal of revision arthroplasty is anatomical and functional restoration of the knee joint, the concomitant presence of bone loss and soft tissue laxity might reduce the chances of final optimal outcome. During revision TKA, increasing levels of prosthetic constraint may be required to maintain stability of the knee joint.

This review article analyzes recent reports comparing the functional outcomes of posterior stabilized, unlinked constrained, or fully constrained prosthetic design options in the management of bone loss and instability in revision TKA.

Evaluation

Instability following TKA can be defined as abnormal and excessive displacement of a knee prosthesis accompanied by clinical failure [2]: it describes a symptom rather than a diagnosis. Connective tissues diseases, rheumatoid arthritis, and severe osteoporosis are risk factors for postoperative instability. Correction procedure for severe varus, valgus, and flexion

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contracture deformities are also related to postoperative instability [3]. Obesity has also been related to increased risk of postoperative instability because collateral ligament injuries tend to occur due to the difficulty of surgical exposure.

The etiology of primary TKA failure should be determined in the preoperative phase: unfortunately, it is often difficult to establish the correct diagnosis in the usual patient setting of diffuse knee pain and generalized instability.

A thorough history and physical examination of the knee is mandatory in detecting the etiology of TKA instability. Medical history taking should start from evaluation of the original procedure films focusing on the degree of the deformity, surgical techniques, type of implant used, and history of trauma following primary TKA. The most common patient-reported symptoms associated with instability include pain ascending and descending stairs, recurrent effusions, and tenderness over the pes anserine bursa. However, an effusion, hemarthrosis, and recurrent synovitis are not specific to any single type of instability. Instability can be suspected analyzing patients gait: stiff-legged gait, hyperextension of the knee during stance phase to “lock” the knee joint, varus or valgus thrust gait, and excessive lower limb external rotation during walking are all suspicious [4]. Isolated flexion instability and extensor mechanism maltracking limit patients’ ability in climbing up and down stairs.

Physical examination should include varus valgus stress test of the collateral ligaments in extension, at 30° of flexion, and at 90° of flexion. An anterior drawer test at 90° of flexion evaluates the antero-posterior stability of the implant. On the other side, a positive sag sign indicates posterior cruciate ligament (PCL) insufficiency in a cruciate-retaining (CR) design. Excessive or recently increased flexion may also indicate PCL incompetence. Mid-flexion instability can be highlighted by stability in full extension and at 90° of flexion and instability in the 30–60° flexion arc [5]. Rarely, genu recurvatum may be a clear cause of instability: collagen-related pathologies or neurologic impairment should be ruled out in the differential diagnosis algorithm.

Radiographic and laboratory evaluation

Patients describing knee instability require a deep radiographic and laboratory evaluation to confirm the diagnosis. Standard antero-posterior and lateral weight-bearing knee radiographs, “patella view” according to Merchant, and a weight-bearing pangenogram are all mandatory to rule out prosthetic loosening, malalignment, and periprosthetic osteolytic lesions. Varus valgus stress views allow assessment of the degree of ligament laxity, providing a more objective indicator of the presence of medial or lateral instability. Because few studies related a poor functional outcome to rotational malalignment of the femoral and tibial components, a computed tomography scan is often helpful to evaluate rotational

alignment of the femoral and tibial components: components mal-rotation might lead to asymmetric flexion space or patellar instability [6]. Nuclear imaging tests are also useful to rule out mechanical loosening of the prosthesis, not always detectable by standard tests.

A periprosthetic joint infection (PJI) algorithm should be always followed to rule out infection: laboratory tests including C-reactive protein and erythrocyte sedimentation rate and analysis of the synovial fluid, including arthrocentesis with cell count, culture, and sensitivity, have been suggested by many authors, including the authors of the current review [7]. Recently, Aggarwal et al. [8] introduced a new leukocyte esterase test that allows for easy detection of infection using joint fluid with high sensitivity and specificity.

Instability classification and management strategies

Prevention is the best treatment with regard to instability following primary TKA: appropriate primary implant selection and good surgical technique might prevent instability in most cases. Instability following primary TKA is generally described based on the evocative position in which it is experienced by the patient (flexion or extension instability).

