Review Article

Total Knee Arthroplasty in Extra-Articular Knee Deformity Patients: A Review of the Surgical Techniques, Surgical Instruments and Prosthetic Designs

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Abstract

Total knee arthroplasty (TKA) is the gold standard procedure for the end-stage destructive arthropathy of the knee. TKA can relieve pain and restore knee function. The post-operative mechanical axis should be within a +/-3 degree of a neutral mechanical axis to ensure a good long-term result and maximize the longevity of TKA. Performing TKA in patients with ipsilateral extra-articular deformity is very challenging. Anatomy distortion, canal sclerosis, retained hardware and prior surgery in this patient group will increase the risk of prosthesis malposition and malalignment of the lower extremity, which may hinder the outcome and survival of TKA. Intra-articular correction technique is suitable when the coronal plane deformity less than 20 degree for femur and less than 30 degree for tibia. If intra-articular correction technique cannot correct the deformity, then extra-articular correction technique is indicate. Computer-assisted surgery (CAS) and Patient-specific instruments (PSIs) will be a good assistant by ignoring the anatomical distortion of patients. Well-planned preoperative planning combined with an appropriate surgical technique, proper surgical instruments and wisely chosen prosthesis design will reduce the risk of complications and thus maximize the outcome and longevity of TKA in patients with extra-articular deformity.

Keywords: Total knee arthroplasty, TKA, extra-articular deformity TKA, intra-articular correction technique, extra-articular correction technique

Introduction

Total knee arthroplasty (TKA) is one of the most successful and reliable operations currently carried out and is the treatment of choice for the end-stage destructive arthropathy of the knee. TKA can relieve pain and restore knee function to nearly normal. Because of these advantageous outcomes, this operation is even extended to younger patients. More than 25,000 TKAs are thought to be carried out every year in Thailand. However, the longevity of the prosthesis is one of the most concerning topic related to this surgery.

The long-term success of TKA depends on a number of factors. The proper restoration of the limb mechanical axis, the proper alignment of the implanted prosthesis and soft tissue balancing are critical for the success of TKA (Hamada, et al., 2013, p. 5; Liu, Pan, & Zhang, 2013, pp. 93-96; Lonner, Siliski, & Lotke, 2000, pp. 342-348; Mullaji, & Shetty, 2009, pp. 1164-1169). Many published studies have supported that proper coronal and rotational alignment is crucial for the long-term success of TKA and shown that malalignment can lead to early loosening, poor functional outcome and the maltracking of the patellar (Garg, & Walker, 1990, pp. 45-58; Jeffery, Morris, & Denham, 1991, pp. 709-714; Krackow, Phillips, Bayers-Thering, Serpe, & Mihalko, 2003, pp. 1017-1023; Oswald, Jakob, Schneider, & Hoogewoud, 1993, pp. 419-426; Wasielewski, Galante, Leighty, Natarajan, & Rosenberg, 1994, pp. 31-43). Achieving a postoperative mechanical axis within a +/- 3 degree of the normal mechanical axis, also as known as the “safe zone”, is the goal of modern TKA, as this should guarantee of the long-term success of this procedure.

The extra-articular deformity of the tibia and femur can occur secondary to various causes, such as previous osteotomy, metabolic bone disease, the malunion of a prior fracture or congenital deformity (Mullaji, & Shetty, 2009, pp. 1164-1169). These extra-articular deformities can be dealt with extensive soft tissue release or combining corrective osteotomy with TKA. However, achieving optimal mechanical alignment in this group of patients is very challenging. A deformed tibia or femur may preclude the use of conventional instruments because of canal sclerosis, the distortion of a bony landmark or retained hardware from previous surgery (Klein, Austin, Smith, & Hozack, 2006, pp. 284-288; Liu, et al., 2013, pp. 93-96). Soft tissue balancing is more complicated due to the atypical bone resection characteristic of performing intra-articular correction (Hamada, et al., 2013, p. 5). Corrective osteotomy may also play a role in severe deformity or in peri-articular deformity patients.

