ABSTRACT • The authors aim at reviewing the guiding principles in revision total knee arthroplasty according to a stepwise surgical technique. Strict preoperative planning is of paramount importance for this surgery. Through clinical history and physical examination, the assessment of limb deformity and knee range of motion as well as knee stability in flexion, extension, and mid-flexion are crucial. Blood exam, standardized radiographic views, and CT scan are powerful tools for etiological diagnosis of total knee arthroplasty failure. Templating is unique and mandatory to provide the surgeon with the critical data concerning the valgus position of the femoral component, the AP size of the femoral component, and the optimal position of the joint line; these three parameters are determinant for the final clinical outcome. A stepwise surgical technique with close adherence to the guiding principles of revision knee arthroplasty should be adopted from skin incision to closure. Femoral and tibia components with modular stem are ideally set at their optimal position as predetermined by templating. Any residual implant-bone gap is filled with metallic augment or bone graft. Finally, repositioning of the patella on a symmetrical bone cut presents a great value for a successful procedure.

Keywords: kinematic alignment; mid flexion stability; gap method

INTRODUCTION

The goal of a total knee arthroplasty (TKA) is to achieve a painless, functional, and stable knee joint. However, a “forgotten knee,” a knee that the patient feels completely normal, is not always reached after a primary TKA. For Bourne et al. [1], 7 to 20% of patients who receive a primary TKA remain dissatisfied despite the absence of any objective reason. It appears that the revision total knee arthroplasty (RTKA) is a constantly increasing procedure due to the rising prevalence of TKA worldwide; in the USA, the TKA is projected to rise by 673% in 2030 and the RTKA by 601% [2]. Achieving a “forgotten knee” after a RTKA represents a more difficult task than after a primary procedure. Revision surgery poses different and more complex hitches for the surgeon, such as the presence of a distorted anatomy, stiffness, bone loss, and patellar problems. The first step in decision making for RTKA should always consider a careful assessment of the patient’s general condition and past history. The decision for revision is made after a thorough discussion with the patient himself, based on a wise balance between the potential advantages of the procedure from one side and the local risks along with the life threats from the other side. Because this complex procedure should be considered not only as a “knee solution” but also as a “life style” solution, the patient’s expectations should be discussed at length and in detail. A careful analysis of the symptoms that are reported by the patient, such as pain, stiffness, or instability, is very important. Assessment of the lower limb alignment for any deformity in any plane or direction is crucial; it should be considered along with the radiographic analysis of deformities, which should ideally be addressed during...
surgery. Blood test and knee joint aspiration are helpful in diagnosing a subclinical infection. A thorough analysis of the radiographs, and CT scan in some situations is fundamental for the preoperative planning, as well as to predict intraoperative potential surgical problems or difficulties. Finally, the “templating” is an essential step that should be considered as a surgical plan or map; it constitutes the first step of the surgical procedure. Lastly, the achievement of the revision procedure is carried out according to the preoperative plan. However, to overcome any unexpected intraoperative situation or “surprise” in “real time,” the surgeon should be equipped with the largest range of revision’s ancillary tools and implants. Based on the current literature, the authors aim at reviewing the guiding principles for revision surgery in aseptic failures of total knee prosthesis.

GENERAL CONDITION AND MEDICAL STATUS OF THE PATIENT

Assessment of the general condition of a patient, who is candidate for a RTKA, is of primary importance. The physiologic age of the patient is evaluated along with the coexistence of any morbid condition. The presence of diabetes mellitus, a body mass index > 40, an associated renal, cardiovascular or cerebrovascular disease [3], the presence of any current infection, the lower limb venous status and thromboembolic risk, the mental status, the smoking habits, any medications intake, or any other comorbid situation should be assessed, because they are predicting factors for higher rates of postoperative complications and mortality.