In revision TKA, it is mandatory to identify the cause of TKA failure and address the specific problems with appropriate treatment options. Component loosening, bone loss, prosthetic breakage, improper component positioning, periprosthetic fracture, wear, and ligament laxity might be all involved at different levels.

Although the reason for an unstable TKA may be multifactorial, six main categories of TKA instability have been described at our institution [9•]:

1. Flexion/extension gap mismatch
2. Component malposition
3. Isolated ligament insufficiency
4. Extensor mechanism insufficiency
5. Component loosening
6. Global instability

Flexion/extension gap mismatch

Gap mismatch must be thoroughly evaluated and confirmed preoperatively and intraoperatively before removal of the components with the patient under anesthesia. Isolated extension instability arises from a poor extension gap balancing: the main cause is excessive distal femoral resection that was not originally managed with a large polyethylene insert. Azzam et al. [10] showed that the use of femoral augments facilitates proper positioning of the revision components and restoration of flexion and extension symmetry as well as restoring the

joint line properly. On the other side, excessive tibial resection increases both the extension and flexion gaps equally: in his case, the use of a thicker polyethylene insert may fill the gaps, but this may also lead to patellar impingement.

Another reason for extension instability following primary TKA is an excessive intraoperative medial or lateral soft tissue release leading to varus valgus instability in extension: this scenario can be treated increasing the level of implant constraint (revision to a PS prosthesis or to a semi-constrained implant). The level of constraint in this setting is usually chosen on the degree of soft tissue laxity: Azzam et al. [10] do not recommend anymore any soft tissue reconstruction, like a collateral ligament repair or soft tissue advancement, because of a high failure rate.

Flexion instability occurs when the flexion gap is significantly larger than the extension gap. There are many reasons for a pure flexion gap instability: excessive resection of the posterior femoral condyles, a small femoral component on the AP plane, an insufficient distal femoral resection with an appropriate posterior femoral resection combined with an adjusted tibial cut to create a normal extension gap, and a progressive attenuation of the PCL in a CR prosthesis. At the time of the revision, an intraoperative anterior drawer more than 5 mm having the patella reduced may be suspicious of flexion instability. A more conservative approach with the use of a thicker polyethylene insert to fill the flexion gap provides better flexion stability but increases tightness in the extension gap, often resulting in a flexion contracture. For this reason, we recommend revising the femoral component in this scenario: posterior femoral augments and/or an upsized femoral component are the gold standard for flexion instability correction during revision TKA.

Mid-flexion instability is becoming a very hot topic in revision TKA. It is characterized by a knee that is stable both in full extension and in flexion at 90°, but instability develops during the 0° to 90° arc of motion. Such instability may be not recognized in most cases because of subtleness of the nature of complaints of the patient. Soft tissue tension should be equal not only medio-laterally but also antero-posteriorly. To better understand this, it should be remembered that main stabilizer of the knee in extension is the posterior capsule and in flexion are the collateral ligaments: it is important to understand the interplay between those soft tissue structures.

In fact, the main causes for the mid-flexion instability phenomenon are the inappropriate balancing of the soft tissues (medial collateral ligament (MCL) and/or posterior capsule) and malpositioning of the implant, both leading to poor ligamentous isometry. The anterior part of the MCL has been shown to be the main knee stabilizer between 30° and 60° of flexion [11]. On the other side, malpositioning of the implant modifies the tibio-femoral geometry and the final position of the epicondyles, influencing collateral ligament isometry and leading to mid-flexion instability too.

Because of this, we routinely classify the mid-flexion instability, when associated with correct implant positioning, in three types: (1) over-released MCL and normal posterior capsule, (2) normal MCL with a tight posterior capsule, and (3) over-release of both the MCL and the posterior capsule.

Another recently highlighted reason as cause of mid-flexion instability is component downsizing: a 2-mm downsizing on the femoral component and a 1-mm downsizing on the tibial component had an equivalent increase in laxity in mid-flexion [12]. Mid-flexion instability surgical treatments, at the time of TKA revision, usually include increasing the femoral condylar offset, proximalization of the joint line, and decreasing of the posterior tibial slope.

A clear understanding of flexion/extension balancing is mandatory before performing either primary or revision surgery (Tables 1, 2, and 3).

