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The Impact of Surgeon Volume and Training Status on Implant Alignment in Total Knee Arthroplasty

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Investigation performed at Washington University in St. Louis School of Medicine, Barnes-Jewish Hospital, St. Louis, Missouri

**Background:** Implant malalignment may predispose patients to prosthetic failure following total knee arthroplasty (TKA). A more thorough understanding of the surgeon-specific factors that contribute to implant malalignment following TKA may uncover actionable strategies for improving implant survival. The purpose of this study was to determine the impact of surgeon volume and training status on malalignment.

**Methods:** In this retrospective multicenter study, we performed a radiographic analysis of 1,570 primary TKAs performed at 4 private academic and state-funded centers in the U.S. and U.K. Surgeons were categorized as high-volume (≥50 TKAs/year) or low-volume (<50 TKAs/year), and as a non-trainee (attending surgeon), trainee (fellow/resident under the supervision of an attending surgeon), or non-trainee (attending surgeon). On the basis of these designations, 3 groups were defined: high-volume non-trainee, low-volume non-trainee, and trainee. The postoperative medial distal femoral angle (DFA), medial proximal tibial angle (PTA), and posterior tibial slope angle (PSA) were radiographically measured. Outlier measurements were defined as follows: DFA, outside of 5° ± 3° of valgus; PTA, >±3° deviation from the neutral axis; and PSA, <0° or >7° of flexion for cruciate-retaining or <0° or >5° of flexion for posterior-stabilized TKAs. “Far outliers” were defined as measurements falling >±2° outside of these ranges. The proportions of outliers were compared between the groups using univariate and multivariate analyses.

**Results:** When comparing the high and low-volume non-trainee groups using univariate analysis, the proportions of knees with outlier measurements for the PTA (5.3% versus 17.4%) and PSA (17.4% versus 28.3%) and the proportion of total outliers (11.8% versus 20.7%) were significantly lower in the high-volume group (all p < 0.001). The proportions of DFA (1.9% versus 6.5%), PTA (1.8% versus 5.7%), PSA (5.5% versus 12.6%), and total far outliers (3.1% versus 8.3%) were also significantly lower in the high-volume non-trainee group (all p < 0.001). Compared with the trainee group, the high-volume non-trainee group had significantly lower proportions of DFA (12.6% versus 21.6%), PTA (5.3% versus 12.0%), PSA (17.4% versus 33.3%), and total outliers (11.8% versus 22.3%) (all p < 0.001) as well as DFA (1.9% versus 3.9%; p = 0.027), PSA (5.5% versus 12.6%; p < 0.001), and total far outliers (3.1% versus 6.4%; p = 0.004). No significant differences were identified when comparing the low-volume non-trainee group and the trainee group, with the exception of PTA outliers (17.4% versus 12.0%; p = 0.041) and PTA far outliers (5.7% versus 2.6%; p = 0.033). Findings from multivariate analysis accounting for the effects of patient age, body mass index, and individual surgeon demonstrated similar results.

**Conclusions:** Low surgical volume and trainee status were risk factors for outlier and far-outlier malalignment in primary TKA, even when accounting for differences in individual surgeon and patient characteristics. Trainee surgeons performed similarly, and certainly not inferiorly, to low-volume non-trainee surgeons. Even among high-volume non-trainees, the best-performing cohort in our study, the proportion of TKA alignment outliers was still high.

**Level of Evidence:** Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

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Impact of Surgeon Volume and Training Status on Implant Alignment in TKA

Primary total knee arthroplasty (TKA) is an effective treatment for end-stage osteoarthritis of the knee, with nearly all implant types attaining ≥95% survival 10 years postoperatively. Long-term implant failure rates, however, have remained unchanged in recent years despite active research to improve prosthetic longevity. Although the persistence of suboptimal failure rates is partially driven by the existence of patient-specific risk factors (age, body mass index [BMI], comorbidities, bone quality), other factors that contribute to prosthetic failure are surgeon-specific. These factors represent actionable opportunities for improvements in implant longevity.