Preoperative Evaluation

The complete history of the patient must be noted and a physical examination carried out. Cause of deformity and history of previous surgery should also be documented. Preoperative range of motion (ROM) should be measured because this correlates with postoperative ROM. The location of prior surgical scarring and skin grafts/flaps as well as the status of the extensor mechanism and collateral ligaments should be documented, too. Whenever there is a clinical suspicion of infection, a complete blood count, erythrocyte sedimentation rate and C-reactive protein level must be required. If there is evidence of infection, the operation should be performed in a stage procedure, with a meticulous debridement with all hardware removal, and a period of organism-base-specific intravenous antibiotics should be given.

Anteroposterior and lateral plain radiographs are necessary to evaluate knee alignment, bony deformity and the location of hardware. Standing hip-to-ankle radiographs are helpful for determining the mechanical axis and identifying limb alignment (Bedi, & Haidukewych, 2009, pp. 88-101). Moreover, computed tomography (CT) and magnetic resonance imaging (MRI) may be necessary in specific situations. Preoperative evaluation and planning are key steps for successful TKA in extra-articular deformity patients, as they help choose the appropriate surgical technique, suitable surgical instrument and proper prosthesis design.

Surgical Techniques

There are two options to correct extra-articular deformity for achieving a neutral mechanical axis, TKA with intra-articular correction and TKA combined with extra-articular correction. Each technique has its advantages and disadvantages. Choosing the appropriate technique for each patient is one of the most challenging steps towards reconstruction in patients with extra-articular deformity.

Intra-articular Correction/Resection

This technique can obtain a proper mechanical axis by deviating the intra-articular bone cut to compensate for the deformity followed by soft tissue release to balance the gap (Wang, & Wang, 2002, pp. 1769-1774). Asymmetrical bone resection will make a cutting surface perpendicular to the planned mechanical axis. Preoperative planning is an important step in this technique. The surgeon should know how much bone must be resected from the medial-lateral side in order to make a cutting surface perpendicular to the planned mechanical axis, preoperatively (Fehring, 2011; Mann John, & Insall John, 2002b). Intraoperatively, resected bone must then be measured to confirm that an intra-articular resection technique will recreate the proper mechanical axis as planned (Figure 1).