HISTORY & CLINICAL ASSESSMENT OF THE PATIENT’S PROSTHETIC KNEE

The global alignment of the lower limb is carefully assessed for varus, valgus, and rotational deformity. The range of motion (ROM) of the knee is noted, as well as any recurvatum or flessum. The stability of the knee is assessed throughout the entire arc of ROM, in flexion, extension, and especially in mid-flexion. Knee pain, stiffness, and instability represent the common symptoms that are reported by the patient; the past history has a primary importance in analyzing these symptoms. Information about the indication, for which the primary procedure has been performed, may help. The term “instability” should be carefully analyzed in conjunction with the physical exam; instability doesn’t always mean laxity, and inversely, laxity is not always associated with instability. In fact, a prosthetic knee may exhibit instability during daily activities because of a weak extensor mechanism; this knee shows no “laxity” on physical examination. On the other hand, an anteroposterior (AP) knee “laxity” on physical exam may not be associated with instability during daily activities; the complaint in this case may be limited to the presence of pain as a lonely symptom. The surgical management of laxity differs according to its etiology. When the components are correctly positioned in the coronal plane, the presence of coronal laxity in knee extension is mainly due to a coexistant capsulo-ligamentous deficiency which can be managed by using a more constrained prosthesis during revision. In opposition, when the components are malpositioned in the coronal plane, or migrated because of loosening or bone loss, the laxity is usually addressed by a correct implantation of the components with regard to their rotation and position. Finally, the information collected from the clinical assessment of the knee is put together with the radiographic analysis.

LABORATORY TESTS

Diagnosis and management of infection of total knee prosthesis are beyond the objective of this article; however, any painful total knee prosthesis should be assessed for infection. Complete blood count, C-reactive protein, and ESR (erythrocyte sedimentation rate) are routinely done for all patients. Knee aspirate is indicated in high index of clinical suspicion for infection; a positive culture on solid medium is considered infected [4]. High level of hemoglobin (HbA1c) has been associated with higher rate of postoperative complications; levels ≤ 8% are acceptable for surgery [5]. Patients with preoperative hemoglobin level ≤ 13 g/dl are significantly more likely to receive postoperative transfusion [6]. To manage postoperative drop in hemoglobin level, several options have been suggested: blood transfusion, iron supplementation, or erythropoietin. Administration of tranexamic acid (an antifibrinolytic agent) has been widely studied [7]. The Mayo Clinic protocol consists on preoperative intravenous administration of 1 g at the time of prophylactic antibiotics administration, and 1 g at the time of wound closure, mixed with 50 cc of normal saline and infused over 10 min [8].

RADIOGRAPHIC EVALUATION

Standardizing radiographic evaluation is crucial in RTKA; it represents a very important tool to determine the ideal anatomic joint line, and the components’ sizes. On the other hand, it allows planning for bone resections, as well as planning for the future positioning of the femoral, tibial, and patellar components, with respect to the mechanical and or kinematical alignment of the knee. The guiding principle of this new emerging concept of kinematic alignment is the restoration of the patient’s prearthritic anatomy [9]. For evaluation of the current situation, as well as for planning and templating of a RTKA, a full length hip-to-ankle weight-bearing AP radiograph (or lower limbs scanogram) is recommended, along with particular radiographic views of both knees: weight-bearing AP view, true lateral view, and axial femoropatellar views. In order to increase the accuracy of the preoperative templating, all radiographic views of the knee must be developed in true size; this is best guaranteed...
and controlled by adding a calibrated marker, such as a metallic coin, on the radiographic film, at the level of the joint line. The weight-bearing AP view is performed with the patella facing anteriorly. The true lateral view is confirmed when both femoral condyles are seen with complete overlap and superposition of their anterior, inferior, and posterior borders. The axial femoro-patellar views are taken at 0°, 30°, and 60° of knee flexion. Particular attention should be made to performing the lower limbs scanogram accurately, because the measures can be affected by the rotation and the distance between both legs. To achieve an ideal scanogram film, the following technical details are recommended: patient in standing position with full weight bearing, both knees in full extension and 45 cm distant from each other, the X-ray beam is first positioned lateral to the knee and adjusted to achieve a true lateral view of the knee under fluoroscopic control, the beam is then 90° anteriorly rotated to face the patella; when all these steps are correctly achieved, the AP scanogram is finally taken. Lastly, all old X-rays, including X-rays of the controlateral knee, before and after the primary procedure, are collected; they contribute in determining the real native anatomy of the knee, as well as analyzing the causes of failure.

