Enhanced Mid-Resection Workflow Technique for Severe Varus Deformity Correction Using Robotic-Arm Assisted Total Knee Arthroplasty

Suhas Masilamani, AB, MBBS, MS, DNB[1]
Consultant Orthopaedic and Joint Replacement Surgeon

Kushal Hippalgaonkar, MBBS, DNB[1]
Consultant Orthopaedic and Joint Replacement Surgeon

Praharsha Mulpur, MBBS, DNB[1]
Consultant Orthopaedic and Joint Replacement Surgeon

Martin W. Roche, MD[2]
Director of Arthroplasty

Adarsh Annapareddy, MBBS, MS[1]
Consultant Orthopaedic and Joint Replacement Surgeon

AV Gurava Reddy, MBBS, D.Orth, DNB, FRCS, M.Ch[1]
Consultant Orthopaedic and Joint Replacement Surgeon

[1]Sunshine Bone and Joint Institute, Sunshine Hospitals, Hyderabad, India
[2]Hospital for Special Surgery, West Palm Beach, Florida

ABSTRACT

Introduction: Robotic technology in total knee arthroplasty has been proven to improve accuracy of component positioning, achieve alignment targets, and balance the knee objectively. However, the utility of robotics in correction of severe varus deformities of the knee has not been investigated in detail. The aim of this paper was to establish the utility and describe the technique of robotic-arm assisted total knee arthroplasty (RA-TKA) in achieving pre-balance in severe varus deformities of the knee.

Materials and Methods: Among the existing Mako (Stryker, Kalamazoo, Michigan) RA-TKA workflows, pre-resection workflow is limited to knees which can be pre-balanced by component positioning according to functional alignment. Mid-resection workflow (distal femur/tibia first) is reserved for complex cases, whereby the extension gap is balanced first. In our experience, both workflows could not achieve pre-balance in severe varus deformities, necessitating the need to develop a novel technique. The ability of the robot to execute precise bone cuts allows for a provisional postero-medial femoral bone cut in flexion, giving access to remove

large inaccessible posterior osteophytes and the tight posterior capsule, thus balancing the knee in extension. The flexion gap is subsequently matched to the extension gap by alterations in axial component positioning.

Conclusion: This novel "enhanced mid-resection workflow" technique establishes the utility of the RA-TKA in balancing severe varus deformities of the knee. We also propose an algorithm which simplifies and helps surgeons choose between the three workflows to pre-balance knees irrespective of the severity of the varus deformity.

INTRODUCTION

Acceptable coronal alignment and ligamentous balance are important factors which can affect functional outcomes and survivorship after total knee arthroplasty (TKA). Many studies have demonstrated excellent survivorship and functional outcomes with the widely accepted alignment target of 0 +/- 3° after TKA.[1–4] However, many patients delay seeking treatment due to various factors, resulting in severe knee deformities where TKA becomes quite a challenging procedure, which can be complicated by instability, necessitating higher constraint.[5]

In manual jig-based TKA (MTKA) with measured resection techniques, surgeons need to commit to bone resections first, followed by soft tissue releases to balance the knee. The instrumentation available often enables a 90° tibial cut at a pre-defined resection depth and slope. In severe varus deformities, standard jig-based bone resection results in a greater amount of bone removed from the lateral tibial plateau and a smaller amount of bone from the medial tibial plateau. This perpetuates the already existing lateral laxity and medial tightness in severe varus knees.[6] The thickness and angulation of bone resection dictates the amount of soft tissue release required to balance the knee. Studies have reported high variability in surgeon-assessed or subjective "balance" of the knee in these manual techniques.[7]

To the contrary, in robotic-arm assisted TKA (RA-TKA), the correctible knee can be balanced before the bone cuts are made, which is known as pre-balancing the knee.[8] RA-TKA has already proven to be superior to MTKA in achieving planned alignment targets (0 +/- 3°).[9,10] Pre-balancing the knee with functional placement of components, even before the cuts are made, ensures that the most conservative bone cuts are made and optimal soft tissue releases are performed, which translates into less post-operative pain, improved knee range of motion (ROM), achievement of earlier rehabilitation goals, and a reduction in length of hospital stays.[11-13]

To the best of our knowledge, the utilization and benefit of RA-TKA in severe varus deformities of the knee has not been reported in detail. There is little evidence to suggest that robotic assistance can aid in achieving pre-balance and alignment targets in complex primary TKAs with severe coronal deformities. Marchand et al.[14] published their experience using RA-TKA in correcting coronal deformities, with a mean of 10° (range, 7 to 18°), and reported achieving near neutral alignment (within 3° of neutral HKA) in all cases of severe varus deformity. In their study, alignment targets set during RA-TKA were met in all cases, without over-correction of deformities in any case.

Presently, there are two existing surgical workflows in RA-TKA to achieve pre-balance: pre-resection workflow and mid-resection workflow (distal femur to proximal tibia cut). Pre-resection workflow is used for correctable deformities in which adjusting the implant position within certain limits can achieve both balance and targeted alignment. Once the knee gap is balanced, all bone cuts are made sequentially without the need for jigs or major soft tissue releases. The mid-resection workflow is reserved for those knees where pre-balance cannot be achieved by adjusting the implant position. In these cases, the extension gap is balanced first, followed by the flexion gap.

The delay in patients seeking surgical treatment for advanced osteoarthritis, gave us the opportunity to implement the mid-resection workflow and to establish its utility in correction of severe varus coronal deformities. This workflow in its current form begins with the proximal tibial and distal femoral cuts to balance the extension gap. Even after the cuts were performed, the extension gap remained unbalanced in some severe varus deformities. The only available option was to finish all of the cuts arbitrarily and balance the knee later in a similar manner to an MTKA, thus losing out on a key feature of RA-TKA, with its