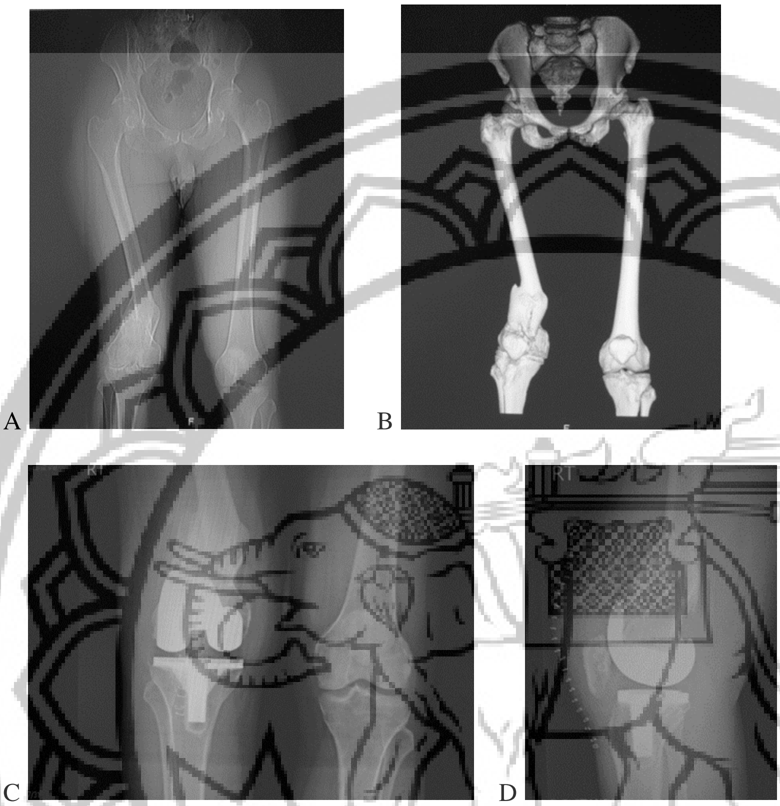


Figure 1 TKA combining with intra-articular correction technique (Preoperative radiograph (A) and 3-D CT scan (B) of patient with extra-articular deformity of right femur. After treated by TKA combining with intra-articular correction technique (C, D).)

The benefit of this technique is its single stage operation, less invasive surgery, lower risk of nonunion and shorter hospital and rehabilitation period. However, extensive soft tissue release and being unable to correct a severe deformity are the limitations of this technique (Chua, & Wang, 2013, pp. 276-278).

Extra-articular Correction

This technique is reserved for patients with extra-articular deformity that cannot be corrected by using the intra-articular resection technique (Figure 2). It can be subdivided into single stage osteotomy (or simultaneous osteotomy) and two-stage osteotomy.

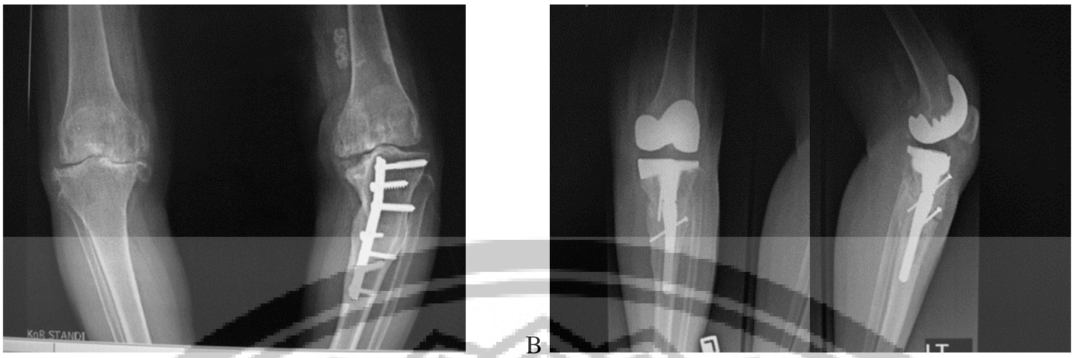
Figure 2 The deformity that beyond the scope of intra-articular correction technique A plain radiograph of patient with malunited fracture of left femoral shaft.

Two-stage Osteotomy

In two-stage osteotomy, the first stage comprises an osteotomy procedure to correct the deformity, and then after the osteotomy site is joined, TKA is performed as the second stage procedure. This two-stage operation can correct even the severest deformity. Moreover, it preserves bone stock, allows for easy ligament balancing and works for both posterior-stabilized (PS) and cruciate retaining (CR) prostheses (Fehring, 2011), as discussed later. However, its disadvantage is that patients have to undergo two operations. In addition, the retained hardware from first stage corrective osteotomy may obstruct the later TKA operation, there is a risk of the nonunion of the osteotomy site and the waiting time between the first and second stage procedures is at least six months for the proper healing of the osteotomy site (Fehring, 2011; Lesiak, Vosseller, & Rozbruch, 2012, pp. 304-308; Yagi, et al., 2006, pp. 386-389).

Single stage Osteotomy/Simultaneous Osteotomy

To avoid the complications of retained hardware and two operations of two-stage osteotomy, single stage osteotomy has been developed. The principle techniques of single stage osteotomy are performing corrective osteotomy simultaneous with TKA via an extensile surgical approach and then the fixation of the osteotomy site by using a cementless long-stem implant (Incavo, Kapadia, & Torney, 2007; Lonner, et al., 2000, pp. 342-348) (Figure 3). Although this technique can solve the problem of having a two-operation procedure and retained hardware, the risk of osteotomy site nonunion, extensile surgical approach and technical demands of this technique are still major disadvantages (Fehring, 2011; Xiao-Gang, Shahzad, & Li, 2012, pp. 2457-2463; Yagi, et al., 2006, pp. 386-389).