The information drawn from the analysis of each one of the radiographic views are multiple and various. The AP weight-bearing radiographs roughly assess the coronal alignment, which is better judged on the scanogram; they also approximately evaluate the presence of any over or under sizing of the femoral and tibial components, as well as any medio-lateral malpositioning. The lateral view assesses the sagittal (anteroposterior) position and size of the prosthetic components. It has been emphasized that an erroneous position of the femoral component in the sagittal plane (flexion or extension malpositioning) affects the flexion gap [10]. Even small flexion malpositioning of the femoral component leads to reduce the flexion gap; only 2° (1.5°-2.5°) flexion of the femoral component results in 1 mm narrowing of the flexion gap [11]. The evaluation of the femoral component anteroposterior matching size is done after measuring the posterior condylar offset (PCO), which is the maximal thickness of the posterior femoral condyle projected posterior to the posterior cortex of the femoral shaft, as seen on the true lateral view (Fig. 1). The choice of an undersized AP femoral component may happen in revision knee surgery if the surgeon inadvertently, or intentionally, elevate the joint line because of presence of distal femoral bone loss; the resultant PCO is consequently less than the anatomic PCO, as judged on the X-ray of the normal controlateral knee or the ipsilateral preoperative X-ray. The same situation also happens when the surgeon deliberately uses a smaller AP femoral component in his attempt to set the femoral component on what is left from the posterior condyles. The best scenario that may happen in these cases is to achieve an equal flexion-extension gap by increasing the polyethylene insert thickness; however, this usually leads to a mid-flexion insta-

![Figure 1. Posterior condylar offset / PCO = A
PCO Ratio = A/B](image)

bility (at 30°- 60° flexion), which clinically manifests by a discomfort in climbing the stairs, up and down, as well as by an anterior knee pain because of occurrence of pseudo-patella baja, related to the elevation of the joint line. The choice of a larger than anatomical femoral component AP size, with PCO less or equal to the native PCO, induces a femoro-patellar overstuffing with consequent anterior knee pain and patellar maltracking.

A modified Blackburne-Peel ratio has been recommended to measure the patellar height on a full extension lateral view of the knee [12]. It is the ratio between the largest patellar diameter and the perpendicular line made from the distal tip of the patella to a tangent line drawn to the distal femoral prosthetic component (Fig. 2). Factors such as height of the polyethylene (PE), inlay slope of the tibial surface, superimposition of the patellar joint line, are accordingly disregarded. Patella alta increases maltracking and knee instability, while patella baja or pseudo-patella baja (with elevated joint line) decreases the ROM and the lever arm of the extensor mechanism, and leads to the occurrence of an extension lag, with impingement of the patella against the tibia, and finally failure of the extensor mechanism.

The axial views are done at 0°, 30°, and 60° knee flexion; they help evaluating the presence of a patellar maltracking, patellar tilt or shift with respect to the femoral trochlear groove (Fig. 3). When the patella has previously been resurfaced, an eventual asymmetrical bone cut (under resection of the medial facet in the majority of cases) can be demonstrated on these views. According to Pangnano et al. [13] asymmetrical patellar cut is measured on sunrise views by patellar prosthesis...
bone angle (between a line drawn through the equator of the patellar bony remnant and patellar bone interface); this situation may cause a patellar tracking with anterior knee pain in up to 52% of cases [6].

COMPUTED TOMOGRAPHY SCAN EVALUATION

The CT scan is a valuable tool in diagnosing and measuring the femoral and tibial bone defects, as well as the previous patellar cut symmetry, the patellar thickness, position, tilt, and shift. In addition, it represents a crucial examination to assess rotational malalignment of the femoral and tibial components. The rotational alignment of the femoral component is measured between the radiographic transepicondylar axis (rTEA) and the femoral prosthetic posterior condylar line (FPPCL) [14,15]. The rotational position of the tibial component is measured between the posterior marginal axis of the tibial prosthesis (PMAt TKA) and the posterior marginal axis of the tibial bone (native PMAt); it is done by the superimposition of two CT cuts: the first cut goes through the tibia base plate and the second goes just below the metallic base plate [15]. An internal rotation of the femoral or tibial component increases the Q angle, leading to a lateral subluxation of the patella and subsequent anterolateral knee pain [15].

TEMPLATING

The templating should be considered as the first step of surgery in RTKA; it may represent a difficult and tricky task because of the presence of deformity, major distortion of the local anatomy, and the absence of the usual anatomic landmarks. The deformity may result from a failure to address the initial alignment of the mechanical axis, or because of components malpositioning during the primary procedure; it may also be due to PE wear with secondary osteolysis and bone loss. Another cause of bone loss is iatrogenic; it is induced by the removal of the different components of the primary prosthesis during the revision procedure. The aim of the templating is to answer two questions, regardless of the amount of bone loss: the first one is the correct size of the revision components, and the second is to define the optimal positioning of the prosthetic components; and finally filling the gap between the metal and the bone. The fatal mistake is to, intraoperatively, determine the size and the position of the revision implants according to the remaining bone after removal of the primary implant.