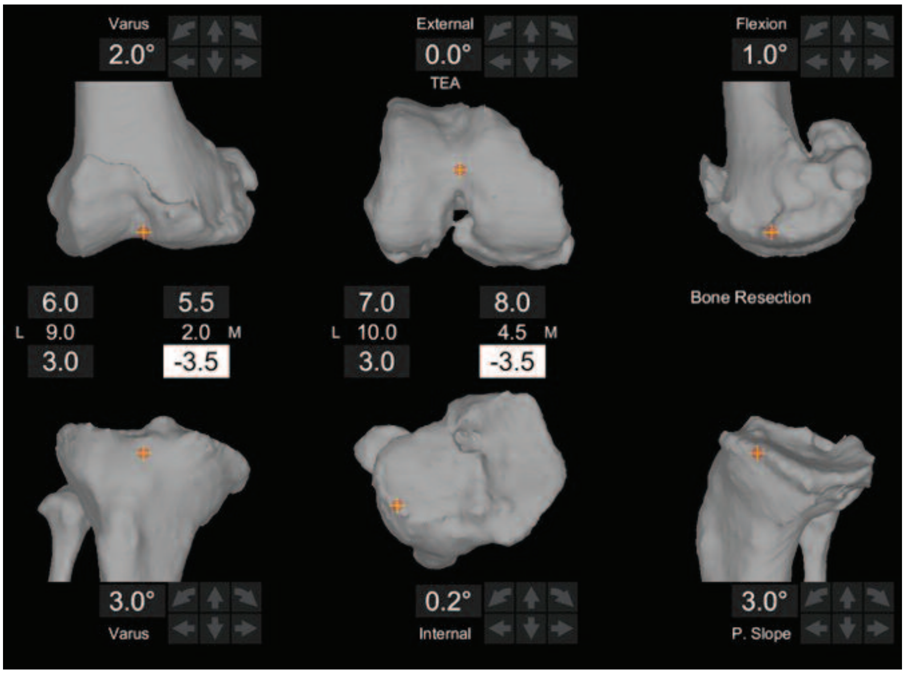


Figure 1. Preoperative CT-based 3D model of the knee showing large postero-femoral and tibial osteophytes.

ability to pre-balance and functionally place the components. This prompted us to look for possible modifications of the mid-resection workflow in order to achieve coronal pre-balance.

There are several reports on the correction of severe coronal deformities of the knee,[15,16] but we are not aware of any that have studied the utility of RA-TKA in the management of severe varus deformities. In this surgical technique, we report on our modification, known as the "enhanced mid-resection workflow" of RA- TKA. We also present an algorithm for surgeons to choose between three workflows to manage cases with optimal pre-balancing being the end-point.

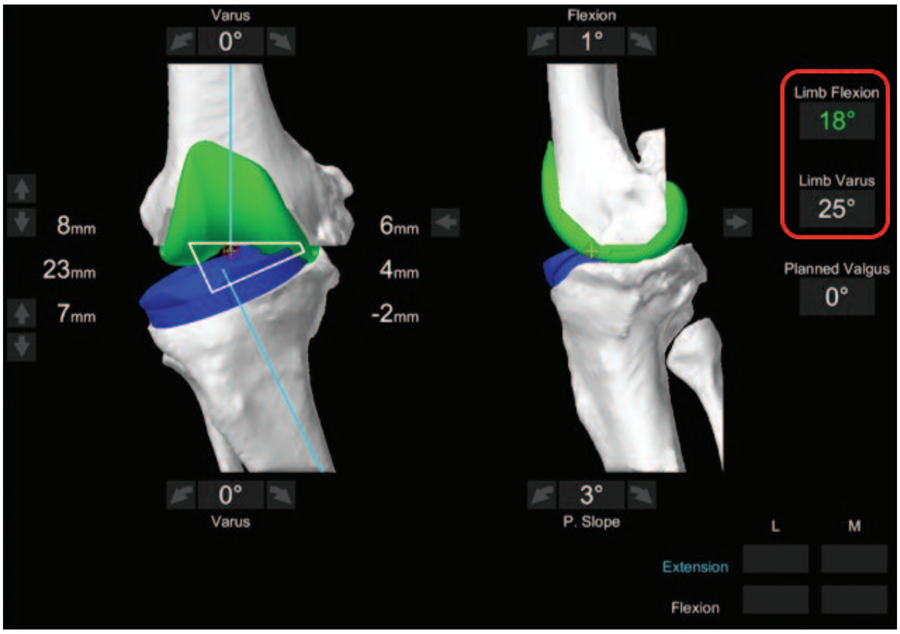


Figure 2. Screenshot from the Mako robotic system monitor showing a coronal deformity of 25° varus and a fixed flexion deformity of 18°. The medial side (4mm gap) is markedly tighter when compared to the lax lateral side (23mm gap).

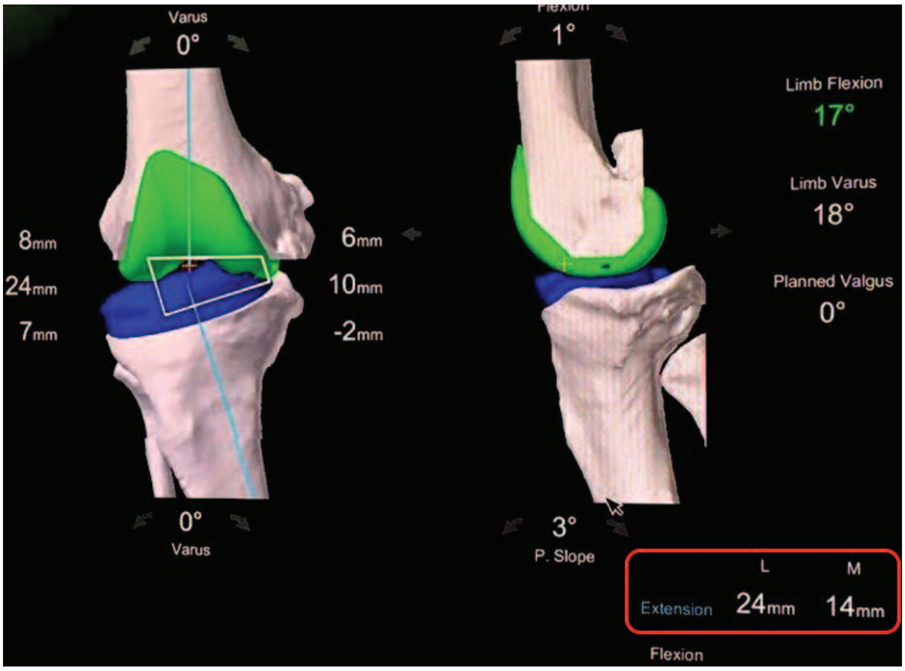


Figure 3. Partial correction of deformity with complete removal of accessible medial femoral and tibial osteophytes. Varus reduced from 25 to 18°. The lateral and medial extension gaps captured are 24 and 14mm respectively.

