Research Article

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Long Leg Radiographs *vs* CT Perth protocol: Mechanical alignment analysis

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ABSTRACT

Background: Long leg radiographs are commonly used to measure alignment in Total Knee Arthroplasty surgery. However, they are time consuming to perform and provide no information regarding implant rotation. The aim of this study was to compare the accuracy of measuring mechanical alignment in the coronal plane between long leg radiographs and CT Perth protocol.

Methods: Patients were recruited from our waiting list for routine TKA surgery. Pre-operative and post-operative Long Leg Radiographs and Perth protocol CT scans were performed. LLR's were reported by 2 blinded orthopaedic surgeons and the CT scans by a blinded consultant radiologist. Intra-class correlation coefficient was compared between the scan results.

Results: Pre-operatively 132 (73 female and 59 male), meet the inclusion criteria with 120 patients completing the post op scans due to loss to follow up. The agreement between the pre-op LLD's and CT scans was excellent with and average difference of 1.8 degrees and an ICC of 0.82. Post-op the agreement was good with an average difference in measurements of 1.58 degrees and an ICC of 0.69.

Conclusion: This study show that CT Perth Protocol achieves similar, reproducible results in determining mechanical alignment in the coronal plane when compared to LLRs. CT scans provide more information and integrate with modern robotic surgical techniques. We propose that all patients undergoing elective TKA should have a pre-operative CT for planning purposes.

KEYWORDS: Total Knee Arthroplasty, Mechanical Alignment, CT Perth Protocol, Long Leg Radiographs

ABBREVIATIONS: ICC: Intra-class correlation coefficient; LLR: Long Leg Radiographs; TKA: Total Knee Arthroplasty

INTRODUCTION

The main aims of total knee arthroplasty (TKA) are to relieve pain and improve function by restoring natural mechanical alignment, preservation of joint line position and achieving a balance of the ligamentous and soft tissues structures. Mechanical alignment of the knee is a critical component of pre-operative planning, as restoring alignment has been shown to affect post-operative recovery, outcomes and rates of revision [1]. A plethora of modalities exist to assess alignment including clinical examination,

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short-leg and long-leg radiographs, CT, MRI, intraoperative supine fluoroscopy and navigation, however no consensus exists on the most accurate and reliable method [2]. Our group has previously demonstrated the reliability of long leg radiographs (LLR) for the measurement of mechanical axis alignment [3]. Long leg radiographs are however time consuming to perform and only provide information in relation to the mechanical axis of the leg [3].

The CT Perth protocol was designed to allow surgeons the ability to determine the mechanical and anatomical axes in multiple planes, which is poorly demonstrated by plain radiographs [4]. It also provides valuable information on the rotational profile of the knee which long leg radiographs do not provide and has wider uses as a research tool. The Perth protocol involves 2.5mm slices from the acetabular roof to the dome of the talus, performed with the patient supine [5]. Additional valuable information such as coupled femoral-tibial rotational alignment, coronal and sagittal alignment is also available from the same scan to further aid clinical decision making.

Previous studies have advocated the use of LLR instead of CT, either due to radiation exposure [2] or under-detection of malalignment [6]. With recent improvements in CT technology and analysis software, the radiation dose of the Perth protocol has decreased to 1.43mSV as utilized in our study. This is the equivalent of less than 9 months of naturally occurring background radiation. The aim of this study was to compare the accuracy of measuring mechanical alignment in the coronal plane between long leg radiographs and CT Perth protocol.

METHODS

Prior to commencing this study ethical approval was obtained from our local board the Southern Adelaide Clinical Human Research Ethics Committee, Approval ID 180.10. The radiographs used in this were obtained from a larger trial performed in our research department. This study was registered on the clinical trials network at ClinicalTrials.gov website identifier: NCT01145157. Patients were recruited from our waiting list for routine primary TKA and had signed consent as part of the original study before undergoing CT scans.

The inclusion criteria were patients over 18 years of age, requiring a primary total knee arthroplasty due to non-inflammatory degenerative joint disease (such as osteoarthritis, traumatic arthritis, avascular necro- sis, or dysplasia) or inflammatory joint disease (e.g., rheumatoid arthritis), and had received an acceptable pre-operative medical clearance. Patients needed to be able to understand the study information and provide written informed consent to participate in the length of the study. The exclusion criteria included patients with active infection or sepsis (treated or un- treated), patients with any vascular insufficiency, muscular atrophy, or neuromuscular disease severe enough to compromise implant stability or post-operative recovery, females of child-bearing age and not taking contraceptive precautions, inadequate bone stock to support the device (e.g., severe osteopenia, family history of severe osteoporosis), known moderate to severe renal insufficiency, known moderate to severe metal sensitivity, immunosuppressed or receiving high doses of cortico- steroids, history of previous knee surgery (except arthroscopy and/or open meniscectomy) on the affected knee, severely overweight (body mass index > 40), emotional or neurological condition that would pre-empt their ability or willingness to participate.