Component malpositioning

Evaluation of component malposition must include preoperative radiographic [13] and intraoperative visual assessment. Component malposition is defined as coronal plane malalignment of >5°, sagittal plane tibial component alignment of <0° (anterior slope) or >10° (excessive posterior slope), or axial malalignment of the femoral component of >5° internal rotation. Component malpositioning can interact with time with the environment around TKA, creating a secondary cause of instability: for example, component malpositioning could attenuate periprosthetic soft tissues with the flight of time and be combined with previously isolated ligament and extensor mechanism insufficiency. In order to consider component malpositioning, surgeons must be able to explain the direction and pattern of instability.

Isolated ligament insufficiency

Isolated ligament insufficiency includes postoperative traumatic rupture or chronic functional attenuation of the PCL in a PCL-retaining TKA, of the MCL, or of the lateral collateral ligament (LCL). The identification of factors causing isolated ligament insufficiency is often difficult and not always useful for planning revision TKA surgery. On the other side, the

Table 1 Technical solutions to balance flexion and extension gaps

	Extension OK
Flexion OK	No changes
Flexion loose	<ul style="list-style-type: none"> • Offset femoral stems • Larger femoral component with posterior augments
Flexion tight	<ul style="list-style-type: none"> • Smaller femoral comp. • Distal augments and thinner poly

Flexion/extension balance

Table 2 Technical solutions to balance flexion and extension gaps

	Extension tight
Flexion OK or flexion loose	<ul style="list-style-type: none"> • Resect more distal femur • Posterior capsule release • Larger fem. comp. with thinner poly
Flexion tight	<ul style="list-style-type: none"> • Resect more tibia • Thinner poly
Flexion/extension balance	

identification of the anatomical feature of the isolated ligament insufficiency and chronicity is rather useful too. The specific differentiation of the insufficient ligament could make the selection of constraint prosthesis more reasonable.

Extensor mechanism insufficiency

Extensor mechanism insufficiency includes acute or chronic patellar or quadricep tendon rupture, patellar bone fracture with displaced non-union, patellar dislocation, or dissociation of the patellar component. According to the cause of knee instability (patellar component problems, patellar bone and bone integrity issues, soft tissue imbalance, or instability of the patello-femoral joint), the revision strategy and the degree of constraint might change consequently.

Loosening of components

Component loosening must be first assessed by preoperative radiographic evaluation and by intraoperative findings subsequently. According to Ryd et al. [14], radiographically loose components are those with a progressive complete radiolucent line of >2 mm in width around the component, a visible fracture of the cement around the components, or a change in component position including subsidence. Knees with component loosening may progress to multidirectional instability: the right degree of constraint must to be chosen at the time of revision surgery in order to obtain neutral alignment, accurate component position, proper component sizing, and fixation.

Table 3 Technical solutions to balance flexion and extension gaps

	Extension loose
Flexion OK	<ul style="list-style-type: none"> • Augment distal femur • Smaller femur with thicker poly
Flexion loose	<ul style="list-style-type: none"> • Thicker poly
Flexion tight	<ul style="list-style-type: none"> • Smaller femur • Distal augments
Flexion/extension balance	

Global instability

Global instability is defined as combined medio-lateral as well as flexion and extension instability. Knees with global instability should be divided in three subcategories: soft tissue attenuation due to chronic synovitis, recurrent hemarthrosis, or under-sizing of polyethylene (PE) insert; direct negative effect of PE insert such as post-fracture or wear; and knee dislocation. Tibiofemoral dislocation is the extreme form of global instability: this is usually due to progression of severe imbalance of flexion gap and extensor mechanism insufficiency.

The time of manifestation of instability symptom could be related to the causes of instability. Technical errors such as flexion/extension gap mismatch and component malpositioning tend to present early. Other categories first tend to produce attenuation of the soft tissues around the knee and then become clinically evident. At our institution, reviewing a consecutive series of TKA revisions [9•], we demonstrated that the interval between the primary and revision surgery was significantly shorter in the gap mismatch and component malpositioning category groups than in other category groups.

Treatment options

Surgical treatment modalities for instability are not one kind of procedure, but several different procedures, according to the category of causes: they range from exchange of PE insert to total revision TKA with variable level of constraint in often complex combined surgeries. It has been recommended to use a minimally constrained type of prosthesis to maintain stability [14, 15].