The ideal size of the revision components, that would give optimal clinical outcome, should be inserted relying on the remaining landmarks in conjunction with the data collected from the preoperative and postoperative radiographs of the knee that is undergoing revision. The radiographs of the controlateral normal knee are also helpful (see paragraphs Radiographic evaluation, and CT scan evaluation). The golden rule is to set the revision components as predetermined by the templating (ideal size and position), and to fill the gap between the prosthetic and the bone with metallic augment, and, or bone graft [10]. The essential data taken from the templating consists of: the angle between the anatomical and the mechanical femoral axis, the AP size of the femoral revision component, and the joint line position. The first step in templating is made on the scanogram of the lower limbs, by drawing a line from the center of the femoral head to the center of the ankle, in order to assess the mechanical alignment of the lower limb. The second step is to calculate the angle between the anatomical and the mechanical axis of the femur; it represents the angle that will be given to the distal femoral cutting jig set on the intra-
medullary femoral road [16]. The traditional “mechanical alignment” protocol recommends a tibial cut at 0° (perpendicular to the mechanical and anatomic tibial axis) [17]; however there has been evidence to support the so-called “kinematic alignment.” The principle of this technique is to restore the patient’s prearthritic anatomy, leaving some degrees of varus [9]. The axial views are used to measure the thickness of the remaining bone of the patella and to identify any asymmetrical bone cut. The preoperative determination of the anteroposterior size of the femoral component is a critical step in the templating process; it constitutes a key element for the ultimate success of the surgical procedure. Templating of the femoral component is performed as mentioned above; some authors reported that the digital templating is a reliable method for measurement [18, 19]. In addition, the manufacturer label of the primary prosthesis (when available in the operative sheet of the previous medical record) helps in determining the primary femoral component size. Satisfactory knee score and clinical outcome have been correlated with an accurate positioning of the joint line [20]. A reliable and reproducible method has been proposed to determine the joint line position in revision surgery, especially where the classical anatomic landmarks are absent because of the distorted anatomy; it consists in setting the joint line according to the location of the adductor tubercle (ATJL) on the AP view, taking into consideration the distal femoral diameter on true lateral view of the knee [21]. This method gives less than 4 mm error when it is applied in conjunction with a correct anteroposterior sizing of the femoral component; the acceptable limits of error are reported as being ± 4 mm [22] to ± 8 mm [23]. Finally, the distance from the adductor tubercle to the joint line (ATJL) is correlated with gender distribution; the values of ATJL reported by some authors are 0.66 FD (mm) + 27.21 in female, and 0.82 FD (mm) + 25.81 in male patients [24] (Fig. 4).

SURGICAL MANAGEMENT

General considerations
All efforts should be done to surgically achieve the preoperative planning and templating as previously detailed. RTKA is a demanding surgical exercise that requires close adherence to the guiding principles in order to achieve a stable knee with the best lower limb mechanical alignment, and hence to maximize the clinical outcome.

Special and different types of implants should be available to deal with special circumstances; the revision set should include implants with different constraints, sleeves, metal augments, and offset stems with different size and length. The use of intramedullary modular stem is mandatory in RTKA to provide alignment and immediate stable fixation of components [24, 25]; it also

![Figure 4](image-url)

**FIGURE 4**

a. Distance from the adductor tubercle to the joint line (ATJL)  
b. Femoral diameter
reduces stress on the metaphyseal area and consequently serves protecting bone graft. Although some authors stated that cemented stems have lower rates of failure and re-revision [26], others reported no significant difference with cementless stems [27]. Pain at the tip of cementless diaphyseal engaging stem may be prevented by avoiding press-fit extended stem. When a cementless stem is used, a large diameter stem with high coefficient of friction and distal taper is recommended [28]. Management of bone loss depends on its size and configuration. Type 1 AORI (Anderson Orthopedic Research Institute) classification [29] of less than 5 mm contained defect is filled with cement. Type 2A (5 to 10 mm defect involving one femoral condyle or hemiplateau) is managed with metallic augment [30]. Type 2B (5 to 10 mm defect of both femoral condyles and/or the entire tibial plateau) is managed with impaction grafting, structural allograft, and highly porous metal metaphyseal cones or sleeves [30]. Type 3 (femoral and or tibial metaphyseal bone loss with possible damage to collateral ligaments and patellar tendon insertion) is managed as same as type 2B (constrained design in some situation) [30].