All study participants received Biomet Vanguard knee prosthesis, with surgeries performed by different orthopedic surgeons within the faculty using either traditional or computer navigated methods, as per the surgeon's regular practice. All patients received both LLRs and CT Perth protocol pre- and post-operatively. The LLRs were performed using at the same center using our standardized protocol. All patients underwent the LLRs at the same facility with the same imaging equipment. A specific LLR protocol was used for all patients with the same distance from the X-ray source to patient and recording sensor plate. Patients were positioned upright, and fully weight bearing, with both feet as flat on the ground as their lower limb would permit, and with patella forward facing. Patients were positioned in their normal stance with respect to angle and base of gait in full extension. If a patient was unable to stand with their feet close together then the radiographer performed a separate exposure for each leg. Images were taken on a digital film and were placed two meters from the imaging source and directly against the digital cassette. All images were stored and uploaded to the Intel viewer TM suite to be accessed remotely by observers for this study.

Mechanical alignment was taken from the center of the femoral head to the center of the tibial intercondylar tubercle to the center of the talus, measured by a single orthopedic surgeon to avoid any interobserver error. The first point was placed in the center of the femoral head, with a straight line drawn to the center of the tibial intercondylar notch, followed by a second line drawn from the latter point to the center of the talus [7]. The angle between the two lines was measured using a digital protractor and rounded to the nearest degree. Angles were recorded in degrees ±180° (neutral) where angles recorded with a negative (-) sign represent a valgus alignment, and angles reported with a positive (+) represent a Varus alignment. CT Perth protocol was obtained with all parameters measured including rotation, flexion / extension of the femoral component, tibial base plate posterior slope, Varus / valgus positioning of the femoral and tibial component and mechanical axes in the coronal and sagittal plane. For the purpose of this study, only the coronal mechanical alignment was utilized. The CT Perth protocol was analysed and reported by a Consultant Radiologist.

Statistical Analysis

Statistical analysis was run using Excel 16.53. Intra-class correlation coefficient (ICC) was calculated pre- and post-operatively to look at the comparability between both imaging modalities. A Bland-Altmann plot was created to identify trends and any specific outliers.

RESULTS

In total 150 patients agreed to participate, with 132 (73 female and 59 male), meeting the inclusion criteria. Post-operatively, 120 patients (64 females, 56 male) were included with 12 withdrawn due to either loss to follow-up or poor post-operative image quality (Figure 1).

Pre-operative measurements had a wide range of values. Using LLRs, the maximum Varus deformity was 16 degrees whilst the largest valgus deformity was 19 degrees, whilst for CT Perth Protocol the maximum varus deformity was also 16 degrees varus, whilst the largest valgus deformity was 10 degrees. Overall, the ICC between classes was 0.82, with the average difference in measurements being 1.86 degrees valgus. The Bland-Altman limits of agreement ranged from 9.91 degrees valgus to 6.19 degrees varus (Figure 2).

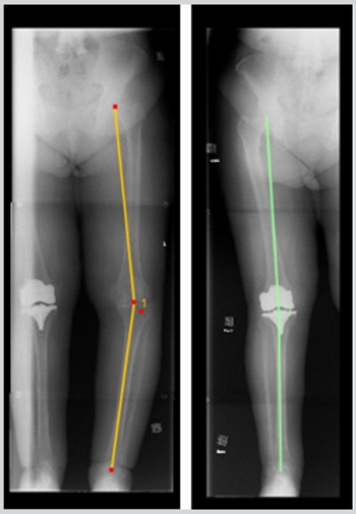

Figure 1: Mechanical axis alignment measurement technique for long leg radiographs, pre- and post-operatively. The line is drawn from the center of the femoral head to the tibial intercondylar notch / center of tibial plate to the center of the talus and this is used to calculate mechanical alignment in the coronal plane.