One of the most impactful surgeon-specific factors affecting long-term implant survival is the accuracy of prosthetic implant alignment. Implant malalignment has been identified as a risk factor for premature mechanical failure and poor clinical outcomes in numerous studies. Ritter et al., for example, demonstrated that a medial distal femoral angle (DFA) measurement of <1.9° or >7.9° of valgus relative to the anatomic axis of the femur was associated with a 10.7-times higher rate of implant failure. Similarly, Kim et al. identified a nearly 2.5-times greater incidence of implant failure with alignment outside of 5° ± 3° of valgus. With respect to the medial proximal tibial angle (PTA), Ritter et al. found that alignment of ≤90° was associated with a 12.1-times greater risk of implant failure, and others have found similar susceptibility to premature failure with a PTA demonstrating a ≥±3° deviation from the neutral axis. With respect to the posterior tibial slope angle (PSA), Kim et al. identified a greater incidence of implant failure when alignment was outside of 0° to 7° of flexion. Importantly, the effect of “outliers” in implant alignment grows even stronger when multiple components are concomitantly malaligned. Knees placed in excessive femoral valgus and tibial varus, for example, were noted to have a 57.6-times higher risk of implant failure compared with well-aligned knees.

As a result of the link between implant alignment outliers and early implant failure, efforts have been made to optimize alignment with the use of robotic navigation and patient-specific instrumentation. However, little work has been conducted to identify the primary surgeon-specific factors that drive these outliers in order to understand the optimal patient populations in which to utilize this expensive technology. Studies of total hip arthroplasty (THA) have demonstrated a strong relationship between surgeon volume and implant alignment in THA. However, parallel studies have not been performed in the setting of TKA, to our knowledge. While ex vivo cadaveric studies have demonstrated improved implant alignment among experienced surgeons in a small cohort, the impact of surgeon experience and trainee status on implant alignment in vivo has not been studied.

Given the divided nature of the existing literature, it is difficult to extrapolate the exact influence of surgeon volume and trainee status on the rate of malalignment in TKA. For example, results from studies assessing the impact of trainee surgeons and surgical experience on clinical outcomes following TKA and THA have demonstrated that neither experience nor trainee status significantly impacts outcomes. However, similar studies assessing outcomes at U.S. Veterans Affairs (VA) training centers demonstrated mixed results. A more thorough understanding of the surgeon-specific factors that contribute to implant alignment outliers following TKA may uncover actionable strategies for improving implant survival. Furthermore, understanding this relationship may have implications as to where to deploy expensive but potentially alignment-improving technologies, such as robotic navigation systems, in the future.

The objective of the current study was to determine the impact of surgical volume and institution type on the frequency of DFA, PTA, and PSA outliers following TKA. We hypothesized that low surgeon volume and trainee surgeons would be associated with an increased frequency of alignment outliers.

### Materials and Methods

#### Study Design

This retrospective multicenter study involved radiographic analysis of 1,570 primary TKAs without complications performed by 9 non-trainee surgeons and 39 trainee surgeons at 4 private academic and state-funded centers in the U.S. and U.K. Data were collected from Barnes-Jewish Hospital (St. Louis, Missouri), John Cochran Veterans Hospital–VA St. Louis Health Care System (St. Louis, Missouri), The Princess Grace Hospital (London, U.K.), and University College London Hospitals (London, U.K.). Institutional review board approval was attained prior to the initiation of this study.

In order to determine the influence of surgeon volume and training status on implant alignment, surgeons were individually categorized according to volume in accordance with the number of procedures performed by each surgeon. Surgeons were defined as high-volume non-trainee (HVNT), low-volume non-trainee (LVNT), or trainee, with HVNT performing ≥100 primary TKAs, LVNT performing <100 primary TKAs, and trainee performing ≥50 procedures in the last 5 years or ≤50 procedures in the last 5 years and ≤500 procedures lifetime. The primary outcome was the frequency of DFA, PTA, and PSA outliers.