SURGICAL TECHNIQUE

The robotic-arm-assisted TKA cases were operated on using the Mako system (Stryker, Kalamazoo, Michigan), which is an image-based semi-autonomous robotic system. The implant used was the cemented Triathlon (Stryker, Kalamazoo, Michigan). In all cases, the posterior cruciate ligament (PCL) was sacrificed and all patients received cruciate-retaining femoral components used in conjunction with a condylar-stabilizing (CS) insert.

Preoperative planning

Since this is an image-based system, all patients undergo a preoperative computed tomography (CT) scan of the ipsilateral hip, knee, and ankle by a standard protocol. A patient-specific three-dimensional (3D) model of the knee is developed from the CT using the process of segmentation so that 3D preoperative planning can be performed. The tibial sizing is based on the antero-posterior fit, and femoral sizing is planned based on medio-lateral fit, matching the trochlea, the restoration of the PCO (posterior condylar offset), and the appropriate flexion of the femoral component in order to avoid notching. Both femoral and tibial components are neutral to the mechanical axes in the coronal plane in the preoperative plan, and these are changed intraoperatively to balance the knee.

Surgical exposure, array set-up, and bony registration

All cases were operated using a midline incision and a medial para-patellar arthrotomy, followed by a deep medial collateral ligament (MCL) release. The PCL was sacrificed in all cases. This is followed by insertion of the femoral and tibial pins for array placement. The gross and fine registration of the native bone is done in a manner such that it matches the 3D-CT model of the knee to less than 0.5mm accuracy. Importantly, any accessible osteophytes are removed only after bone registration.

Dynamic joint balancing

Balancing the knee begins with the assessment and recording of the flexion and extension gaps. The knee is tensioned both in flexion and extension to restore physiological lengths of the collateral ligaments by using either manual stresses or osteotomes. Once the gaps are captured, the implant position can be altered in 6° of freedom in order to

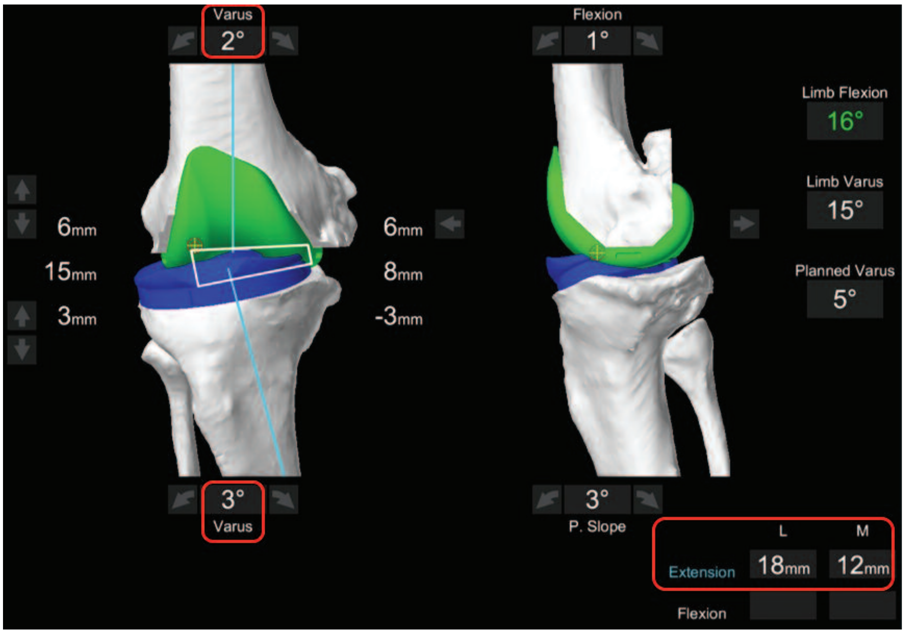


Figure 4. The tibial resection was reduced by 4mm and distal femoral resection reduced by 2mm. This was followed by 3° of varus applied to the tibial component and 2° varus applied to the femoral component, with the fulcrum of correction on the medial side. This resulted in an extension gap of 18mm–12mm, and varus was reduced from 18° to 15°.

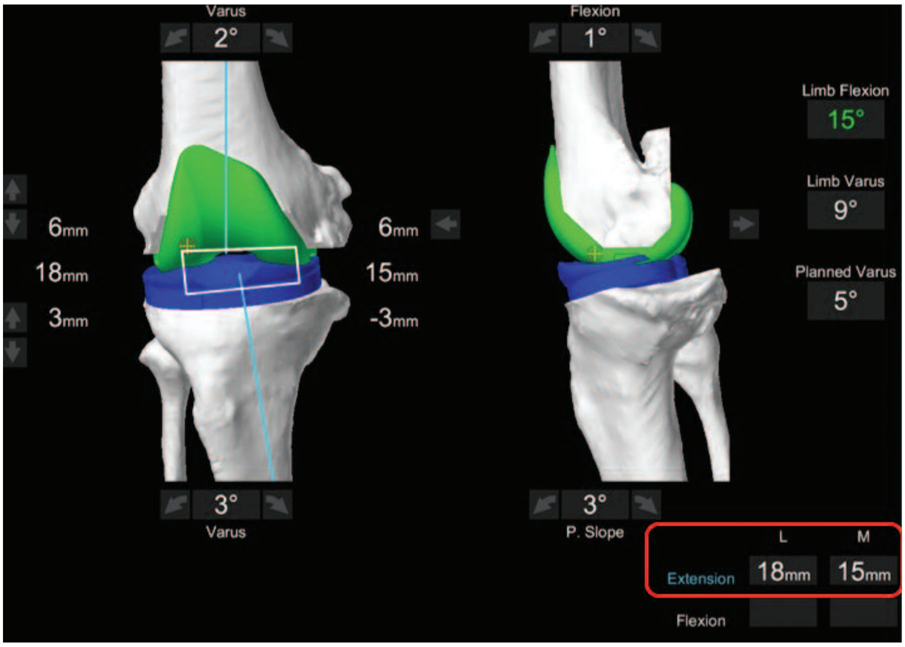


Figure 5. After completion of the mid-resection workflow, removal of medial tibial osteophytes and soft tissue release beyond the mid-coronal plane, the extension gap is still unbalanced. Varus is corrected up to 9°.