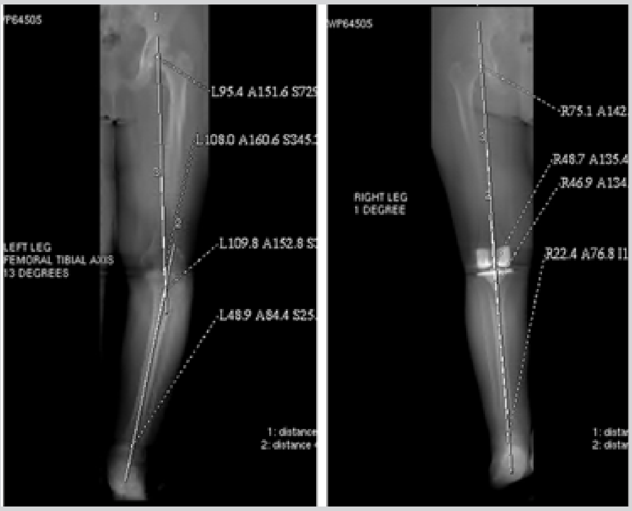

Figure 2: Mechanical axis alignment measurement technique for CT Perth Protocol, pre- and post-operatively. Calculations determined by a line drawn from the centre of the femoral head to the tibial intercondylar notch/ center of tibial plate to the centre of the talus.

Post-operatively there was a much narrower range of values. Using LLRs, the maximum varus deformity was 7 degrees, whilst the largest valgus deformity was 8 degrees, whilst for CT Perth Protocol the maximum varus deformity was 9 degrees whilst the largest valgus deformity was 7 degrees. Overall, the ICC was 0.69, with the average difference in measurements being 1.58 degrees valgus. The Bland-Altman limits of agreement ranged from 6.33 valgus to 3.18 degrees varus. These findings are summarized in Table 1.

Table 1: Pre- and post-operative measurements of the mechanical axis between LLRs and CT Perth Protocol.

	Average	Standard Deviation	ICC*	Bland-Altman Limits of Agreement
Pre-operative	-1.86	4.03	0.82	-9.91 to 6.19
Post-operative	-1.57	2.38	0.69	- 6.33 to 3.18

*(ICC = Intra-class correlation coefficient)

DISCUSSION

Our results demonstrate that there is good correlation reliability between LLRs and CT Perth protocol when measuring mechanical alignment in the coronal plane. In the pre-operative measurements, it was however observed that LLRs exaggerated the deformity in patients whose deformity was larger. This could potentially be explained by the impact of the weight bearing force through the joint in the LLR's compared to the non-weight bearing CT, however this requires further analysis. The average difference in measurements was just 1.8 degrees valgus, representing good consistency reliability between the two modalities and an excellent interclass correlation (ICC = 0.8). Further analysis of the Bland Altman limits (Figure 3) of agreements reveals a large range of 9.9 degrees valgus to 6.2 degrees Varus, for pre-operative agreement between methods.

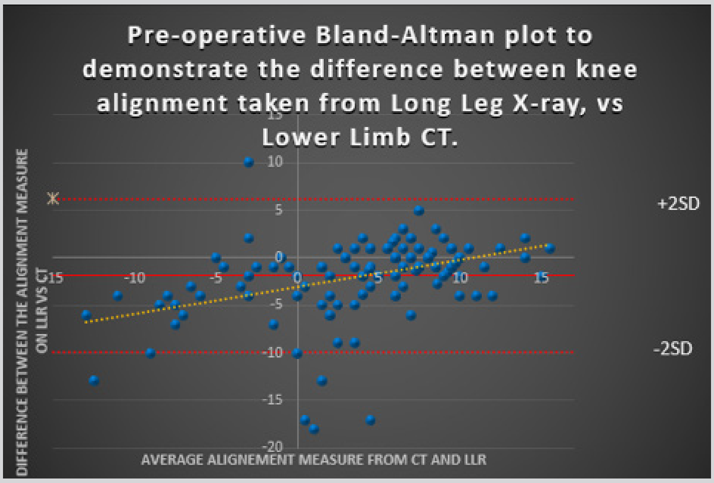

Figure 3: Relationship between the difference between the pre-operative alignment as measured by CT and LLRs.

The post-operative results are more consistent reliable with the average matching the trend line of the data and remaining at 1.57 valgus for the average difference in measurements between modalities. The Bland Altman limits of agreement range from 6.33 degrees valgus to 3.18 degrees Varus (Figure 4) remains a large range, however this large valgus measurement can be shown to be exaggerated by a few outlier data points. The narrower range of values in measurement post-operatively is in keeping with expected findings, as one of the goals of TKA is to improve mechanical alignment. The ICC is shown to be 0.69, which demonstrates good correlation between modalities. Both pre- and post-operative Bland Altman plots identified several outlier data points. These were individually analysed and upon further investigation, appear to be largely attributable to interpretation error, rather than a true reflection of the severity of the deformity.

