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# Correlations in radiographic and MAKO Total Knee Robotic-Assisted Surgery intraoperative limb coronal alignment

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**Robotic-assisted arthroplasty has become increasingly established in recent years. The aim of the study is to determine if intraoperative coronal alignment during robotic-assisted total knee arthroplasty correlates with radiographic alignment. We prospectively compared the pre- and postoperative limb alignment values measured on long leg standing radiographs with intraoperative robotic-assisted measurements for 100 patients who underwent primary total knee arthroplasty. Two-tailed bivariate Pearson correlations were performed to evaluate the strength of the association between radiographic and robotic-assisted alignment. The intraclass correlation coefficient (ICC) was used to estimate interrater reliability. There was a male/female ratio of 1.16 and the mean age was 67 years (range 42-88). Robotic-assisted measurements slightly overestimated the degree of varus relative to radiographs. Radiographic and robotic-assisted measurements were strongly correlated ($r = 0.915$, $p < 0.001$) preoperatively, with a difference of 1.6 ± 3.2°. The average measure ICC was 0.996 with a 95% confidence interval from 0.995 to 0.997 ($p < 0.001$). Postoperatively a bigger difference was measured (3.1° ± 1.9°), comparing radiographic and MAKO alignment. A moderate correlation was observed between the postoperative radiographic and MAKO outcome alignment ($r = 0.604$, $p < 0.001$). The average measure ICC was 0.977 with a 95% confidence interval from 0.967 to 0.984 ($p < 0.001$). There is a strong correlation in the preoperative setting between radiographic and robotic-assisted lower limb alignment and a moderate correlation in the postoperative setting. The values measured by the MAKO Total Knee application were considerably more in varus.**

**Keywords** : Total knee arthroplasty; robotic-assisted surgery; coronal limb alignment; long leg standing radiographs; MAKO.

## INTRODUCTION

Robotic technology has become more widely used in joint arthroplasty during the past decades. It has rapidly evolved during the last several years as almost every implant company is developing or offering a robot *(1,2)*. Introduction of robotic-assisted arthroplasty in orthopedics may result in multiple benefits: improved implantation accuracy, reduced

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instrumentation, improved soft tissue balancing, lower complication rates, increased implant survival and finally improved patient satisfaction scores *(3-6)* Additional research regarding robotic-assisted surgery is currently awaiting to further objectify these potential benefits. Longer term outcomes are paramount to investigate improved function and implant durability, the most important outcome parameters of joint arthroplasty.

The MAKO robotic system is a closed, semi-active, CT-based system and is available for assisting Total Knee Arthroplasty (TKA), Unicompartmental Knee Arthroplasty (UKA) and Total Hip Arthroplasty (THA). The surgical plan is determined preoperatively. A robotic arm assists in bone resection based on stereotactic references below and above the joint. The resection plan can be adjusted intraoperatively based on real-time referencing. When the surgeon deviates from the planned resection plane during bone resection, he will be prevented from doing this through feedback on the computer screen and spatial limits *(7)*.

Restoration of neutral mechanical axis has since long been accepted as a prognostic factor for long-term implant survival in TKA. It was assumed that a valgus or varus alignment of more than 3° was associated with an inferior outcome and lower implant durability *(8,9)*.

However, this was nuanced by more recent research. Alignment outliers did not always adversely influence implant survival, especially residual varus alignment *(10,11)*.

To avoid this malalignment, reliable and reproducible measurements of limb alignment are therefore useful in the planning, performance and evaluation of total knee arthroplasty to avoid this malalignment.

The use of long leg standing radiographs have been shown as well to be reproducible for measurements of coronal plane limb alignment, despite the well-known sources of error such as limb rotation, knee flexion contractures or other positional errors during radiograph acquisition *(8-14)*.

With the introduction of navigation-assisted systems it became possible for orthopedic surgeons to obtain a real time intraoperative limb alignment measurement. Navigation-assisted surgery has already shown promising results in reliability of reporting mechanical axis, although patients are measured in a prone position in contrast to the standing radiographs *(15)*.