### Results

#### TABLE I Comparison of Preoperative Characteristics*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>HVNT</th>
<th>LVNT</th>
<th>Trainee</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>68.4 (10.4)</td>
<td>65.9 (9.0)</td>
<td>69.6 (9.9)</td>
<td>67.5 (10)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>30.3 (5.7)</td>
<td>32.0 (6.0)</td>
<td>30.6 (4.9)</td>
<td>30.6 (5.5)</td>
</tr>
</tbody>
</table>

*The values are given as the mean, with the standard deviation in parentheses. HVNT = high-volume non-trainee, LVNT = low-volume non-trainee, and BMI = body mass index.

The impact of surgeon volume and training status on implant alignment was statistically significant. HVNT had a lower frequency of outliers compared with LVNT and trainee surgeons. These findings have important implications for improving implant longevity and reducing the risk of mechanical failure.
with methods previously described for hip arthroplasty by Barrack et al.\textsuperscript{34}. Surgeons were categorized as “high-volume” if they performed $\geq$50 TKAs/year and as “low-volume” if they performed <50 TKAs/year. Surgeons were also classified as a “trainee” (a fellow/resident under the supervision of an attending surgeon) or as a “non-trainee” (an attending surgeon). On the basis of these categorical assignments, 3 distinct groups were created: high-volume non-trainees (HVNTs), low-volume non-trainees (LVNTs), and trainees. A breakdown of the number of surgeons and the number of knees within each group is shown in Table I.

**Study Population**

Included in the analysis were male and female patients $\geq$18 years of age who underwent TKA at 1 of the aforementioned institutions during the period of 2012 to 2017 and who had available postoperative radiographs. Patients were excluded if they underwent revision TKA or primary TKA with complicating factors, or if nonconventional TKA (robotic, custom instrumentation) was performed. Preoperative patient characteristics (age and BMI) by group are shown in Table II.

**Radiographic Analysis**

DFA, PTA, and PSA measurements were made on anteroposterior and lateral short-leg radiographs by 2 authors (G.S.K., M.J.D.) using digital measurement tools. Readers were blinded to surgeon. The methodology was similar to measurement methods used in prior studies and is detailed in Figures 1-A, 1-B, and 1-C.\textsuperscript{2,7,42}

In order to validate these measurements, interreader reliability was assessed for a subset of 50 radiographs by an additional author (T.N.B.). Although the use of short-leg radiographs in the assessment of TKA has been debated, evidence suggests that this method is an acceptable substitute for long-leg radiographs in the

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**Fig. 1-A** The distal femoral angle (DFA) was measured on anteroposterior radiographs and was defined as the medial angle (red) between (1) the anatomic axis of the femur (proximal-to-distal line in the medullary canal bisecting the femoral shaft) and (2) a line drawn parallel to the distal aspect of the femoral component (parallel to the medial and lateral condyles of the femoral component).\textsuperscript{7} Line 1 (blue) was defined by 2 points (green): (1) the proximal-most point of the radiograph at the center of the femoral shaft and (2) 10 cm superior to the knee joint, equidistant from the medial and lateral medullary cortices of the femur.\textsuperscript{42}

**Fig. 1-B** The proximal tibial angle (PTA) was measured on anteroposterior radiographs and was defined as the medial angle (red) between (1) the anatomic axis of the tibia and (2) the line parallel to the superior aspect of the tibial plate.\textsuperscript{7} Line 1 (blue) was defined by 2 points (green): (1) 10 cm inferior to the knee joint, equidistant from the medial and lateral medullary cortices of the tibia and (2) the distal-most point of the radiograph at the center of the tibial shaft.

