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Mukesh Laddha & Sahu Gaurav

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ORIGINAL ARTICLE

Assessment of Limb Alignment and Component Placement After All Burr Robotic-Assisted TKA

Mukesh Laddha[1] · **Sahu Gaurav**[2]

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Abstract

Background All burr robotic-assisted total knee arthroplasty (R-TKA) is the new way of doing TKA without conventional jigs and saw. The aim of this study is to assess the accuracy of limb alignment and component placement after R-TKA.

Methods and Materials This is the prospective study of 63 patients who underwent R-TKA between March and October 2019. Standing scanogram and AP/lateral radiograph were done on day of discharge, 5th day after surgery to calculate limb alignment and component placement angles in coronal and sagittal plane. Deformity correction Bone Ninja software had been used to calculate all this angles.

Results Mean difference between robotic achieved and postoperative limb alignment was 1.24°. Mean difference between planned and achieved component placement in coronal and sagittal plane for tibia was 0.33° and 0.66° and for femur was 0.62° and 0.30°, respectively. Posterior condylar offset difference was 0.03. As per planned by Navio software, R-TKA had reduced the overall outlier of coronal limb alignment from 3° to less than 1.2° and component placement malposition to less than 1° in coronal and sagittal plane.

Conclusion R-TKA provides near perfect limb alignment and near accurate femoral/tibial component placement as planned in both coronal and sagittal plane. Posterior condylar offset was also perfectly maintained. R-TKA had reduced the overall outlier of coronal limb alignment from 3° to less than 1.2° and component placement malposition to less than 1° in coronal and sagittal plane.

Keywords Robotic TKA · Component placement · Limb alignment · PCO · TKA

Introduction

End-stage arthritis of the knee is effectively managed with total knee arthroplasty (TKA) [1]. According to the database of Healthcare Cost and Utilization Project (HCUP) and Journal of American Medical Association 600,000 TKAs were performed by 2010 [2]. Most of TKAs significantly relieves pain and improve functional outcome [3], but 20% patients were unsatisfied within 1 year of surgery [4, 5]. Thus, it is of significance to achieve the perfect component placement or alignment in all three planes with neutrally aligned limb with mechanical axis 180° ± 3° and no tibia–femoral rotational mismatch [6, 7]. In frontal plane, varus or valgus deviations of > 3° are associated with an increased loosening rate [8]. In sagittal plane, posterior tilting of tibial component affects femoral rollback on tibia [9]. In transverse plane, excessive internal rotation of components increases patellar subluxation and anterior knee pain [10]. Appropriate implant positioning in all three planes is difficult to achieve using saw and intra- or extramedullary alignment guides [11]. To improve coronal alignment and component placement, computer-aided surgery (CAS) [12] had been introduced since long but alignment beyond ± 3° was shown in 4–21% of cases [13]. Kinematic balanced knee improves biomechanical and functional outcome by restoration of patient's pre-arthritic anatomy and axis with balanced knee through entire ROM [14]. In kinematic balanced knee, distal and posterior

✉ Mukesh Laddha
drmsl1812@gmail.com; dr.msl@rediffmail.com

Sahu Gaurav
sahujigauravji@gmail.com

1 Robotic Joint Replacement and Arthroscopy Specialist (Shoulder, Knee and Hip Surgeon), RNH Hospital, Balraj Marg, Near Dhantoli Garden, Dhantoli, Nagpur, Maharashtra 440022, India

2 Consultant Orthopaedic Surgeon, Dhamtari Christian Hospital, Dhamtari, Chhattisgarh, India

femoral joint lines of femoral component are balanced to the original primary transverse axis of femur [14]. Patient's pre-arthritic state is achieved by transforming arthritic knee to its pre-arthritic state via 3D modelling from preoperative CT scan or MRI or simply performing tibial resection in 2°–3° of varus [15]. It is highly difficult to get kinematic balanced TKA with routine jigs [16].

The aim of our study is to assess the accuracy of this novel method of doing TKA without using any conventional jigs and saw; it is all burr robotic-assisted TKA (R-TKA). We also want to assess the accuracy of limb alignment and component placement both in coronal and sagittal plane on simple radiographs along with accuracy of maintaining posterior condylar offset. We also want to assess whether the outlier of overall coronal limb alignment can be reduced below 3° using this technique. To the best of our knowledge, this is first of its kind of study in India.