Recent study showed an acceptable correlation between intraoperative navigation and radiographic lower limb alignment *(16,17)*. We hypothesized that this correlation holds true for robotic-assisted surgery as well. Only limited data was available on this subject given the novelty of this technology *(18,19)*. The aim of the present study was therefore to evaluate the pre- and postoperative correlation between long leg standing radiographs and intraoperative robotic-assisted limb alignment.

## MATERIALS AND METHODS

Pre- and postoperative limb alignment values measured on long leg standing radiographs were compared with intraoperative robotic-assisted measurements for 100 patients who underwent primary RATKA for osteoarthritis (OA) of the knee. Data were collected prospectively of all patients undergoing primary TKA from July 2019 until January 2020 in our hospital, regardless of the cause of OA. Five patients were excluded from the final analysis. Three patients were lost to follow up because they did not consult for the postoperative radiograph and two patients were not positioned correctly for the long leg preoperative standing radiograph. The study was in accordance with institutional rules for ethical review. All patients signed informed consent to participate in the study with anonymization of their data.

The total knee arthroplasty and intraoperative analysis was performed with the MAKO Total Knee Arthroplasty system (Stryker, USA). Preoperatively all patients underwent a CT-scan of the knee according to the MAKO protocol. The surgical approach which was used is a modified subvastus approach. The cases were all performed by a single surgeon (GL) with great experience in robotic-assisted surgery, using a ligament balancing technique. Alignment target was neutral, however residual varus/valgus alignment was accepted in severe deformed limbs. Limb alignment was registered before bone cutting and after prosthesis implantation (Triathlon CS, Stryker).

Long leg standing radiographs were taken preoperatively and between 6 weeks and 3 months postoperatively. All radiographs were taken with the legs fully extended and the patella and feet facing forward on a single long cassette *(8)*. The mechanical axis was independently measured pre- and postoperatively by 2 orthopedic surgery residents and 1 medical trainee. The mean of these 3 values was used in the analysis. The mechanical axis was defined as the angle measured between the line drawn from the center of the femoral head to the center of the knee and the line drawn from the center of the knee to the center of the talus *(20)*. These angular values were measured using Centricity Universal Viewer (GE Healthcare, United States). Varus alignment was defined as a positive angulation, whereas valgus alignment was defined as a negative angulation.

The mechanical axis given by the MAKO system is automatically generated by the computer when the leg is fully extended. It is based on the CT landmarks, verified by the surgeon before each procedure. Intraoperative measurements were registered before any cuts were made and again postoperatively after the robotic-assisted cuts were made and definitive implants were inserted.

The primary outcome measure in this study was to determine the correlation between robotic-assisted and pre- and postoperative radiographic measurements in terms of mechanical alignment. Two-tailed bivariate Pearson correlations were performed to evaluate the strength of the association between pre- and postoperative radiograph and robotic-assisted alignment. The strength of correlation was indicated by the correlation coefficient (r) as strong (>0.7), moderate (0.4-0.7), or weak (<0.4). The intraclass correlation (ICC) was used to estimate interrater reliability between the three independent observers. An analysis was performed on pre- and postoperative radiographic and robotic assisted measurements to determine mean values, standard deviation, minimum, maximum and the difference between the means. Statistical significance was assumed at a threshold of $p < 0.05$. All statistical analyses were performed using SPSS version 24 (IBM, USA).

## RESULTS

For the 95 patients who underwent primary RATKA from July 2019 until January 2020 there was a male/female ratio of 1.16 and the mean age was 67 years (range 42-88 years). Of the arthroplasties 43 (45.3%) were conducted left-sided and 52 (54.7%) right-sided, 82 (86.3%) were cemented and 13 (13.7%) were cementless (Table I).

Table I. – Patient demographics

| | |
|---|---|
| Mean age (years) (range) | 67 (42-88) |
| Sex (male/female) | 51/44 |
| Side (left/right) | 43/52 |
| Cement (cemented/cementless) | 82/13 |

Table II. – Pre- and postoperative radiograph and robotic-assisted measurement of mechanical alignment

| Measurement | Mean | Minimum | Maximum | Standard deviation |
|---|---|---|---|---|
| Preoperative | | | | |
| MAKO (°) | 3.1 | -7 | 13 | 4.4 |
| Radiograph (°) | 1.5 | -16 | 18 | 6.7 |
| MAKO:radiograph difference (°) | 1.6 | -5.0 | 10.7 | 2.3 |
| Postoperative | | | | |
| MAKO (°) | 2.4 | -3 | 8 | 2.0 |
| Radiograph (°) | -0.7 | -5.3 | 5.7 | 2.4 |
| MAKO:radiograph difference (°) | 3.1 | -1.6 | 8.3 | 1.9 |