**Fig. 1-C** The posterior slope angle (PSA) was measured on lateral radiographs and was defined as the posterior angle (red) between (1) the tibial anatomic axis and (2) the tibial plate plateau. Line 1 (blue) was drawn according to the methods described for Line 1 of the PTA measurement in Fig. 1-B, except using the lateral radiographs and the anterior and posterior medullary cortices of the tibia.
assessment of TKA alignment. In order to internally validate this methodology, we separately assessed 200 TKAs with available short-leg and long-leg radiographs and compared the findings to determine whether the rate of implant alignment outliers was similar between these methods.

**Defining Postoperative Radiographic Outliers**

Prior studies have described the relationship between the accuracy of implant alignment and the subsequent risk of postoperative mechanical failure. While the definition of "outlier" varies drastically between studies, our measurement ranges are based on previous research identifying clinically relevant "safe zones," outside of which increased failure rates were noted. On the basis of Ritter et al., we defined DFA outlier status as alignment outside of $5^\circ \pm 3^\circ$ of valgus, and on the basis of Kim et al. and Ritter et al., we defined PTA outlier status as a $>\pm 3^\circ$ deviation from the neutral axis. On the basis of Kim et al., optimal PSA
alignment was defined as 0° to 7° of flexion in knees that underwent cruciate-retaining TKA, and on the basis of our own senior surgeons’ experience, optimal alignment for posterior-stabilized knees was defined as 0° to 5° of flexion. A “far outlier” was defined as any measurement that fell >±2° outside of the aforementioned outlier ranges. “Highest-risk” outliers were defined as outliers that concomitantly had a DFA of ≥8° and a PTA of ≤90°.

**Statistical Analysis**

Descriptive statistics were calculated for continuous variables and categorical data. Continuous variables were compared using Student t tests and described using means and standard deviations. Categorical variables were compared using 2-proportion Z tests. The threshold for significance was established at p < 0.05.

Using SAS (version 9.4, PROC GLIMMIX; SAS Institute), we also performed multivariate analyses with a multilevel random-intercepts logistic regression. Two separate models were assessed: the first, a fixed-effects multivariable model, did not include random effects for variation in individual surgeons; the second, a random-effects mixed model, integrated the covariates of patient age and BMI and random effects for individual surgeon in
order to assess whether individual surgeons and patient characteristics had an impact on alignment outcomes. The output for this assessment was odds ratios (ORs) and p values.

**Results**

**Overall Alignment**

For the 1,570 knees included in this study, the mean post-operative measurements were as follows: DFA, 96.0° (95%...
The high-volume non-trainee (HVNT) group outperformed the low-volume non-trainee (LVNT) group on nearly all measures. A significantly greater proportion of knees in the HVNT group had outlier measurements for the PTA (17.4% compared with 12.0%; p < 0.001), the PSA (33.3% compared with 17.4%), and overall (total outliers, 22.3% for trainee compared with 11.8% for HVNT) (all p < 0.001). In addition, a significantly greater proportion of knees in the trainee group demonstrated far outliers for the DFA (3.9% compared with 1.9%; p = 0.027), the PSA (12.6% compared with 5.5%; p < 0.001), and overall (total far outliers, 6.4% for trainee compared with 3.1% for HVNT; p = 0.004) (Table III). The proportion of knees with 0 outliers was significantly higher in the HVNT group (69.0% for HVNT compared with 44.8% for trainee), and the number of knees with 1 (26.7% for HVNT compared with 35.2% for trainee) and 2 (4.1% for HVNT compared with 12.0%) outliers was significantly lower in the HVNT group (all p < 0.001).

