Extension and Flexion Gap Balancing and Its Correlation With Alignment in Navigated Total Knee Arthroplasty

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Abstract

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Computer-assisted surgery was developed to improve the results of conventional total knee arthroplasty (TKA). The authors investigated the preoperative varus/valgus deformity influence on the production of balanced extension and flexion gaps using computer-assisted surgery. This study evaluated data from a prospective case series. A total of 132 patients (107 women and 25 men) underwent navigated TKA. Patients were divided into the following 3 groups according to the degree of the initial varus/valgus deformity: group 1, 0° to 3°; group 2, 3° to 9°; and group 3, greater than 9°. The final lower limb mechanical axis (LLMA) and the final flexion and extension gaps were measured. Knees exhibiting up to 3° of deviation on the frontal plane and a difference of up to 3 mm between the lateral and medial gaps were considered to be aligned and balanced, respectively. Average LLMA deviation decreased from 5.58° (±4.80°) to 1.87° (±1.66°). For knees with varus deviation, the percentage of balancing relative to the flexion gaps was 97.8% and that relative to the extension gap was 100% (P>.05). For knees with valgus deviation, the percentage of balancing relative to the flexion gaps was 95.1% and that relative to the extension gap was 97.6% (P>.05). Approximately 92% of the LLMA alignment was achieved in the group with varus deformity, whereas 71.4% was observed in the group with valgus deformity (P<.05). Computer-assisted TKA could attain proper flexion and extension balance regardless of coronal plane malalignment magnitude. Severe valgus and varus knees are more difficult to align using navigation. No difference was found in the balance of flexion or extension gaps in valgus or varus knees, independent of the severity.

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Total knee arthroplasty (TKA) is commonly performed in patients with osteoarthrosis who do not respond to conservative treatment because this approach has been shown to induce consistent improvements in life quality. The number of individuals who receive TKA for pain relief has increased with the aging of the overall population. As a result of technical advances that increase implant survival, TKA can also be performed in younger patients. Because the total number of TKA procedures performed is rapidly increasing, the search for new options that could improve the results and implant survivorship and optimize the procedure is highly relevant. Computer-assisted surgery (CAS) was developed to improve the outcome of TKA, functions, and the precision of implant positioning. In addition, this is a precise and reproducible method used for bone resection, ligament balancing, and limb alignment. Computer-assisted TKA (CATKA) was developed to produce a more objective and precise standard measurement of ligament balancing in comparison to conventional arthroplasty, where this measure is obtained by manual verification of equal opening of the medial and lateral sides using laminar spreaders, ligament tensiometers, or block spacers. Inasmuch as the relevance of ligament balancing was emphasized by Freeman’s principles, CATKA represents a significant step forward in this field. This approach enables accurate adjustment, better understanding of each step of ligament release, and improved balancing, thus resulting in better limb alignment. The technique of CATKA is considered an excellent method to control the flexion gaps and the best way to assess it objectively. Therefore, in the current prospective study, navigated TKA was primarily used to investigate the influence of the degree of preoperative varus/valgus deformity on the production of balanced extension and flexion gaps. The authors hypothesized that valgus knees would be more difficult to align and balance with navigation than varus knees. As a secondary aim, the authors sought to establish the influence of those deformities on the results relative to the postoperative mechanical axis.

**Materials and Methods**

**Sample Design and Sample Characteristics**

This prospective case series study was performed following the approval of the Research Ethics Committee of São Paulo Hospital–Federal University of São Paulo (Universidade Federal de São Paulo–UNIFESP). A total of 132 patients were consecutively selected for TKA according to the inclusion criteria (radiographic diagnosis of primary arthrosis of the knee and at least 6 months of conservative treatment without pain and functional improvement) and exclusion criteria (ipsilateral hip prosthesis, active or recent infection, and severe quadriceps insufficiency). All participants exhibited an indication for arthroplasty. Of the included individuals, 25 were men, and the right knee was affected in 73 cases. Average age of the sample population was 69 years, and a navigation system (OrthoPilot; Aesculap, Center Valley, Pennsylvania) was used in all procedures to assist with TKA.

**Surgical Technique**

Following a skin median longitudinal incision, the medial parapatellar approach was used for deep dissection. The joint was exposed and trackers were placed on the anterior-medial region of the distal femur and proximal tibia. The navigation parameters (femoral intercondylar notch, center of rotation of the hip, knee internal and external rotation, knee arc of motion between 0° and 90°, center of rotation of the ankle, posterior limits of the femoral condyles, femoral anterior cortex, center of the medial and lateral plateaus, center of the proximal tibia, center of the ankle beyond the lateral and medial malleoli, and femoral slope) were measured, and the data were stored using software. Following data collection, the navigation system provided the patient’s (initial) mechanical axis. Next, the cuts were initiated, beginning with the tibia (always orthogonally, with the tibial mechanical axis, and a 0° slope). Ligament balancing was performed before the femoral cut in both flexion and extension using laminar spreaders, under navigation millimetric control. The data related to ligament balancing in flexion and extension were stored using the navigation system.