Methodology

This was a prospective study which includes 63 cases of severe tricompartmental osteoarthritis of knee who were treated surgically by single surgeon (ML) at RNH Hospital, a recognized Centre for Robotic Joint Replacement and Sports Medicine, between March 2019 and December 2019. Pre- and postoperative standing scanogram were taken for the assessment of limb alignment. Pre- and postoperative routine AP and lateral X-rays were taken for coronal and sagittal plane assessment of both tibial and femoral components. Postoperative radiographs were done on 5th day after surgery at the time of discharge. For proper dead lateral view of knee, C-arm images were used for calculation of posterior condylar offset ratio (PCO). The inclusion criteria of our study was primary severe osteoarthritis, rheumatoid arthritis, post-traumatic arthritis of knee joint and the exclusion criteria were unicondylar arthroplasty, bone defect requiring bone graft or augments and stiff knee.

Bone Ninja Software was used to measure all pre- and postoperative angles. It is an iPad-based app, a teaching tool developed by Dr. Shawn Standard and Dr. John Herzenberg at the International Centre for Limb Lengthening, Baltimore. The analysis of the radiographs is based on methodology taught for more than 2 decades at their annual Baltimore Limb Deformity Course [17]. This app is quite accurate in calculating pre- and postoperative angles for deformity correction, hence same had been applied here. The principles of angle calculation remain same, but this is being applied for the first time in TKA patients.

Robot-Assisted TKA

The NAVIO robotics-assisted surgical system involves handheld robotics with an intuitive CT-free registration and patient-specific planning processor [18]. The NAVIO software guides surgeon in creating implant plan that localizes components and balance soft tissue, and using handheld instrument with multiple control modes to help the surgeon to precisely create 3D model of bone for implantation of tibial and femoral components. The system then allows the surgeon to plan the bone resection and implant sizes prior to beginning the bone resection with the burr tool. It also objectively mentions tightness and laxity of both collateral ligament before the bone cuts. Component placement planning is done as per pre-operative deformity and ligament balancing shown on screen before bone cuts. The system tracks the patient's limb and the hand-held high-speed milling or burring tool attached to its arm of 5 mm diameter, stopping or retracting the burr to keep the surgeon within the defined limits of the implant resection. The resected surface of bone is as flat as obtained after saw cut-provided burr is used properly in circumferential manner (Fig. 1a). The digital angel is then used to recheck the cut surface (Fig. 1b). Internal water-cooling and irrigation is integrated into the milling tool to prevent thermal necrosis. After completing milling, trial implants were placed and soft tissues were balanced. Balance in collateral ligaments is shown objectively before and after completion (Fig. 1c). The final components were then inserted manually after cement application (Fig. 1d).

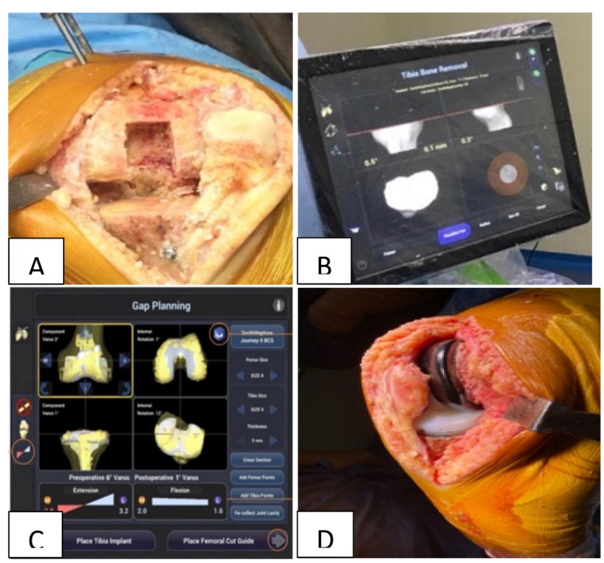

Fig. 1 **a** Smooth cut surface, **b** rechecking with digital angle, **c** component placement and gap balancing, **d** final implants