### TABLE III Comparison of the Proportion of Outliers in the HVNT, LVNT, and Trainee Groups*

<table>
<thead>
<tr>
<th>Group</th>
<th>HVNT (N = 730)</th>
<th>LVNT (N = 230)</th>
<th>Trainee (N = 610)</th>
<th>Overall (N = 1,570)</th>
<th>HVNT vs. LVNT</th>
<th>HVNT vs. Trainee</th>
<th>LVNT vs. Trainee</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFA outlier</td>
<td>12.6%</td>
<td>16.5%</td>
<td>21.6%</td>
<td>16.7%</td>
<td>0.130</td>
<td>&lt;0.001</td>
<td>0.101</td>
<td></td>
</tr>
<tr>
<td>PTA outlier</td>
<td>5.3%</td>
<td>17.4%</td>
<td>12.0%</td>
<td>9.7%</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.624</td>
<td></td>
</tr>
<tr>
<td>PSA outlier</td>
<td>17.4%</td>
<td>28.3%</td>
<td>33.3%</td>
<td>25.2%</td>
<td>&lt;0.001</td>
<td>0.027</td>
<td>0.113</td>
<td></td>
</tr>
<tr>
<td>Total outliers</td>
<td>11.8%</td>
<td>20.7%</td>
<td>22.3%</td>
<td>17.2%</td>
<td>&lt;0.001</td>
<td>0.004</td>
<td>0.342</td>
<td></td>
</tr>
<tr>
<td>DFA far outlier</td>
<td>1.9%</td>
<td>6.5%</td>
<td>3.9%</td>
<td>3.4%</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.996</td>
<td></td>
</tr>
<tr>
<td>PTA far outlier</td>
<td>1.8%</td>
<td>5.7%</td>
<td>2.6%</td>
<td>2.7%</td>
<td>&lt;0.001</td>
<td>0.292</td>
<td>0.033</td>
<td></td>
</tr>
<tr>
<td>PSA far outlier</td>
<td>5.5%</td>
<td>12.6%</td>
<td>12.6%</td>
<td>9.3%</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.960</td>
<td></td>
</tr>
<tr>
<td>Total far outliers</td>
<td>3.1%</td>
<td>8.3%</td>
<td>6.4%</td>
<td>5.1%</td>
<td>&lt;0.001</td>
<td>0.004</td>
<td>0.654</td>
<td></td>
</tr>
<tr>
<td>0 outliers</td>
<td>69.0%</td>
<td>49.6%</td>
<td>44.8%</td>
<td>56.8%</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.214</td>
<td></td>
</tr>
<tr>
<td>1 outlier</td>
<td>26.7%</td>
<td>38.7%</td>
<td>44.1%</td>
<td>35.2%</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.159</td>
<td></td>
</tr>
<tr>
<td>2 outliers</td>
<td>4.1%</td>
<td>11.7%</td>
<td>10.7%</td>
<td>7.8%</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.654</td>
<td></td>
</tr>
<tr>
<td>3 outliers</td>
<td>0.1%</td>
<td>0.0%</td>
<td>0.5%</td>
<td>0.3%</td>
<td>0.575</td>
<td>0.236</td>
<td>0.288</td>
<td></td>
</tr>
<tr>
<td>Highest risk</td>
<td>8.6%</td>
<td>11.7%</td>
<td>16.1%</td>
<td>12.0%</td>
<td>0.159</td>
<td>&lt;0.001</td>
<td>0.118</td>
<td></td>
</tr>
</tbody>
</table>

*The proportion of outliers was compared using 2-proportion Z tests. *Far outliers* were defined as any measurement that fell ±2∗ outside of established outlier ranges. HVNT = high-volume non-trainee, LVNT = low-volume non-trainee, DFA = distal femoral angle, PTA = proximal tibial angle, PSA = posterior slope angle.

**HVNT Compared with Trainee Group**

The HVNT group outperformed the trainee group on nearly all measures. A significantly greater proportion of knees in the trainee group had outlier measurements for the DFA (21.6% compared with 12.6%), the PTA (12.0% compared with 5.3%), the PSA (33.3% compared with 17.4%), and overall (total outliers, 22.3% for trainee compared with 11.8% for HVNT) (all p < 0.001). In addition, a significantly greater proportion of knees in the trainee group demonstrated far outliers for the DFA (3.9% compared with 1.9%; p = 0.027), the PSA (12.6% compared with 5.5%; p < 0.001), and overall (total far outliers, 6.4% for trainee compared with 3.1% for HVNT; p = 0.004) (Table III). The proportion of knees with 0 outliers was significantly higher in the HVNT group (69.0% for HVNT compared with 44.8% for trainee), and the number of knees with 1 (26.7% for HVNT compared with 44.1% for trainee) and 2 (4.1% for HVNT compared with 10.7% for trainee) outliers was significantly lower in the HVNT group (all p < 0.001). The proportion of knees that fell into the highest-risk category was significantly greater in the trainee group (16.1% compared with 8.6%; p < 0.001).