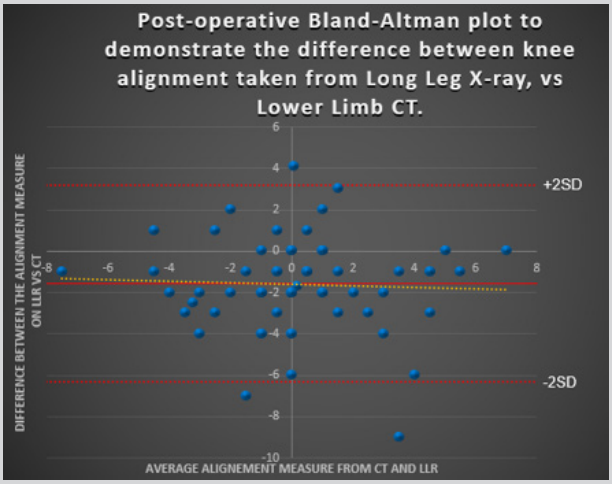

Figure 4: Relationship between the difference between the post-operative alignment as measured by CT and LLRs.

Primary total knee arthroplasty (TKA) is one of the most frequently performed orthopedic procedures in Australia, with 57,189 primary TKA's performed in 2019, representing an increase of 160.9% since 2003 [8]. The burden on the Australian healthcare system from primary TKA already exceeds $1 billion AUD annually and with the increasing rates of obesity in our aging population, is forecast to eclipse $5 billion AUD annually by 2030 [9].

Revision knee arthroplasty is associated with enormous clinical and economic implications to the patient and broader healthcare system [10]. The exact impact of alignment on rates of revision is not known, however a range of studies have shown that restoration of mechanical alignment contributes to better implant survivability [11-13]. Whilst the small increase in revision rates of poorly aligned knees may initially seem trivial or inconsequential, when considered in the context of overall TKA's performed, represents a sizeable number of avoidable costly and resource-consuming surgeries [14,15].

Achieving accurate alignment is therefore a critical aspect of knee arthroplasty and it has been well-established that post-operative alignment impacts implant survivability [14], although there remains ongoing debate and research comparing kinematic and mechanical alignment as the optimal implant alignment [15]. Whether a surgeon uses mechanical alignment, kinematic alignment or a gap balancing technique accurate measurement both pre and post op are essential to plan surgery and evaluate out comes. The use of computer navigation assisted, and robotic surgery is becoming more common and pre-operative CT scans can be used to program the Robotic equipment and obtain a pre-op surgical plan [16,17].

Post-operatively the use of CT imaging, both 2D and 3D has been reported upon by various authors, and been validated for use, particular when there are concerns surrounding implant positioning [18,19]. However, the routine pre-operative imaging source of choice remains up for debate, particularly with recent advancements in the field of medical imaging, allowing for higher quality CT images to be performed with lower radiation doses [20].

Post operatively accurate information can be obtained from the surgical reports, CT scans and if required RSA analysis. The CT data can also be used for digital modelling as a research tool and provide much more information for the surgeon or researcher than LLDs can provide. These modern robotic surgical techniques increase surgical accuracy and reproducibility. They don't require the use of long leg radiographs and with expanding use of their technique the need to use LLR's at all may be becoming obsolete with CT scan and other more advanced imaging becoming routine in orthopedic surgery. Furthermore, the CT data can also be used to provide the surgeon and researcher a variety of information as a modality which LLRs cannot. Aside from rotational data, information from CT scans can be used for additional purposes such as RSA analysis and digital monitoring.

In cases where a pre-operative CT is already required, such as where the patient is undergoing a robotic TKR, we would suggest that given the ability to determine the mechanical axis in the coronal plane with this information, the routine use of LLRs is not required. Considering the significant reduction in radiation given recent advancements in medical imaging and plethora of additional information available to the surgeon. For patients who do not otherwise require a CT scan pre-operatively, in the setting of a conventional or navigated TKA, it is reasonable to question whether LLRs remain the gold-standard in imaging.

One of the primary limitations of this study is that images were each only analysed by a single reviewer. Given the method used to determine mechanical alignment, pinpointing the tibial spine at the center of the knee can be difficult, especially in patients with more severe osteoarthritis and larger deformities. Variability could have been reduced by having each radiograph analysed by multiple reviewers, minimizing the effect of outlier measurements, particularly given the relatively small cohort of patients.

CONCLUSION

This study has demonstrated that CT Perth Protocol achieves similar, reproducible results in determining mechanical alignment in the coronal plane when compared to LLRs. This result is achieved with similar radiation exposure for the patient and in less time. Considering the large amounts of additional information obtainable from a CT scan and their integration with modern surgical techniques we propose that all patients undergoing elective TKA should have a pre-operative CT for planning purposes in place of a routine LLR.

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