balance the knee. The goal is to achieve 18mm gaps in both planes, which corresponds to an 8.5mm distal femur implant thickness + 9.4mm (tibial base plate + 9mm polyethylene thickness) = 17.9mm. Functional alignment strategy[17] was used as a guide to decide the limits of coronal alignment and rotations of the implants. In this workflow, we accept an overall limb varus limit of 5°, with a maximum of 3° for the tibial component and 2° for the femoral component. The tibial slope was set to 3° in the sagittal plane in all cases. The implant positions are adjusted to open up the medial side in a varus knee, and to tighten a lax lateral extension gap. This involves putting varus for the tibial component and external rotation for the femoral component, with the fulcrum or pivot point anchored on the lateral side. A recent technique report outlined that the fulcrum of the coronal plane component placement could be adjusted to differentially affect the medial or lateral gaps.[18] If the gaps are balanced with functional placement of implants, pre-balance is achieved and the surgeon can proceed with bony resections.

If pre-balance is not achieved, we proceed to the mid-resection workflow. In this workflow, extension gaps are balanced first by performing the distal femoral and proximal tibial resections. The extension gap is then assessed with a spacer or knee tensioner. Any residual tightness on the medial side of the tibia can be dealt with by further release of the postero-medial capsule and the semimembranosus muscle attachments. Most knees with moderate deformities can be corrected with these releases.

Severe or substantial varus deformities of the knee, especially those with large osteophytes on the postero-femoral side with associated flexion deformities, can remain unbalanced even after utilizing the mid-resection workflow. We propose the enhanced mid-resection workflow as the solution to achieve a pre-balanced knee before definitive bone cuts are made.

Steps and modifications in the enhanced mid-resection workflow

1. Preoperative 3D model of the knee from the Mako Robotic plan showing large posterior femoral and tibial osteophytes (Fig. 1).
2. In cases of severe varus knee with flexion deformity, deformity is recorded before (Fig. 2) and after osteophyte removal (Fig. 3). These are the accessible medial femoral and tibial osteophytes up to the mid-coronal level.
3. Functional implant positioning. Tibial and femoral varus is applied (maximum 3° in tibia and 2° in the femur) with the pivot point placed laterally to open the medial extension space. Tibial varus effects both medial extension and flexion. In the illustrated case, following 5° of varus, the tibial resection was reduced by 4mm and the distal femoral resection was reduced by 2mm in order to reduce the lateral gap from 23 to 18mm (Fig. 4). Functional positioning of the implants did not achieve pre-balance.

4. Mid-resection workflow is adopted at this stage where the distal femur and proximal tibial cuts are performed, giving us access to the tight postero-medial structures on the tibial side. Further releases are done on the tibial side in an attempt to balance the extension gap (Fig. 5).
5. Since the extension gap is still unbalanced, we move on to the "Enhanced mid-resection workflow," that allows us to take a "provisional postero-medial femoral resection to gain access to the postero-femoral osteophytes and tight capsule. Using the implant planning mode, the femoral implant is posteriorized, such that instead of cutting a standard 8mm, we take a thinner 4 to 5mm cut (Fig. 6). Once the provisional cut is made with the help of the robotic arm, a curved osteotome is used to remove all osteophytes from behind the femur and we release the posterior capsule as needed to balance the gap (Fig. 7). After each step of the sequential release, the gap is reassessed.

   A tibial reduction osteotomy to balance the extension gap is usually reserved when concomitant flexion tightness is anticipated.
6. After the extension gap is balanced (Fig. 8), the femoral implant position is reverted back to the original 8mm postero-medial resection. The knee is flexed to 90° and the flexion gap is captured again using the tensioning device (Fig. 9). This is paramount because the tibial varus is applied and releases may affect the medial flexion gap. Now, residual medial flexion tightness is corrected with appropriate femoral external rotation with the pivot point placed on the lateral epicondyle (Fig. 10). Once the flexion gap is balanced, the remaining bone resections (anterior, anterior and posterior chamfer, posterior medial, and lateral femoral) can be completed.
7. With trialling, the surgeon achieves a perfectly balanced knee using the enhanced mid-resection workflow, with optimal combination of bone cuts and soft tissue releases (Fig. 11).

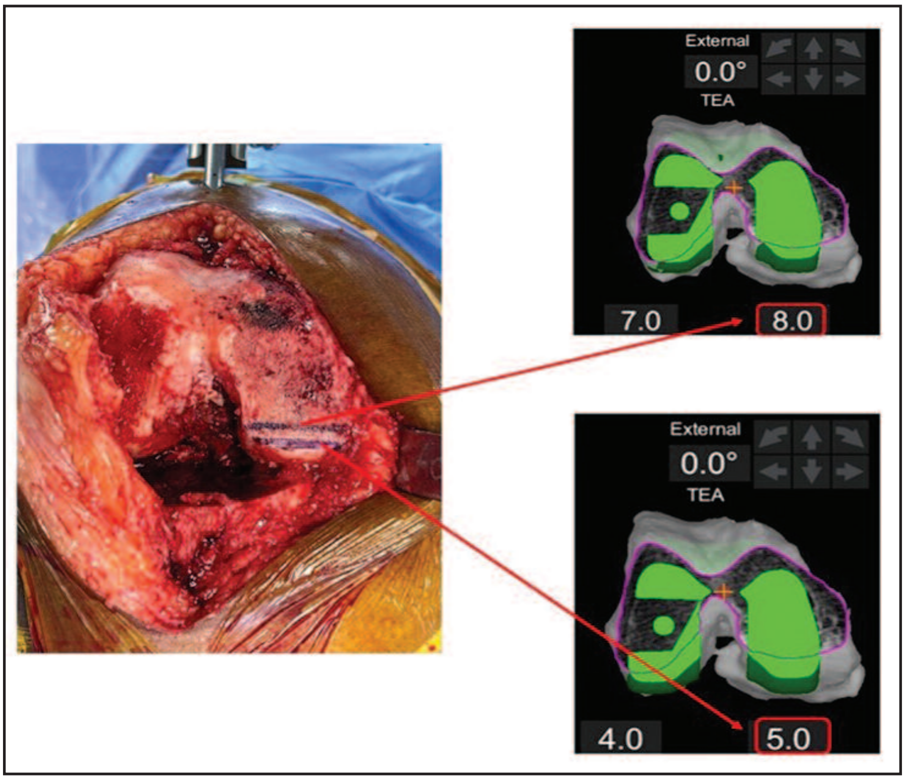


Figure 6. Provisional postero-medial femoral cut planned on the Mako implant planning screen by moving the femoral component posteriorly. The femoral component is restored to the preset plan (8mm postero-medial femoral bone resection depth) after removal of the posterior femoral osteophytes.