**LVNT Compared with Trainee Group**

The LVNT and trainee groups performed similarly across nearly all measures. A significantly greater proportion of knees in the LVNT group had outlier measurements for the PTA (17.4% compared with 12.0%; p = 0.041) and far outliers for the PTA (5.7% compared with 2.6%; p = 0.033), but the percentages for total outliers (20.7% compared with 22.3%; p = 0.624) and total far outliers (8.3% compared with
6.4%; p = 0.342) were similar between the 2 groups. No significant differences were identified for any of the other measures in this study when comparing these 2 groups (Table III).

**Multivariate Analysis**

Our multivariate analysis with fixed effects demonstrated trends identical to those of the univariate analysis with respect to significant differences in outliers, far outliers, and high-risk malalignment when comparing the HVNT, LVNT, and trainee groups (Table IV). The mixed model with random effects demonstrated similar overall trends, with the exception of the analysis of PTA outliers. While the univariate analysis identified significant differences in terms of PTA outliers and far PTA outliers when comparing the HVNT and LVNT groups and when comparing the LVNT and trainee groups, the random-effects model did not (Table IV).

A subset of 200 TKAs with available long and short-leg radiographs was assessed to determine if the proportion of outliers was significantly different when assessed by short-leg radiographs. No significant differences were found, as shown in Table V. The interreader reliability was 98% in categorizing measurements as “aligned,” “malaligned,” or “far outliers.”

**Discussion**

In the current study, we assessed the relationship between surgeon volume, trainee status, and implant alignment outliers in TKA in the hopes of uncovering potential surgeon-specific,
and hence modifiable, factors that contribute to alignment outliers. Similar to the findings of prior studies, we identified a moderately high frequency of implant alignment outliers in our overall cohort, including DFA, PTA, and PSA alignment outliers. Furthermore, a surprisingly low proportion of knees (only 56.8%) demonstrated alignment within the target range for all measurements assessed in this study, while the LVNT and trainee groups performed similarly. The general findings from the multivariable analysis confirmed that these effects were being driven by differences in surgeon volume and training status, and not individual surgeon performance or patient demographics. However, these factors may contribute to differences detected in PTA outliers and far PTA outliers when comparing the HVNT and LVNT groups and the LVNT and trainee groups. Despite a lack of an instrument designed to improve outcomes. Even among HVNTs, the best-performing low surgical volume and trainee status were notable risk factors for implant alignment outliers in TKA. Weaknesses of this study include the use of short-leg radiographs and the lack of follow-up regarding outcomes and survival. However, our short-leg measurements were largely similar to paired measurements made on a subset of long-leg radiographs.

**Conclusions**

Low surgical volume and trainee status were notable risk factors for outlier and far-outlier alignment, even when accounting for differences in individual surgeon and patient characteristics. These findings may suggest that increasing the proportion of TKAs performed at high-volume centers or employing technology to optimize alignment in higher-risk surgeon populations could improve outcomes. Even among HVNTs, the best-performing cohort in our study, the proportion of TKA alignment outliers was still high. Finally, trainee surgeons performed similarly to, and certainly not inferior to, low-volume surgeons.

**Note:** The authors acknowledge the following surgeons for their contribution of patients to our study: Regis O’Keefe, Douglas McDonald, Cara Cipriano, Muyibat Adelani, and Ryan Nunley.

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References