Varus: >0° and valgus: <0°

As pathophysiologically expected the mean preoperative radiographic alignment was in slight varus (1.5° ± 6.7°). Varus alignment was observed in 56 knees (59.0%) and valgus alignment in 39 (41.1%). Only 22 patients (23.2%) had a normal preoperative radiographic alignment between 3° of varus and 3° of valgus. The MAKO system registered a mean preoperative varus alignment of 3.1° ± 4.4°. Robotic-assisted measurements slightly overestimated the degree of varus relative to radiographs (1.6° ± 2.3°). Radiographic measurements had a greater range and variability than the MAKO data (Table II). Radiographic and robotic-assisted measurements were strongly correlated (r = 0.915, p < 0.001) (Table III; Figure 1). A high degree of reliability was found between radiographic and robotic-assisted measurements. The average ICC was 0.996 with a 95% confidence interval from 0.995 to 0.997 (p < 0.001) (Table III).

Postoperatively there was a MAKO alignment between 3° of varus and 3° of valgus in 73 patients (76.8%). These results are inherent to the ligament balancing technique. The mean postoperative radiographic alignment was slightly in valgus (-0.7° ± 2.4°), in contrast to the MAKO alignment where a varus alignment is observed (2.4° ± 2.0°). There was a greater discrepancy between radiographic and MAKO alignment postoperatively (3.1° ± 1.9°) than preoperatively (1.6° ± 2.3°). A moderate correlation was observed between the postoperative radiographic and MAKO outcome alignment (r = 0.604, p < 0.001) (Table II, Figure 2). Postoperatively a high degree of reliability was found between radiographic and robotic-assisted

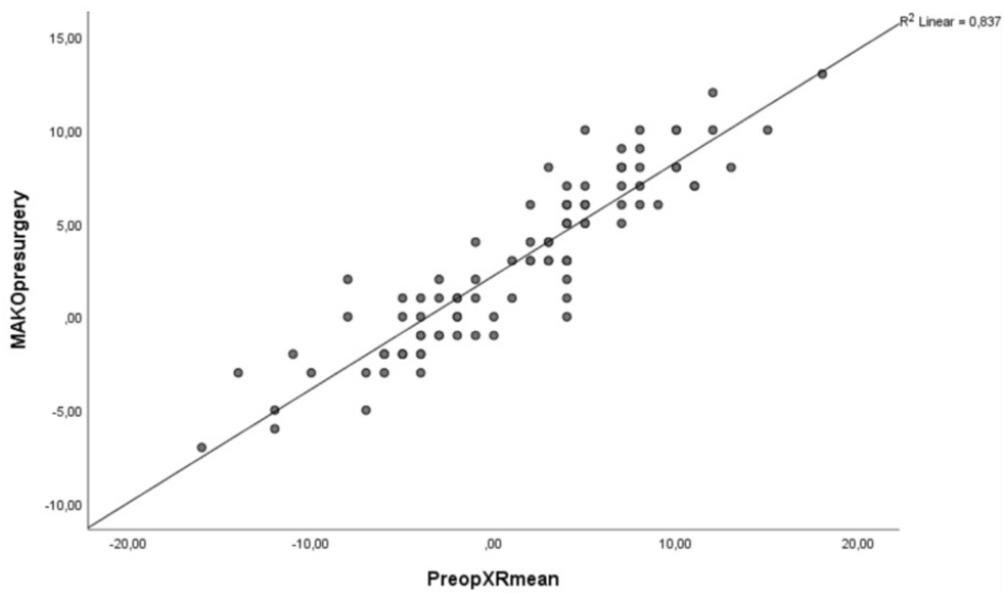


***Figure 1.*** — Correlation between preoperative long standing radiographic and MAKO limb alignment.

Table III. — An analysis of radiograph to MAKO correlation and interobserver reliability

| Alignment measurements | Radiograph: MAKO Pearson correlation coefficient* | Observer 1: Observer 2: Observer 3 Intraclass correlation coefficient** |
|---|---|---|
| Mechanical axis preoperative | 0.915 | 0.996 (95% CI 0.995 - 0.997) |
| Mechanical axis postoperative | 0.604 | 0.977 (95% CI 0.967 - 0.984) |