A B

Figure 3 Single stage osteotomy (Patient with previous fracture of left tibia status post open reduction and internal fixation with plate (A). Single stage osteotomy technique combine with TKA was choose for this patient (B).)

Intra- or Extra-articular Correction

One-stage TKA combined with the intra-articular correction technique is a feasible and effective procedure for patients with extra-articular deformity and severe arthritis of the knee, when the extra-articular deformity of the femur is <20 degrees (or <30 degrees of the tibia) from the coronal plane (Wang, & Wang, 2002, pp. 1769-1774)). In addition to coronal plane deformity, this technique can even correct sagittal plane deformity. The antecurvatum and recurvatum sagittal plane extra-articular deformity of the knee <15 degrees can also be corrected by using this technique (Wang, Chen, Lin, Hsu, & Wang, 2010, pp. 1392-1396; Xiao-Gang, et al., 2012, pp. 2457-2463).

The extra-articular correction technique may be necessary if the deformity is close to the joint line, if the coronal plane deformity is >20 degrees and >30 degrees in the femur and tibia, respectively, if the sagittal plane is >15 degrees as described earlier, if the preoperative planning of the distal femoral cut perpendicular to the normal mechanical axis would damage the collateral ligament attachment or if the distal tibial intramedullary axis passes outside the proximal tibial plateau. All these conditions are far beyond the scope of the intra-articular correction technique to correct the deformity and are thus suitable for the extra-articular correction technique (Higuera Carlos, Bottros John, & Barsoum Wael, 2009, pp. 35-37; Mullaji Arun, 2012, pp. 27-30). Intra- and extra-articular correction techniques have their own advantages and disadvantages. The appropriate technique must thus be tailored to individual patients to achieve successful TKA.

Surgical Instruments

To achieve successful TKA, many instruments have been developed. For example, conventional instruments rely on an anatomical landmark of patients, while computer-assisted navigation/surgery (CAN/CAS) recreates the mechanical axis by using a computer and patient-specific instruments (PSIs) simulate the mechanical axis of patients and then construct a custom-made cutting block for individual patients. All these instruments have been developed to restore a neutral mechanical axis and ensure the proper alignment of the implanted prosthesis. Choosing the right instrument will guide the proper alignment and make the operation easier.

Conventional Instruments

Standard surgical instruments for most TKAs recreate the mechanical axis by reference to the anatomical axis/landmark (intramedullary or extramedullary reference) (Mann John, & Insall John, 2002a; Seo, Moon, Park, Shim, & Kim, 2012, pp. 1339-1348). Such conventional instruments and their surgical techniques are familiar to all arthroplasty surgeons and they save patients from additional costs for special equipment such as CAS.

On the other hand, distorted anatomy, intramedullary canal sclerosis or retained hardware may prevent the use of conventional instruments in these patient groups (Hamada, et al., 2013, p. 5; Liu, et al., 2013, pp. 93-96; Mullaji, & Shetty, 2009, pp. 1164-1169). In extra-articular deformity patients, conventional instruments will increase the risk of prosthesis malposition and of poor clinical outcomes and may be unable to correct malrotation (Bedi, & Haidukewych, 2009, pp. 88-101; Chua, & Wang, 2013, pp. 276-278; Higuera Carlos, et al., 2009, pp. 35-37).

Computer-Assisted Surgery (CAS)/ Computer-Assisted Navigation (CAN)

CAS simulates the mechanical axis of each patient by using the center of the hip, knee and ankle joints regardless of the angular deformity, retained hardware or canal sclerosis. Through CAS, surgeons can evaluate and determine the proper mechanical axis and good prosthesis alignment by altering their bone cut. Thereafter, the computer will calculate and demonstrate the intraoperative mechanical axis in real time (Hamada, et al., 2013, p. 5; Higuera Carlos, et al., 2009, pp. 35-37; Liu, et al., 2013, pp. 93-96).