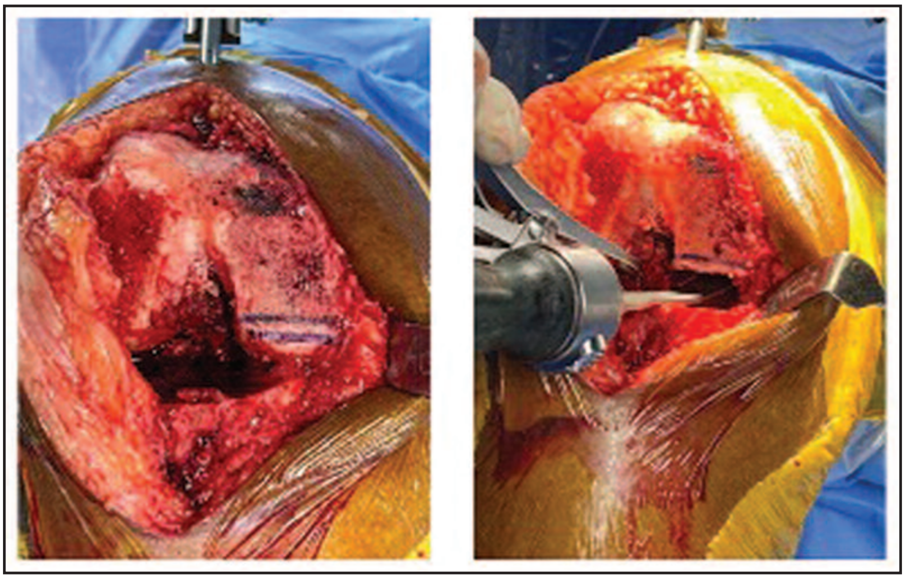


Figure 7. Intraoperative photograph shows the original 8mm postero-medial femoral condyle bone resection marked. A provisional bone cut is taken at a smaller 5mm thickness, thus providing the surgeon access to posterior osteophytes and tight posterior knee capsule.

DISCUSSION

Patients who have advanced knee arthritis associated with severe varus deformities are commonly encountered in our surgical practice. Our ability to use RA-TKA in these severe deformity cases allows us to explore and establish the utility of various existing workflows to achieve pre-balance. Pre-resection workflow is reserved for knees in which pre-balance is achieved simply by altering the position of the implants with minimal or no soft tissue releases. Lustig et al. reported that soft tissue releases are rarely performed or reduced in cases of kinematic or functional alignment.[19] For knees with partially correctible or

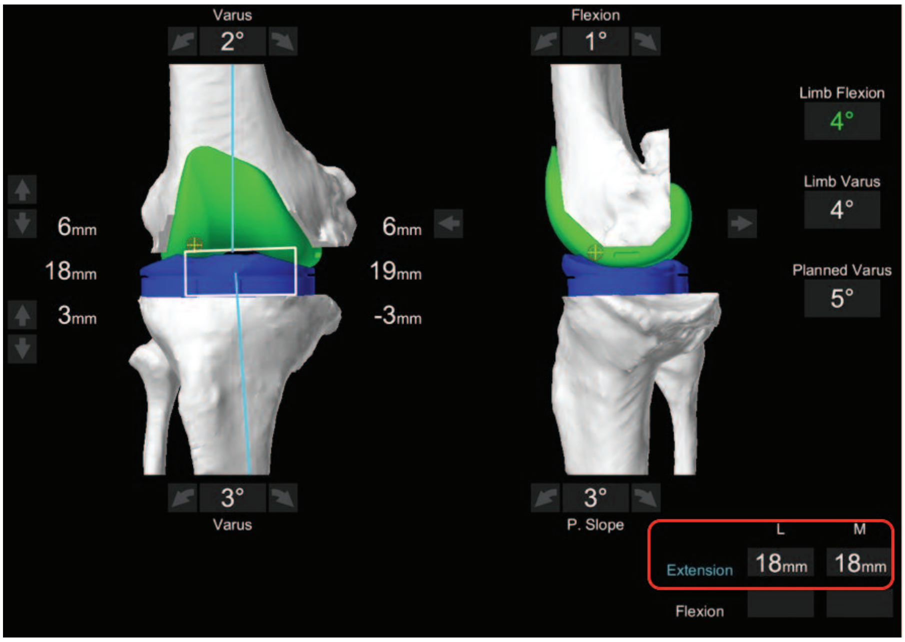


Figure 8. With removal of the femoral osteophytes and release of the tight posterior capsule through the provisional cut, the extension gap is now balanced.

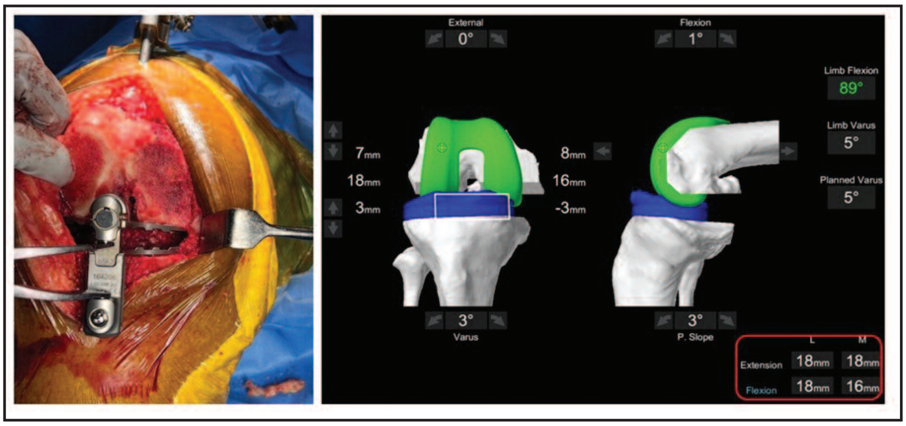


Figure 9. Tensioning device used to assess the flexion gap. The femoral posterior-medial resection thickness is restored to the originally planned 8mm, before flexion gaps are recaptured. In this case illustration, the lateral and medial flexion gaps were captured as 18mm and 16mm respectively.