* Correlation is significant at the 0.01 level (two-tailed). ** Reliability is significant at the 0.01 level (two-way mixed effect model, average measure)

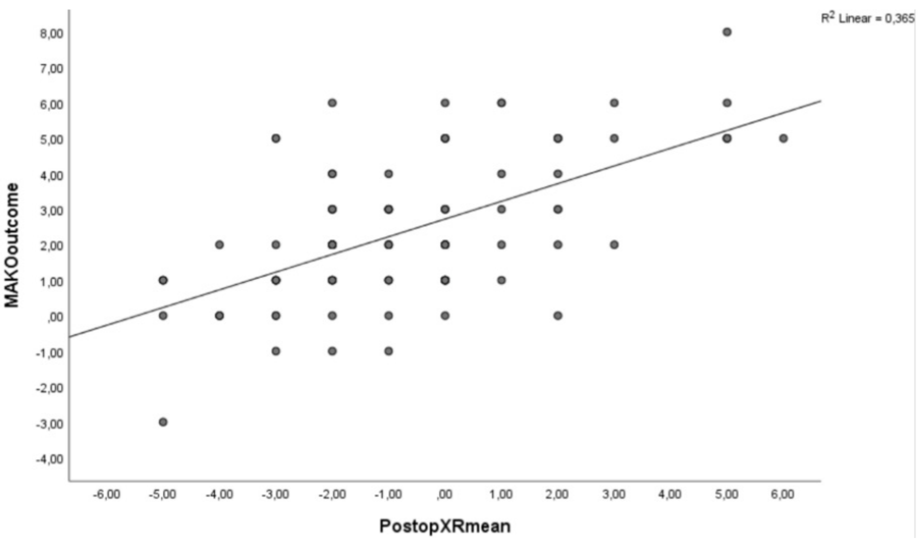


***Figure 2.*** — Correlation between postoperative long standing radiographic and MAKO limb alignment.

measurements. The average ICC was 0.977 with a 95% confidence interval from 0.967 to 0.984 ($p < 0.001$) (Table III).

## DISCUSSION

The main goal of this study was to determine if intraoperative limb alignment during RATKA correlated with pre- and postoperative coronal limb alignment on long leg standing radiographs. Accurate pre- and postoperative limb alignment measurements are necessary to plan, perform and evaluate the outcomes of TKA. The preoperative analysis showed a strong correlation ($r = 0.915$, $p < 0.001$) between the preoperative radiographs and the intraoperative pre-cut measurement. Consequential this implies that the MAKO Total Knee system correctly analyzed the preoperative limb alignment and that there is no difference between the preoperative weight bearing and supine alignment. This means that preoperative long leg standing radiographs to measure mechanical alignment could be redundant when using the MAKO system. Postoperatively this was less pronounced as the correlation was only moderate ($r = 0.604$, $p < 0.001$). Multiple studies report similar results for navigation-assisted versus radiographic hip-knee angle measurement *(16,21)*. Different factors may influence this disparity.

A first factor is that the radiographic mechanical alignment was measured in standing position and the intraoperative mechanical alignment in supine position. However, to date, there is no consensus on the effect of weight-bearing on mechanical alignment measurement of the knee. Most studies found no effect of weight-bearing on standing and supine alignment *(10-12)*. Other studies reported that mechanical alignment measured with long leg standing radiographs on average were relatively more in varus than in a supine position *(13,22)*. Our results on the other hand showed more varus measurements with the MAKO Total Knee system (measured in supine position). This difference does not seem to be attributable to the patient position during mechanical alignment measurement. On the other hand, it seems plausible that the effect of weightbearing is dependent on the proper soft tissue balancing achieved intraoperatively, but this only applies to the postoperative measurements.