There are four basic treatment options to treat instability:

1. Isolated polyethylene exchange
2. Single component revision
3. Full component revision
4. Hinged arthroplasty

Isolated polyethylene exchange

Isolated polyethylene exchange is an attractive low morbidity option for prosthetic knee instability. The prerequisites for isolated polyethylene exchange are proper alignment and stable fixation of both components. It is most helpful in cases of global instability where it appears that the polyethylene originally placed was not thick enough: in this scenario, the patient knee will go into recurvatum and will have AP instability at 90° of flexion. Another scenario includes when posterior cruciate insufficiency occurs in a patient with a posterior cruciate

retaining implant: in this case, if the manufacturer has an available ultracongruent polyethylene insert, this could substitute for the attenuated posterior cruciate ligament. A final, but rare, type of instability where isolated polyethylene exchange is still appropriate is varus/valgus ligamentous imbalance: in this scenario, the soft tissues on tight compartment can be gradually released to catch up with the stretched compartment and a thicker polyethylene be placed to appropriately balance the knee. Unfortunately, it is well known [16–19] that the results of isolated polyethylene exchange are usually poor and unpredictable.

Single component revision

The prerequisite for this technique is stable fixation and proper axial alignment of the retained modular implant. The primary indication for this technique is in a posterior cruciate-retaining knee when the posterior cruciate ligament becomes incompetent: in this scenario, the femoral component can be revised to a posterior stabilized implant and a posterior stabilized polyethylene placed to solve the instability issue. Another instance of isolated femoral component revision is the case of isolated medial collateral ligament incompetence: the femoral component can be revised to a constrained condylar design, and a constrained tibial insert can be placed into the stable well-fixed and well-aligned tibial base plate. Early isolated femoral loosening in the picture of an otherwise stable, well-fixed, and well-aligned knee is another indication for single femoral component revision (Fig. 1). Isolated femoral revision allows surgeons to adjust the joint line position, the flexion/extension gap as well as adjusting the level of constraint.

Isolated tibial revision is indicated in the event of isolated tibial loosening (Fig. 2) with a well-fixed and well-aligned retained implant: if this scenario is caught early, there might be still little damage to the soft tissue knee environment, allowing for the use of a posterior stabilized implant without increasing the level of constraint.

Full component revision

Full component revision is indicated when there is malalignment of the components, a poor track record of the retained implant, or inadequate constraint options of the existing implant. The revision of femoral and tibial components allows realignment, correct flexion/extension gaps balancing, and restoration of the joint line.

Complete TKA revision is a stepwise procedure: first, the entity of bone loss needs to be detected and addressed; second, femoral and tibial implants need to be chosen; and third, the level of constrained needs to be intraoperatively selected.

Treatment of bone loss during revision TKA has evolved considerably over the past decade, primarily due to the emergence and rapid adoption of metaphyseal fixation devices. In

Fig. 1 Right TKA. Femoral (CR) component loosening: visible fracture of the cement (*left*). Femoral component revision: a short cemented stem and a PS polyethylene insert have been used. CR = cruciate-retaining, PS = posterior stabilized

general, there are two basic categories of metaphyseal fixation devices [20]: (1) porous coated solid sleeves that are unitized to an intended implant stem (Fig. 3) and (2) highly porous

Fig. 2 Left total knee arthroplasty. Loosening of the tibial component and overall varus malalignment (*top*). The tibial component has been revised with a metaphyseal porous coated solid sleeve and a cementless stem: a posterior stabilized (PS) polyethylene insert has been used (*bottom*)

Fig. 3 Left total knee arthroplasty. Severe polyethylene wear and retrofemoral osteolytic lesion (*top*). Revision TKA using porous coated sleeves, no stem, and a semi-constrained polyethylene insert (*bottom*)

cones that are implanted into the metaphyseal region separate from the intended final implant.