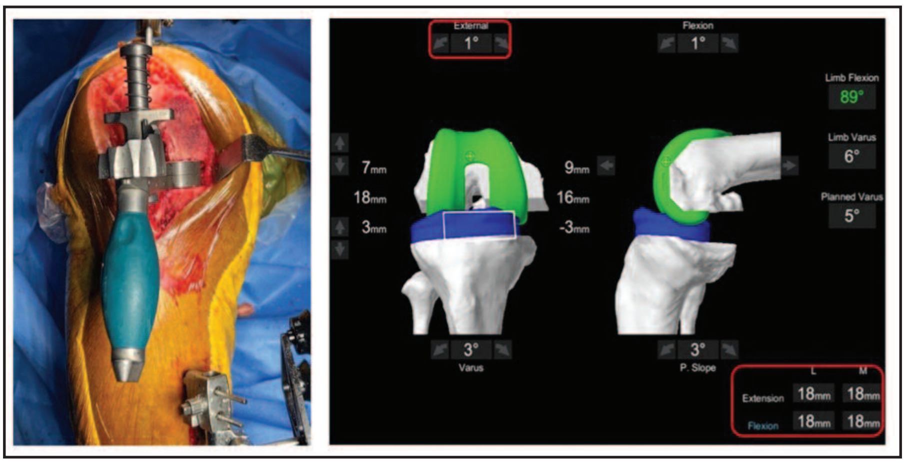


Figure 10. With a femoral external rotation of 1° now applied to balance the flexion gap, all the bone resections are completed to achieve a balanced knee. The spacer, when inserted, depicts a perfect 18mm gap.

un-correctable deformities, mid-resection workflow is recommended. In our experience, while this workflow helped us in achieving pre-balance, in some cases, the initial two cuts allowed us to gain access on the tibial side to do soft tissue releases and or to perform a reduction osteotomy. For some severe varus deformities with large femoral osteophytes and a tight posterior capsule, we found that mid-resection workflow was not sufficient to obtain pre-balance. It was very evident from our experience that recommendations in the algorithm could not be based on the degree of deformity, but rather on the ability to achieve pre-balance or not. The degree of deformity could not be used as a predictor to choose between the three workflows.

Severe varus deformities with medial bone loss and soft-tissue contracture result in medial tightness with compensatory lateral laxity. In MTKA, jigs allow surgeons to perform the tibial resection perpendicular to the mechanical axis, with more bone resected from the uninvolved lateral tibial plateau, and this further contributes to lateral laxity and persistent medial tightness. If too much or too little tibial bone is removed, it can result in increased lateral laxity (as these knees may have lateral laxity to begin with) or medial tightness, respectively. The degree of medial tightness in relation to the lateral gap usually dictates the amount of medial release needed to balance the knee.[6] Bone resection has been shown to be error-prone and variable with manual jig instrumentation.[20,21] Studies have also shown a wide variation in the valgus correction angles needed to restore the femoral mechanical axis, as variations in the relationship between the posterior condylar axis and the trans-epicondylar axis affect the rotation of the femoral implant.[22–24] Standard jig-based bone resections are an over-simplification of the surgical plan needed to optimize femoral rotation to balance the flexion gap in these primary TKA cases.[24] RA-TKA is superior to manual jig-based instrumentation in terms of accuracy of bone resection and component positioning.[25–27]

In RA-TKA, surgeons can preoperatively assess and plan bone resections, based on the mechanical axes and rotational landmarks, which are accurately derived from the CT scan. This obviates the need for measuring the valgus correction angle. Surgeons can decide femoral rotation, relative to the PCA/TEA, and accurately manage flexion gap imbalances. Pre-balancing the knee using the feature of dynamic joint balancing gives the ability to either reduce the lateral extension gaps for lateral laxity or increase the medial gaps in a severely varus knee. Sherman et al. reported on the ease of balancing the knee by applying varus/valgus and femoral rotational changes by adjusting the fulcrum point during RA-TKA.[18] Balancing the knee with equal flexion-extension gap values derived from the robotic system has been quantitatively shown to achieve balance by definition of intra-compartmental pressure difference assessment with sensor technology.[8] The precision of robotic arm assisted bone preparation, along with dynamic gap balancing, helps us predict the gaps consistently, even before the bone resections are done.

We wanted to investigate if severe varus knees could be pre-balanced using the extension-gap first technique of a mid-resection workflow. After the distal femur/proximal tibial cuts and removal of osteophytes around the tibia are done, the extension gaps remained unbalanced in many severely deformed varus knees. The only way to balance the extension gaps further is to gain access to the femoral osteophytes on the medial side and the tight postero-medial capsule. The precise and accurate bone cuts performed by the robotic arm gave us the ability to make provisional postero-medial cuts on the femoral side. The usual postero-medial cut in a triathlon femur is 8mm. We decided to perform a provisional posterior-medial femoral bone resection, less than the planned 8mm; just enough to gain access to the posterior structures. For