Meta-analysis has shown significant improvement in prosthesis orientation and in the mechanical axis when CAS is used (Mason, Fehring, Estok, Banel, & Fahrbach, 2007, pp. 1097-1106). Many published studies of extra-articular deformity patients have shown that CAS-TKA will reduce the alignment outlier group, better position the implanted prosthesis and increase the accuracy of the proper mechanical axis, resulting in reproducible good outcomes compare with conventional instrument (Hamada, et al., 2013, p. 5; Hernandez-Vaquero, Suarez-Vazquez, Sandoval-Garcia, & Noriega-Fernandez, 2010, pp. 1237-1241; Higuera Carlos, et al., 2009, pp. 35-37; Kim, Ramteke, & Bae, 2010, p. 658; Liu, et al., 2013, pp. 93-96; Mullaji, & Shetty, 2009, pp. 1164-1169; Siston, Giori, Goodman, & Delp, 2007, pp. 728-735; Tigani, et al., 2012, pp. 1379-1385). The limitations of CAS are malrotation and deformity close to the joint. Some surgeons have concerns about the additional costs and increased surgical time of CAS (Kuo, Bosque, Meehan, & Jamali, 2011, pp. e917-920).

Patient-Specific Instruments (PSIs)

PSI is the newest instrument for ensuring a proper mechanical axis and good component alignment (Figure 4). The process begins by sending patients for a CT or MRI scan and then evaluating the data to create a specific cutting block for each patient. This specific cutting block will give a bone cut that has an appropriate rotational axis and coronal axis as planned by the surgeon.

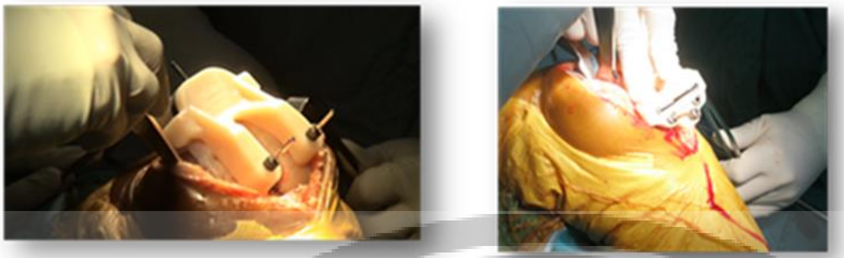


Figure 4 Patient-specific instruments (PSIs)

Although recent studies (Chareancholvanich, Narkbunnam, & Pornrattanamaneewong, 2013, pp. 354-359; Chotanaphuti, Wangwittayakul, Khuangsirikul, & Foojareonyos, 2014, pp. 185-188; Thienpont, Schwab, & Fennema, 2014, pp. 1052-1061) have shown no significant difference in coronal axis alignment compared PSI-TKA with conventional TKA, the case of performing TKA in knees with extra-articular deformity is different. PSI has the same advantages as CAS except it also has a shorter surgical time. Further, post-resection alignment and the amount of bone resection can be determined in the preoperative planning step, before creating the specific cutting block (Thienpont, Paternostre, Pietsch, Hafez, & Howell, 2013, pp. 407-411). However, the additional costs for this instrument are higher and the waiting time for creating a specific cutting block is at least 1-2 weeks.

Conventional or CAS or PSI?