Tibial implant choice should allow reconstruction of a stable platform without overhanging, stem impingement, and with good stem support. Wedges should allow bone substitution, raising the joint line to its natural height. Femoral implant choice should allow to recreate the posterior condylar offset as good as possible to recreate flexion gap stability. The use of a long straight femoral stem should be avoided because of the tendency to increase the anterior offset leading to over resection of the posterior condyles and an increase in flexion gaps: this happens because the diaphyseal fit of the stem leads to a relative extension position of the femur compared to the relative slightly flexed position of the native femur. In this scenario, recreating flexion gap stability will need a bigger polyethylene insert and thus a more proximal femoral resection to fit the same polyethylene in extension, leading to patella baja too. The use of posterior offset stems allows to recreate the natural femoral condylar offset

The guiding principle for the surgical treatment of instability is to use the least constrained implant to solve the instability problem [21]. Unfortunately, in most unstable knees requiring ligament reconstruction, it is practically impossible to achieve stability without implanting a semi-constrained or fully constrained prosthesis [22]. In fact, posterior stabilized only implants provide AP stability but little varus/valgus stability: they are mainly used to substitute for the posterior cruciate ligament. Differently, a constrained insert can help stabilize the knee in a variety of planes: it provides AP as well as varus and valgus stability, and it is used primarily to

substitute for deficient collateral ligaments. The height of the post helps prevent posterior dislocation and is generally taller than a posterior stabilized construct. Constraint differs between manufacturers with regard to varus/valgus constraint, rotational constraint, and post height [23].

Hinged arthroplasty

Primary indications for using a hinged arthroplasty are severe distal femoral bone loss (Fig. 4), severe flexion gap instability which cannot be matched by the extension gap, and in presence of a totally disrupted medial collateral ligament in an elderly patient. However, in a younger patient using a constrained condylar design with a medial collateral ligament, allograft may be a better choice. In fact, hinged knee implants have limited usage among relatively young and active patients because they have been associated with increased risk of a secondary revision due to early loosening caused by excessive stress at the fixation interface [24]. When a surgeon is forced to use a hinged device, he should use a rotating bearing design because the theoretical advantage to diminish stress at the interface. Last, when using a hinge, the surgeon must be aware of the variability in disengagement potential between manufacturers [25].

Few studies [10, 17] demonstrated that patients undergoing revision of femoral and tibial components had a better outcome than those undergoing isolated polyethylene exchange. Revision of all components provides the opportunity for use of more constrained implants, which may improve stability of

Fig. 4 Left knee. Antibiotic-loaded cement spacer following left total knee arthroplasty septic loosening (*top*); revision total knee arthroplasty with a hinged implant (*bottom*)

the final construct. Controversy exists in regards to different levels of constraint in revision TKA. Hass et al. [26] and Hwang et al. [27] reported that the clinical outcomes, when using PS systems, were better than those when using constrained implants. On the other side, Shen et al. [28•] and Lachiewicz et al. [29] showed inferior clinical results when an unconstrained prosthesis was utilized, also in the Anderson Orthopaedic Research Institute (AORI) [30] type I bone defect patients. There is also controversy between the outcome of unlinked constrained knees and hinged knee prostheses. Barrack et al. [31], Hossain et al. [32], and Kim et al. [33] all demonstrated comparable results between condylar constrained prosthesis and hinged prosthesis. Shen et al. [28•] suggested unlinked constrained prostheses offering superior results when used in aseptic AORI type II and type III patients; on the other side, the septic AORI type II and type III patients were found to have a better outcome when hinged prostheses were utilized.

Conclusion

The unstable TKA may result from a variety of distinct etiologies, which must to be identified and treated at the time of revision with different degree of constraint available.

PCL-retaining revision arthroplasty could theoretically be used to revise early failure of a unicompartmental knee without major osteolytic lesions: integrity of collateral ligaments and a competent PCL are mandatory requirements. PCL resection revision arthroplasty can be performed releasing the posterior cruciate ligament and substituting it by an ultracongruent polyethylene insert. In the PCL substituting revision arthroplasty, the function of the PCL will be substituted by a standard cam and post-mechanism: integrity of collateral ligaments and a competent posterior capsule are mandatory requirements. Semi-constrained revision arthroplasty requires the presence of some collateral ligaments function and posterior capsule competency. The higher central post eventually increases stability in the presence of unbalanced gaps, but its function is related to the contemporary presence and continuity of the collateral ligaments. Hinged revision arthroplasties are designed to substitute collateral and cruciate ligaments, bone loss, and incompetent posterior capsule. Rotating hinge designs have the theoretical advantage of reducing bone implant stresses and early aseptic loosening.

Compliance with Ethics Guidelines

Conflict of Interest The authors have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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