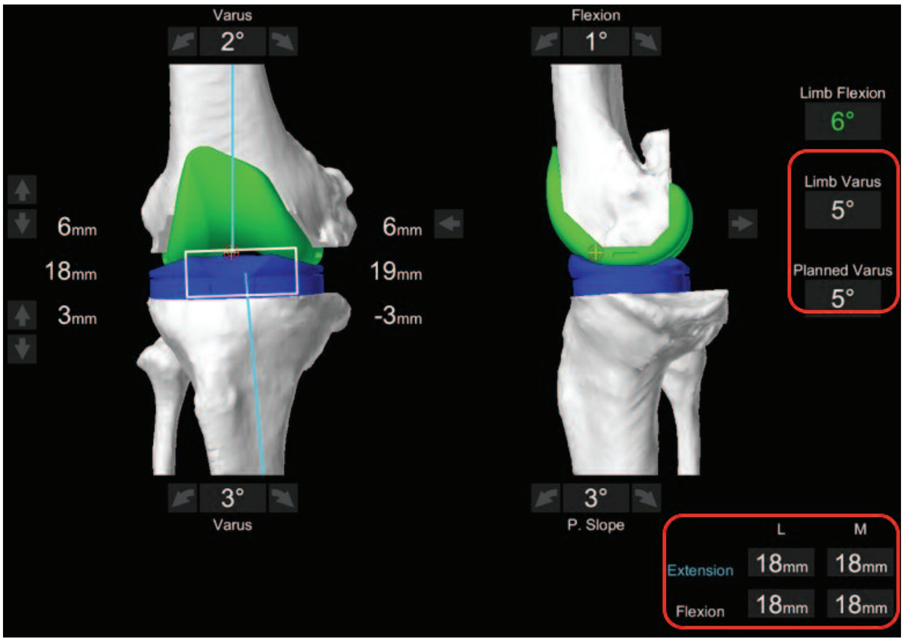
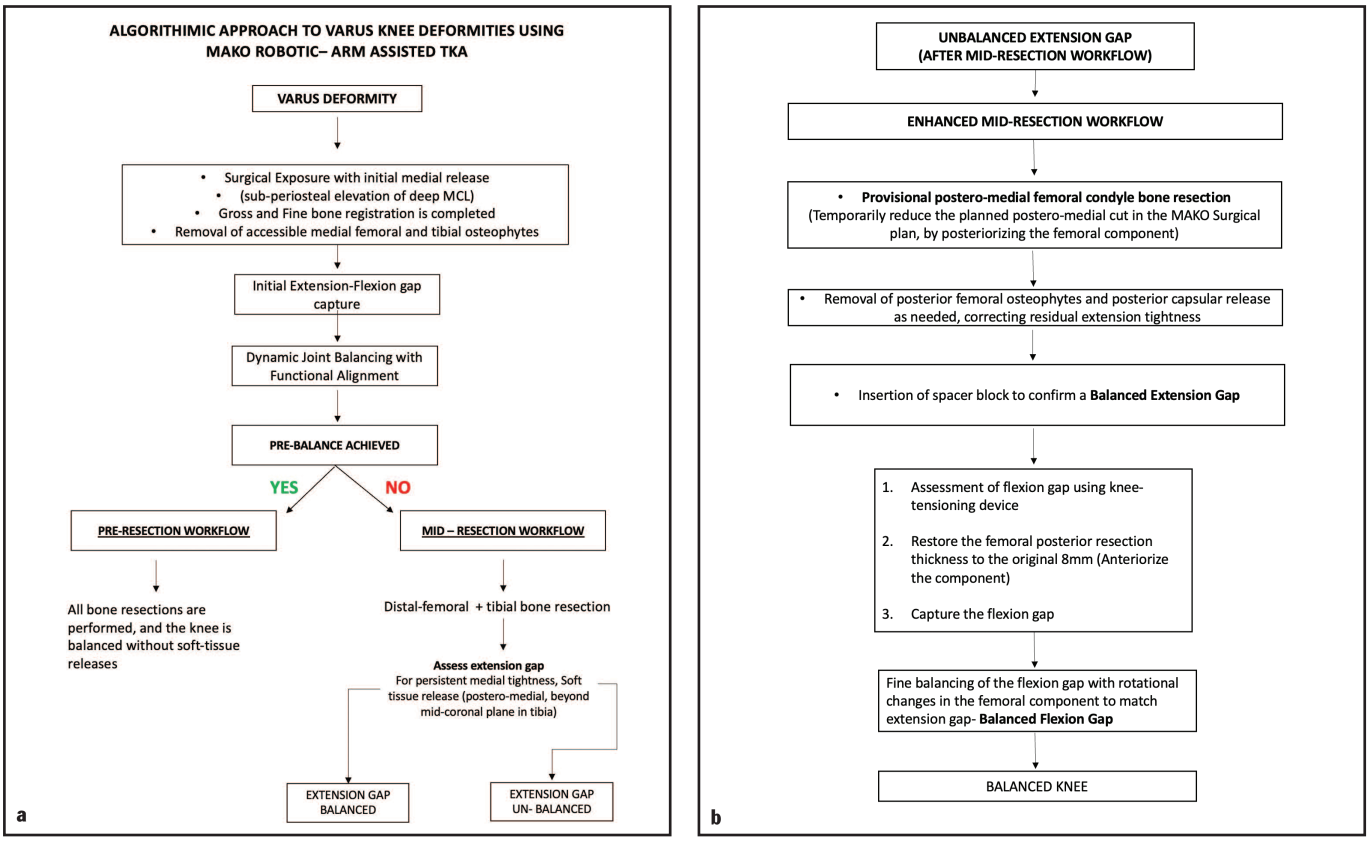


Figure 11. Final achievement of a balanced knee in flexion and extension, with no residual medial tightness or lateral laxity. A 9mm insert was used in this case with the limb varus matching a planned varus of 5°.



Figures 12a and b. Algorithmic approach to varus deformities with the Mako robotic system.

the sake of uniformity, we took the cut around 4 to 5mm, which is exactly 50% of the originally planned resection thickness. This is done by temporarily moving the femoral component posterior on the robotic surgical plan. A definitive cut is not taken since the rotation of the femur and the flexion gap assessment has not been done yet. Once the provisional cut is made, the femoral osteophyte removal is done first followed by postero-medial capsular release. This release is sequentially done until the lateral and medial extension gaps are balanced to 18mm. Matching the flexion gap to extension gap is now relatively easy to achieve and involves optimizing the rotation of the femoral component, based commonly on the intent to close the lateral flexion or open the medial flexion gap.[18]

Apart from quantitative balancing, the enhanced mid-resection workflow has other advantages. Firstly, it optimizes the thickness of bone cuts, and thus the technique is bone conserving. Secondly, gap balancing is more objective and can be accomplished in a gradual manner as each release can be quantified and confirmed in a step-wise fashion with visual feedback on the screen. This is better than relying on the subjective feel of the surgeon to assess correction of gaps.[7] Thirdly, the conservative bone resection and limited soft-tissue release allows the surgeon to balance the knee and restore the joint line using a relatively thin polyethylene insert.

It has also become evident that we cannot make recommendations in the algorithm based on the degree of varus deformity as there was no consistency between the degree of varus and when the knee could be pre-balanced. Hence the proposed algorithm is driven by when the knee gets pre-balanced. We are confident that the algorithm will guide surgeons to choose between the pre-resection, mid-resection, and enhanced mid-resection RA-TKA surgical workflows (Figs. 12a and 12b) in order to achieve consistent results both in terms of functional alignment and adequate balancing irrespective of the nature of varus deformity.