Pearls for a stepwise technique

A tourniquet is put in place and can be inflated only at the cementing time. After a clear marking of all previous skin incisions, the surgical approach uses the safest and most appropriate preexisting one. The lateral most incision is usually used because the blood supply to the anterior aspect of the knee is predominantly derived from the transverse incisions should be transected with an angle from deep to superficial [31]. Medial femoral epicondyle, or 15 mm proximal to the lateral femoral epicondyle, or 25 mm distal to the lateral femoral epicondyle, or 15 mm proximal to the fibular head [32].

The second step is to refresh the proximal tibial cut using a cutting jig, set perpendicular to the intramedullary tibial road in the coronal plane; the road is being representative of the mechanical axis of the tibia. The same exercise is done for the distal femoral cut. The distal femoral cutting jig is set on the intramedullary femoral road according to the angle between the anatomic axis and the mechanical axis of the femur, as previously determined on the scanogram; the femoral road represents the anatomic axis of the femur.

The third step is to set the joint line according to the location of the adductor tubercle; we believe this method of ATJL, as previously described, is very reliable. Other authors suggest placing the joint line 30 mm distal to the medial femoral epicondyle, or 25 mm distal to the lateral femoral epicondyle, or 15 mm proximal to the fibular head [32].

The fourth step is to insert the intramedullary femoral guide with the femoral cutting jig of accurate anteroposterior size as previously determined by the templating; the tibial trial component is then inserted with a long tibial stem and the smallest plastic trial spacer (9 mm). Offset ancillary can be used to overcome mismatch between the diaphyseal canal and the centre of the component in both sides. The height of the plastic insert is adjusted to the level of the predetermined joint line; any residual gap between metal and bone is filled with metallic augment.

When the knee is brought into 90° flexion, an external rotation of the femoral cutting jig will be automatically set because of the rectangular flexion gap dictated by the plastic tibial spacer. This “gap method” to determine optimal rotation of the femoral component has the lowest variability and lowest percentage of surgical outliers [10]. At this stage, any tightness of the flexion gap is addressed with a posterior capsular release. The knee is then fully extended with the plastic tibial spacer in place. This maneuver will automatically set the femoral cutting jig at the optimal height (as the jig remains free to move in supero-inferior direction), with equal rectangular extension and flexion gap. The femoral guide is subsequently fixed, and all femoral cuts are refreshed. The femoral component is subsequently set with the adequate stem according to the cuts that have been made; any residual distal or posterior femoral gap is filled with metallic augment. Any tightness or looseness in flexion
or extension is addressed according to the algorithm by Mc Dermot et al. [33] as shown in table I. Setting the joint line within 8 mm limits from the predetermined joint line would not affect functional outcome [20]. A large flexion gap, with irreconcilable mismatch between flexion and extension, is regularly secondary to soft tissue failure; it commonly ends up with a flexion instability and secondary failure of the revision procedure. In this case, it is the surgeon’s preference to use either a linked or a non-linked constrained prosthesis [33]. Finally, the tibial component is rotated to face the medial third of the tibial tubercle, as recommended by many authors [34, 35]. The final step is to deal with the patellar component. A stable patellar component with symmetrical bone cut and adequate thickness (within 2 mm of the preoperative thickness of the native patella) is left without revision [36]. Otherwise, the preexisting patellar component is removed with great caution to preserve a minimum of 12 mm thickness of the native bone [37, 38]; a new patellar polyethylene insert is then set a bit more medially and superiorly for better patellar tracking and lesser impingement.

CONCLUSION

Standardized templating is a crucial step in successful RTKA. Templating and application of principles of knee arthroplasty allow the surgeon to choose optimal component size and position. Due to the distortion of the native anatomy in revision cases, the golden rule is to set the femoral and tibial components at the optimal position and then to fill the gap between metal and bone with adapted augment or bone graft.

REFERENCES

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### TABLE I TREATMENT OF GAP IMBALANCE POSSIBILITIES (Modified)

<table>
<thead>
<tr>
<th>Flexion</th>
<th>Normal</th>
<th>Tight</th>
<th>Loose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Nothing</td>
<td>Increase distal femoral cut</td>
<td>Distal femoral augmentation</td>
</tr>
<tr>
<td>Loose</td>
<td>Larger femoral component</td>
<td>Increase distal femoral cut</td>
<td>Larger PE insert</td>
</tr>
<tr>
<td>Tight</td>
<td>Increase posterior femoral cut</td>
<td>Resect proximal tibia</td>
<td>Downsize femoral component, augment distally</td>
</tr>
</tbody>
</table>


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