Every instrument has its advantages and disadvantages. Although they have no additional costs and are more familiar to surgeons, conventional instruments need more experience and expertise than other instruments. The risk of technical error is also higher for conventional instrument compared with CAS and PSI. When the deformity precludes using conventional instruments, CAS is beneficial. Some authors (Chua, & Wang, 2013, pp. 276-278; Higuera Carlos, et al., 2009, pp. 35-37; Mullaji, & Shetty, 2009, pp. 1164-1169) conclude that CAS is a useful alternative to conventional TKA for knees with extra-articular deformity. PSI-TKA has some advantages over CAS-TKA, but PSI provides significant accuracy in rotational alignment (Chotanaphuti, et al., 2014, pp. 185-188). The proper mechanical axis and satisfactory results can easily be obtained with PSI when the extra-articular deformity is <20 degrees (Thienpont, et al., 2013, pp. 407-411).

Choice of Prosthesis

In general, the chosen prosthesis should provide a symmetrical well-balanced flexion-extension gap, but with the fewest constraints. PS prosthesis is recommended in combination with the intra-articular correction technique because the asymmetrical bone resection of this technique makes balancing the posterior cruciate ligament tension very complicated (Xiao-Gang, et al., 2012, pp. 2457-2463), while CR prosthesis limits the extensive soft tissue release of the intra-articular correction technique (Wang, & Wang, 2002, pp. 1769-1774); Wolff, Hungerford, & Pepe, 1991).

The status of the collateral ligament will determine the requirement for a more constrained prosthesis (Bedi, & Haidukewych, 2009, pp. 88-101). Hinged prostheses and mega-prostheses are reserved for senile low-demand patients with global ligamentous deficiency and severe bone loss.

Discussion

After Shiers performed the first TKA in 1954 with his "hinge prosthesis" (Shiers, 1954, pp. 553-560), John N. Insall, the father of modern TKA, developed his "total condylar knee prosthesis" - the basis of our current total knee prostheses - in 1974 (R.D.S., 2001, p. 635). There is no argument that TKA is the gold standard treatment for end-stage knee arthrosis, but how to obtain its optimal outcome and maximize its survival are major concerns for orthopedic surgeons.

The outcome and longevity of TKA is correlated with postoperative alignment. In particular, the coronal plane alignment of the lower extremity should be within 3 degrees of a neutral mechanical axis to ensure an optimal outcome and longevity of TKA (Abdel, Oussedik, Parratte, Lustig, & Haddad, 2014, pp. 857-862).

Recent clinical data revealed that TKA in complex preoperative deformity results in a worse pain scale and poorer functional outcome (Shearer, Chow, Bozic, Liu, & Ries, 2013, pp. 432-436) and an increased risk of postoperative malalignment (as known as the "outlier group") (Hsu, Hsu, & Weng, 2010, pp. 1323-1327; Mullaji, Shetty, Lingaraju, & Bhayde, 2013), which may reduce the survival rate of TKA (Ritter, et al., 2013, pp. 126-131). These studies support the fact that performing TKA in patients with extra-articular deformity results in a poorer outcome and higher complication rate compared with TKA in primary osteoarthritis patients (Bedi, & Haidukewych, 2009, pp. 88-101; Weiss, Parvizi, Hanssen, Trousdale, & Lewallen, 2003, pp. 23-26). This has been attributed to malunion, nonunion, limb malalignment with the alteration of the mechanical axis, poor bone stock, multiple previous operations, retained hardware and compromise of the surrounding soft tissue (Papadopoulos, Parvizi, Lai, & Lewallen, 2002; Shearer, et al., 2013, pp. 432-436; Weiss, et al., 2003, pp. 23-26). However, good preoperative planning, a proper operative technique and a suitable operative instrument will increase the postoperative outcome and reduce the complication rate (Manzotti, Pullen, Cerveri, Chemello, & Confalonieri, 2014).

Corrective osteotomy and TKA has been considered to be the treatment of choice for patients with extra-articular deformity and the arthrosis of the knee, because this technique achieves a neutral mechanical axis and violates less soft tissue (Wang, & Wang, 2002, pp. 1769-1774)). However, the risk of the nonunion of the osteotomy, retained hardware, extensive exposure of the surgical approach and technical demands are the disadvantages of this technique. If the attachment of the collateral ligament is not jeopardized, the intra-articular correction technique followed by soft tissue release might be more appropriate. With good preoperative planning and asymmetrical bone resection, the intra-articular correction technique can restore a neutral mechanical axis without any risk of osteotomy nonunion, retained hardware and an extensile surgical approach. Nevertheless, the excessive soft tissue release and technical demands are still disadvantages of this technique.