Radiological Assessment

Bone Ninja Software is used for the calculation of different radiological alignment parameters based on The Knee Society Total Knee Arthroplasty Roentgenographic Evaluation and Scoring System [16]. The coronal tibiofemoral mechanical angle/limb alignment is formed by drawing a line from the centre of the femoral head down to centre of the ankle through the centre of the knee (Fig. 2a). The coronal femoral component angle (CFA)/mechanical lateral distal femoral angle (mLDFA) is defined as the angle between the femoral mechanical axis and the tangent formed by the distal femoral condyle (Fig. 2b). The coronal tibial component angle (CTA)/mechanical medial proximal tibial angle (mPTA) was measured as the angle between the tibial mechanical axis and the sclerosed part of lateral and medial tibial plateau (Fig. 2c). Flexion of the femoral component is measured as the angle between the line across the bottom of the femoral implant and the femoral shaft axis (Fig. 3a) [19]. Lateral (or sagittal) tibial component angle, is ideally positioned so that the tibia is 0°–7° flexed compared to right angle with the tibial plate (Fig. 3b). To calculate posterior condylar offset (PCO) ratio, a true lateral knee radiograph is necessary which were taken on C-arm pre- and postoperatively. It is a distance in millimetres from the tangent of the femoral diaphysis posterior cortex to the posterior condylar margin ratio to the distance in millimetres from the posterior condylar border to the tangent of the femoral diaphysis anterior cortex (Fig. 3c).

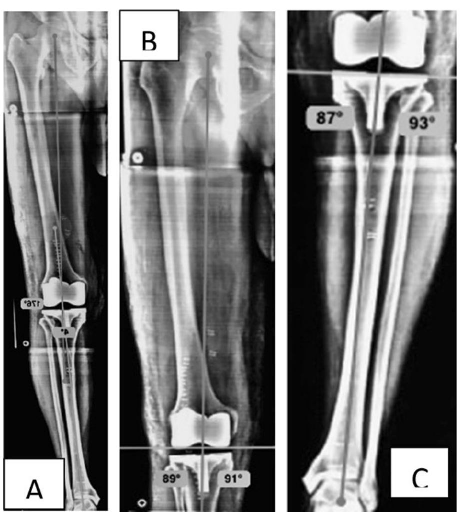

Fig. 2 **a** Overall coronal limb alignment, **b** femoral component coronal placement, **c** tibial component coronal placement

Results

Out of 63 cases, 39 (61.9%) were female and 24 (38.1%) were male. Though there was preponderance of females, there was no significant difference in their age distribution ($p=0.167$). Mean age was 66.42 ± 7.45 years. 33 (52.38%) knees were right-sided and 30 (47.62%) knees were left sided. The mean preoperative limb alignment on standing scanogram was 12.9° ± 4.55° varus.

The mean postoperative limb alignment on standing scanogram was 3.71° ± 1.79° varus. As we aimed for kinematic balanced knee, the mean difference between pre- and postoperative varus degrees on standing scanogram was 9.19° ± 4.40°. Thus, positive, fairly strong and significant correlation was indicated by $r=0.275$ and $p=0.050$. The mean for intraoperative hip–knee–ankle varus degree after release shown by robotic was 8.55° ± 4.02° (Table 1). The mean for planned varus correction by robotic was 2.04° ± 0.97°. The mean for achieved varus degree shown by robotic was 2.47° ± 1.61°. The mean difference between planned and achieved varus degree by robotic was − 0.42° ± 1.32° with $p=0.013$. The mean difference between intraoperative (8.55°) varus degree and achieved (2.47°) varus degree shown by robotic was 6.08° ± 3.63° with $p=0.001$. The difference between postoperative varus on standing scanogram (3.71°) and achieved by robotic (2.47°) at end of operative procedure was 1.24°. Also,

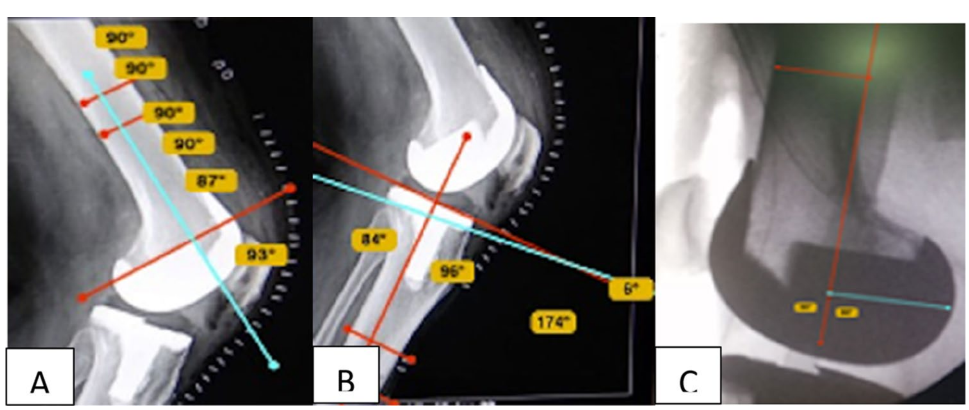

Fig. 3 **a** Sagittal femoral component, **b** sagittal tibial component, **c** PCO ratio

postoperative varus degree on scanogram and achieved by robotic was positive, fairly strong and significant in correlation as indicated by $r=0.4047$ and $p=0.001$ value.