CONCLUSION

Robotic technology has been established in an attempt to improve the accuracy of bone resection, for accurate component positioning, and to reduce soft tissue damage compared to manual TKA. However, the utility of robotics has mostly been assessed in cases with mild to moderate varus deformities. The utility and benefit of robotics in severe coronal deformities has not been studied widely. To our knowledge, this is the first surgical technique outlining the approach to severe varus deformities of the knee using RA-TKA. With this new surgical technique, surgeons can achieve pre-balance in severe coronal deformities in a reliable and consistent manner. STI

AUTHORS' DISCLOSURES

Dr. Masilamani, Dr. Annapareddy, Dr. Hippalgaonkar, Dr. Roche, and Dr. Reddy are consultants for Stryker.

Dr. Mulpur has no conflicts of interest to disclose.

REFERENCES

1. Lotke PA, Ecker ML. Influence of positioning of prosthesis in total knee replacement. J Bone Joint Surg Am 1977;59(1):77–9.
2. Hsu RW, Himeno S, Coventry MB, et al. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. Clin Orthop Relat Res 1990;(255):215–27.
3. Ritter MA, Faris PM, Keating EM, et al. Postoperative alignment of total knee replacement. Its effect on survival. Clin Orthop Relat Res 1994;(299):153–6.
4. Bargren JH, Blaha JD, Freeman MA. Alignment in total knee arthroplasty. Correlated biomechanical and clinical observations. Clin Orthop Relat Res 1983;(173):178–83.
5. Sculco TP. The role of constraint in total knee arthoplasty. J Arthroplasty 2006;21(4 Suppl 1):54–6.
6. Okamoto S, Okazaki K, Hiroaki M, et al. Lateral soft tissue laxity increases but medial laxity does not contract with varus deformity in total knee arthroplasty. Clin Orthop Relat Res 2013;471(4): 1334–42.
7. MacDessi SJ, Wood JA, Diwan AD, et al. Surgeon-defined assessment is a poor predictor of knee balance in total knee arthroplasty: a prospective, multicenter study. Knee Surg Sports Traumatol Arthrosc 2021; 29(2):498–506.
8. Chang JS, Kayani B, Wallace C, et al. Functional alignment achieves soft-tissue balance in total knee arthroplasty as measured with quantitative sensor-guided technology. Bone Joint J 2021;103-B(3):507–14.
9. Zhang J, Ndou WS, Ng N, et al. Robotic-arm assisted total knee arthroplasty is associated with improved accuracy and patient reported outcomes: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc 2021. Ahead of print.
10. Hampp EL, Chughtai M, Scholl LY, et al. Robotic-arm assisted total knee arthroplasty demonstrated greater accuracy and precision to plan compared with manual techniques. J Knee Surg 2019;32(3):239–50.
11. Kayani B, Konan S, Tahmassebi J, et al. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: a prospective cohort study. Bone Joint J 2018;100-B(7):930–7.
12. Khlopas A, Chughtai M, Hampp EL, et al. Robotic-arm assisted total knee arthroplasty demonstrated soft tissue protection. Surg Technol Int 2017;30: 441–6.
13. Hampp EL, Sodhi N, Scholl L, et al. Less iatrogenic soft-tissue damage utilizing robotic-assisted total knee arthroplasty when compared with a manual approach: A blinded assessment. Bone Joint Res 2019;8(10): 495–501.
14. Marchand RC, Sodhi N, Khlopas A, et al. Coronal correction for severe deformity using robotic-assisted total knee arthroplasty. J Knee Surg 2018; 31(1):2–5.
15. Mullaji AB, Padmanabhan V, Jindal G. Total knee arthroplasty for profound varus deformity: technique and radiological results in 173 knees with varus of more than 20 degrees. J Arthroplasty 2005;20(5): 550–61.
16. De Muylder J, Victor J, Cornu O, et al. Total knee arthroplasty in patients with substantial deformities using primary knee components. Knee Surg Sports Traumatol Arthrosc 2015;23(12):3653–9.
17. Oussedik S, Abdel MP, Victor J, et al. Alignment in total knee arthroplasty. Bone Joint J 2020;102-B(3): 276–9.
18. Sherman WF, Freiberger C. Use of fulcrum positioning as a balancing tool during total knee arthroplasty on a robotic platform. Arthroplast Today 2021;8: 176–80.
19. Lustig S, Sappey-Marinier E, Fary C, et al. Personalized alignment in total knee arthroplasty: current concepts. SICOT-J 2021;7:19.
20. Hohmann E, Tetsworth K. Do manual cutting guides for total knee arthroplasty introduce systematic error? Int Orthop 2016;40(2):277–84.
21. Iorio R, Bolle G, Conteduca F, et al. Accuracy of manual instrumentation of tibial cutting guide in total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2013;21(10):2296–300.
22. Mullaji AB, Shetty GM, Kanna R, et al. The influence of preoperative deformity on valgus correction angle: an analysis of 503 total knee arthroplasties. J Arthroplasty 2013;28(1):20–7.
23. Shi X, Li H, Zhou Z, et al. Individual valgus correction angle improves accuracy of postoperative limb alignment restoration after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2017;25(1): 277–83.
24. Gurava Reddy AV, Mathur RK, Mugalur A, et al. Reference axes for optimal femoral rotational alignment in varus osteoarthritic Indian knees - A CT based study. J Clin Orthop Trauma 2016;7(Suppl 2):215–9.
25. Wan X, Su Q, Wang D, et al. Robotic arm-assisted total knee arthroplasty improves preoperative planning and intraoperative decision-making. J Orthop Surg Res 2021;16(1):670.
26. Deckey DG, Rosenow CS, Verhey JT, et al. Robotic-assisted total knee arthroplasty improves accuracy and precision compared to conventional techniques. Bone Joint J 2021;103-B(6 Supple A):74–80.
27. Sires JD, Craik JD, Wilson CJ. Accuracy of bone resection in Mako total knee robotic-assisted surgery. J Knee Surg 2021;34(7):745–8.

Surg Technol Int. 2022, June 05; 41. pii: sti41/1612