Conventional instruments, CAS and PSI have their own advantages and disadvantages. Conventional quipment is easy to use and more familiar to arthroplasty surgeons, but patients with extra-articular deformity (malunion, retained hardware or intramedullary canal sclerosis) may not be suitable for using this instrument. Although an extramedullary reference guide might avoid these problems (Seo, et al., 2012, pp. 1339-1348), the higher rate of prosthesis malorientation and higher incidence of mechanical axis “outliers” have been found with these instruments compared with CAS or PSI (Hernandez-Vaquero, et al., 2010, pp. 1237-1241; Mason, et al., 2007, pp. 1097-1106; Thienpont, et al., 2013, pp. 407-411). CAS and PSI ignore the problem of the anatomical distortion of this patient group. The major benefits of CAS and PSI are that the mechanical axis and prosthesis position can be known intraoperatively or preoperatively. Nevertheless, their complexity and additional costs are the disadvantages of CAS and PSI.

The PS prosthesis might be suitable for the intra-articular correction technique because of its excessive soft tissue release. Both CR and PS prostheses are usable for the extra-articular correction technique. More constrained prostheses such as condylar constrained knee or hinge prostheses are usually preserved for patients with ligamentous insufficiency.

The author prefers to use the intra-articular correction technique when the extra-articular deformity is less than 20 degrees from the femoral coronal plane and less than 30 degrees from the tibial coronal plane. The extra-articular correction technique is preserved for deformity that cannot be corrected by using the intra-articular correction technique or when the intra-articular technique would damage the attachment of the collateral ligament (Figure 5). The author is familiar with conventional instruments and has had less experience with CAS or PSI. With well-planned preoperative planning, the author has also found that the intra-articular technique combined with conventional instruments is cost-effective. The author chooses the least constrained prostheses that provide stable ROM, with PS prostheses usually the first choice. For patients with ligamentous deficiency, more constrained prostheses might be considered.

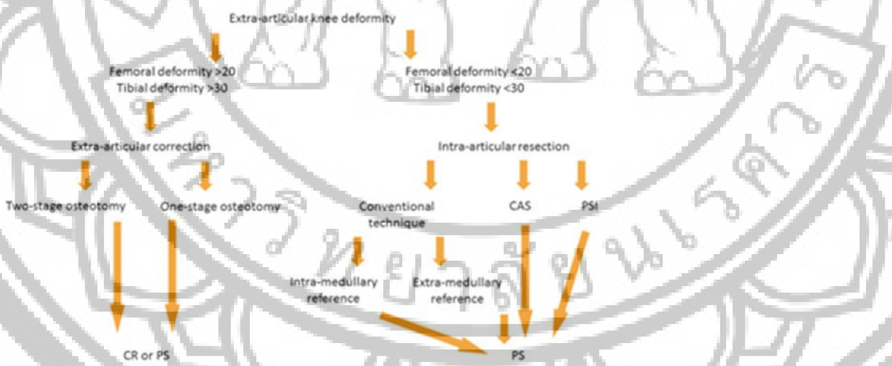


Figure 5 A decision diagram for treating knee arthrosis patients with extra-articular deformity

There are various types of surgical techniques, surgical instruments and prosthesis designs for TKA in knee arthrosis patients with ipsilateral extra-articular deformity. To achieve a good long-term result and increase the longevity of TKA, four cardinal steps should be followed. Preoperative planning with a standing hip-to-ankle radiograph is the first important step. Second, surgeons must choose an appropriate surgical technique for each patient’s conditions. Third, they must use the right instrument that will facilitate the operation. Aiming for least constrained prostheses that provide stable ROM is the last step.

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