For tibial component accuracy, we measured mPTA in coronal plane. Mean planned varus degree by robotic was 1.67° ± 1.11° and the mean achieved varus degree on AP radiograph was 2.0° ± 1.11° (Table 2). The mean difference between planned and achieved was – 0.33° which is significant as $p=0.008$. Correlation between planned and achieved in tibial component placement was positive, fairly strong and significant as shown by $r=0.631$ and $p=0.001$. In sagittal plane, mean planned tibial slope by robotic was 5.76° ± 0.66 and mean achieved tibial slope on dead lateral radiograph was 5.10° ± 0.96 (Table 2). The mean difference was 0.66 which was significant as $p=0.001$. Correlation between them was negative and non-significant as shown by $r=0.086$ and $p=0.501$.

For femoral component accuracy, we measured mLDFA in coronal plane. Mean planned varus degree by robotic was 0.32° ± 0.47° and the mean achieved varus degree on AP radiograph was 0.94° ± 0.67° (Table 3). The mean difference between planned and achieved was – 0.62° which is significant as $p=0.001$. Correlation between planned and achieved femoral component in coronal plane was positive and non-significant as indicated by $r=0.1818$ and $p=0.1539$. In sagittal plane, mean planned flexion degree by robotic was 2.62° ± 1.04°. The mean achieved flexion degree on dead lateral radiograph was 2.32° ± 1.04° (Table 3). The mean difference is 0.31° which was significant as $p=0.001$. Correlation between planned and achieved femoral component in sagittal plane was positive, strong and significant as indicated by $r=0.7824$ and $p=0.0001$.

For 30 patients PCO, we have taken the ratio on dead lateral view of C-arm image, mean preoperative PCO ratio was 1.27 ± 0.17 and mean postoperative PCO ratio was 1.23 ± 0.15. The mean difference between pre- and postoperative PCO was 0.03 which was significant as $p=0.050$. Correlation between pre- and postoperative means of PCO ratio was positive, strong and significant as indicated by $r=0.821$ and $p=0.0001$.

Discussion

TKAs have shown long-term success rate, some concern still persists regarding limb alignment and component placement as they are risk factor for aseptic loosening [20]. Coronal alignment had an important role for well-functioning TKA [21]. Earlier studies have shown that coronal plane alignment within the range of 3° varus/valgus is associated with better survival of the prosthesis and this cannot be achieved by conventional method in 30% of cases [22]. For this reason, CAS was introduced for TKA. Mason et al. [23] performed a meta-analysis for comparison between CAS-TKA and conventional TKA alignment and found that mechanical axis malalignment of greater than 3° occurred in 9.0% of

Table 1 Statistics summary of preoperative, intraoperative and postoperative limb alignment

Parameter	Variable	Cases	Mean	Std. dev.	Min	Max
X-ray varus degree	Pre-op X-ray varus	63	12.90	4.55	4	25
	Post-op X-ray varus	63	3.71	1.79	1	8
Robotic varus degree	Intra-op varus	63	8.56	4.03	0	20
	Planned varus	63	2.05	0.97	0	4
	Achieved varus	63	2.47	1.62	0	8

Table 2 Statistics summary of intraoperative and postoperative tibial component placement

Parameter	Variable	Cases	Mean	Std. dev.	Min	Max
Tibial component coronal plane	Planned	63	1.67	1.11	0	3
	Achieved	63	2.0	1.11	– 1	4
Tibial component sagittal plane	Planned	63	5.76	0.67	4	7
	Achieved	63	5.10	0.96	2	7

Table 3 Statistics summary of intraoperative and postoperative femoral component placement

Parameter	Variable	Cases	Mean	Std. dev.	Min	Max
Femoral component coronal plane	Planned	63	0.32	0.47	0	1
	Achieved	63	0.94	0.67	0	2
Femoral component sagittal plane	Planned	63	2.62	1.04	0	4
	Achieved	63	2.32	1.04	0	4