Another factor for this disparity may be the timing of the postoperative radiographs. In our study, these were taken mostly at 6 weeks postoperatively. Radiographic correlation between navigation and radiographic measurements correlate better

3 months after arthroplasty *(23)*. In patients with minimal deformity radiographic measurements can be accurate, but this is not applicable to patients with extreme deforming osteoarthritis as they are more prone to error *(8,24)*. In previous publications about radiographic to navigation measurements there was a greater discrepancy between radiographic and MAKO alignment measurements with increasing preoperative deformity *(25,26)*. To avoid measurement errors due to flexion contracture, long leg standing radiographs should be taken only if patients achieved full or near full extension of the knee *(27,28)*. Correct limb rotation during radiograph also influences the measurement correlation. Less difference was observed between navigational and radiographic mechanical alignment measurements if the long leg standing radiograph was taken in neutral rotation *(14,17)*. Errors on this can be greatly diminished with standardized measurement and acquisition methods *(8,24)*. In our study, we tried to minimize this error by using standardized patient positioning as described by Cooke et al. *(8)*.

In addition, alignment measurements on radiographs are two-dimensional while MAKO generated measurements are three-dimensional. The difference in dimensions between radiograph and MAKO are potentially a cause of overestimation of the discrepancy between the radiographic alignment and the corresponding MAKO measurement. Surgeons should be aware of this and take this into account while determining the bone cuts and not to overcorrect what appears to be a major deformity on radiograph. Additionally, it is the responsibility of the surgeon to check the landmarks which are mapped on the CT-based planning by the Product Specialist before surgery. As landmark mapping can differ individually, it can be seen as a potential source of error as well.

Possibly the soft-tissue envelope had not sufficiently healed for adequate long leg standing radiographs to be taken correctly. Postoperative scar tissue could account for delayed limb extension. We also hypothesize that there is insufficient healing at this stage of the medial side (inherent to the subvastus surgical approach), leading to increased laxity and more valgus alignment (-0.7° ± 2.4°) on the long leg standing radiographs. This mediolateral laxity may affect deformity exacerbation on the standing radiographs *(20)*, however it was not evaluated in our study.

Our study has multiple strengths. We assumed that the MAKO Total Knee system could generate accurate alignment measurements when properly used. Although there is a paucity on literature regarding the MAKO Total Knee system, two articles also confirm its accuracy *(26,27)*. This assumption about validity was made due to the large number of studies validating the accuracy of navigation-assisted Total Knee Arthroplasty systems *(16,17,29)*. The radiographic mechanical axis was measured independently by three different observers and an excellent ICC was obtained. This accounted for most measurement errors on the radiographic part of the analysis. In a previous study there was a high degree of inter-observer correlation mentioned for measurement of the mechanical axis for the method used in our study *(25)*. Due to the prospective nature of the study, there were clear, pre-defined endpoints and no missing data leading to less chance of bias. Post hoc power analysis showed a power of 99.8% for the preoperative and 99.9% for the postoperative analysis.

There were also limitations to our research. There are several points during the acquisition of alignment measurements with MAKO subtle errors can be inadvertently introduced. These points are during the determination process of anatomic landmarks on the CT, the measurement process based on errors during registration and small intraoperative changes as for example movements of pins or arrays. The aforementioned errors may on the other hand be minimized through experience with MAKO and by developing a consistent registration technique.

Sires et al. reported a high accuracy for the coronal limb alignment using MAKO using CT-scans 18. Our data equally suggests a correlation, however in the postoperative situation there is still some discrepancy compared to the conventional long leg standing radiographs. Radiographic measurements have inherent limitations and it may not be suitable to function as the gold standard for total knee arthroplasty alignment evaluation. In the hands of an experienced surgeon it is still unclear to exactly which degree the MAKO Total Knee system is capable to determine accurately alignment measurements. A high-quality study comparing computed tomography, MAKO and radiographic alignment would provide great value to assess accuracy of MAKO alignment and the relationship between intraoperative robotic-assisted measurements and long-term clinical and functional outcomes.

## CONCLUSION

Comparison of the radiographic long leg standing mechanical alignment and the intraoperative mechanical alignment, obtained with the MAKO Total Knee Arthroplasty system, showed a very good correlation in the preoperative setting and a moderate correlation in the postoperative setting. The measurements with the MAKO system were considerably more in varus. This ensures making a preoperative radiograph to measure the mechanical alignment redundant, there is less firm fundament to say the same about the postoperative radiograph.

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