CAS-TKA versus 31.8% of conventional TKA cases. Thus, for further research and improvement in limb alignment and component placement, robotic TKA surgery was introduced. Song et al. [24] performed a prospective randomized study on 100 patients of primary TKA and found that robotic-arm-assisted surgery improves accuracy of mechanical alignment compared to conventional TKA with reduced outliers of greater than 3° in planned alignment (0% versus 24%, $p < 0.001$). Also, in our study, the mean postoperative varus on standing scanogram is 3.71° and intraoperative robotic achieved varus is 2.47° on lying down position. Thus, the outlier for overall limb alignment is reduced much below 3° and on average its 1.24°. Bellemans et al. [25] had reported that restoring patients with constitutional varus to neutral mechanical alignment may not optimize outcomes. Using kinematic alignment principles to resect tibia in a few degrees of varus and re-establish the obliquity and location of pre-arthritic joint line should require minimum soft tissue release and results in a more "natural feeling" knee [26]. Vanlommel et al. [27] reported that pre-operatively deformed varus knees that were left in mild mechanical varus (3°–6°) at TKA had greater post-operative functional scores compared to knees corrected to mechanical neutral alignments (0° ± 3°). So believing in same principle of kinematic balance, our study also showed overall limb alignment is 3.47° varus which can be very well achieved with R-TKA. Michael et al. [28] reported that changes in lower limb alignment between supine to standing positions across knee suggests soft tissue envelope restraining the knee may have a greater influence on dynamic alignment changes than the underlying bony deformity. Their study demonstrates that for osteoarthritic knees difference was 1.1° more varus ($p = 0.009$) and TKA knees was 1.9° more varus ($p < 0.001$). Our study also shows similar difference in limb alignment from supine to standing position. Our study also shows 1.24° more varus between robotic achieved (supine position) to postoperative standing scanogram.

Sharkey et al. [29] performed a retrospective review of 212 revision surgeries after primary TKAs and reported component malalignment and malposition to be present in 11.8% of revisions, leading to both early (less than 2 years from the index procedure) and late (more than 2 years from the index procedure) failures. According to Baier et al. [30], the femoral varus/valgus alignment accuracy of 0.3 ± 1.5° and flexion alignment accuracy of 3.0 ± 2.1° was observed. They achieved tibial varus/valgus alignment error of 0.0 ± 0.6 and slope alignment error of 5.4 ± 1.2° using image-free CAS system. Lad et al. [31] reported mean placement of tibial component in coronal plane (91.30°) and sagittal planes (3.60°) was significantly accurate with CAS. The difference was statistically insignificant for mean coronal alignment of the femoral components 90.34° in navigation group and 90.54° in jig group. Garvin et al. [32] reported that femoral coronal alignment was within ± 2° of neutral in 94% of the specimens. Sagittal alignment was within 0°–5° of flexion in all specimens. Navigated freehand bone cutting (NFC) system used in all specimens. From all above-mentioned studies, it is quite clear that component malposition is quite common after conventional and CAS-TKA. Hence, in Bellemans et al.'s [33] study, 25 patients underwent robotic-arm-assisted TKA and achieved femoral and tibial implant alignment within 1° of planned positions in all three planes. Similar results were achieved in our study, femoral and tibial component placement was within 1° of the planned position in both coronal and sagittal planes.

Restoration of PCO plays an important role in the optimization of active knee flexion during weight-bearing conditions after posterior-stabilized TKA, while it has no benefit to non-weight-bearing knee flexion or any other clinical result [34]. According to Bauer et al. [35] study of 410 cases, pre-op PCO was 28.3 and post-op PCO was 29.4 with mean difference of 1.1. In our study, we observed 30 knees for PCO, mean preoperative PCO ratio is 1.26 and mean postoperative femoral PCO ratio is 1.22. The mean difference is 0.04 which is significant as $p = 0.050$. Thus, PCO ratio is maintained after all burr robotic-assisted TKA.

Limitations of our study are that we were unable to calculate axial component placement angle as CT scan was not done. Another limitation is that postoperative patient satisfaction and clinical outcome were also not studied. Also, whether this accurate component placement and limb alignment improve longevity of TKA is not studied.

Conclusion

R-TKA helps to reduce overall coronal limb alignment outlier form 3° to less than 1.24° and component malposition to less than 1°. Thus, R-TKA is precise and accurate in terms of component placement and limb alignment. Whether this improves clinical outcome, patient's satisfaction and long-term survival of TKA needs to be studied in future.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Standard Statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent For this type of study, informed consent is not required.

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