Next, the authors accessed the femoral cut planning screen and used the data related to limb alignment, flexion and extension gap balancing, and femoral slope to establish the implant size and its best position, taking systematically into account the relationship between implant position and mechanical axis. Following the femoral, tibial, and patellar cuts, the authors placed the corresponding test components and rechecked the limb alignment with the navigation system (mechanical axis on the coronal and sagittal planes).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>No.</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial LLMA</td>
<td>5.58</td>
<td>4.80</td>
<td>4</td>
<td>0</td>
<td>24</td>
<td>132</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Final LLMA</td>
<td>1.87</td>
<td>1.66</td>
<td>1.5</td>
<td>0</td>
<td>10</td>
<td>132</td>
<td></td>
</tr>
</tbody>
</table>

*Abbreviations: LLMA, lower limb mechanical axis; TKA, total knee arthroplasty.*

*Results of the paired Wilcoxon test.*

Table 1

Deviation of the LLMA on the Frontal Plane Before and After TKA: Varus or Valgus

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**TKA: Varus or Valgus**

This prospective case series study was performed following the approval of the Research Ethics Committee of São Paulo Hospital–Federal University of São Paulo (Universidade Federal de São Paulo–UNIFESP). A total of 132 patients were consecutively selected for TKA according to the inclusion criteria (radiographic diagnosis of primary arthrosis of the knee and at least 6 months of conservative treatment without pain and functional improvement) and exclusion criteria (ipsilateral hip prosthesis, active or recent infection, and severe quadriceps insufficiency). All participants exhibited an indication for arthroplasty. Of the included individuals, 25 were men, and the right knee was affected in 73 cases. Average age of the sample population was 69 years, and a navigation system (OrthoPilot; Aesculap, Center Valley, Pennsylvania) was used in all procedures to assist with TKA. The technique of CATKA is considered an excellent method to control the flexion gaps and the best way to assess it objectively. Therefore, in the current prospective study, navigated TKA was primarily used to investigate the influence of the degree of preoperative varus/valgus deformity on the production of balanced extension and flexion gaps. The authors hypothesized that valgus knees would be more difficult to align and balance with navigation than varus knees. As a secondary aim, the authors sought to establish the influence of those deformities on the results relative to the postoperative mechanical axis.
authors also checked whether balancing was appropriate for the programmed polyethylene component size, and the corresponding data were recorded. Next, all of the components, including the patellar (all patellae were replaced), were cemented and placed into position. The final data were collected, thus ending the navigated step of the procedure, and the surgical wound was closed.

All surgical procedures were performed by the same surgeon (M.V.M.L.). The implant used for TKA was the Columbus PS (Aesculap), and the OrthoPilot 4 navigation system was used in all patients. Intramedullary guides were not used. The bone cuts and all other procedures were guided by the navigation system.

Method for Data and Variable Extraction

In the current study, the lower limb mechanical axis (LLMA) and the lateral and medial flexion and extension gaps were measured intraoperatively using the navigation system, as described above.

Based on the qualitative assessment of the LLMA, the patients were allocated to 2 groups—the first corresponding to valgus alignment and the other to varus alignment. Each group was subdivided into the following 3 subgroups as a function of the degree of LLMA alignment: group 1, 0° to 3°; group 2, 4° to 9°; and group 3, greater than 9°.

The alignment and balancing achieved by surgery were verified according to the LLMA and the final flexion and extension gaps, respectively. Knees were considered to be aligned when they exhibited up to 3° of deviation on the coronal plane after arthroplasty and were rated as balanced when the difference between the medial and lateral gaps was not greater than 3 mm, with both measures assessed by intraoperative navigation.

Statistical Methods

The mean, median, and corresponding standard deviation (SD) were used as descriptive statistics. When applicable, the proportions of the various subgroups were calculated (as percentages). Inferential analysis to assess proportions among groups was performed using likelihood ratio analysis. The paired Wilcoxon test was used to assess difference in mean values among the groups. The confidence level in inferential statistics was 95%.

RESULTS

Of the 132 participants included in the current study, 19% (n=25) were men, and the average age of sample was 69 years. The average value of the angle formed by the line that links the center of the femur head and the center of the knee, with the line that links the center of the knee and the center of the ankle (LLMA on the frontal place), demonstrated 5.58° of varus deformity (SD=4.8) prior to TKA and 1.87° (SD=1.66) postoperatively. This improvement was statistically significant (P<.001), as successful alignment is traditionally represented as values approaching zero (Table 1).

Table 2

Balancing After TKA as a Function of the Flexion and Extension Gaps: Distributed According to the Degree of Deformity Before TKA—Varus

<table>
<thead>
<tr>
<th>Deviation of LLMA Before TKA, deg</th>
<th>0-3 (Group 1)</th>
<th>4-9 (Group 2)</th>
<th>Greater Than 9 (Group 3)</th>
<th>Total</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balancing in flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balanced knees b</td>
<td>35</td>
<td>97.2</td>
<td>41</td>
<td>97.6</td>
<td>13</td>
</tr>
<tr>
<td>Nonbalanced knees</td>
<td>1</td>
<td>2.8</td>
<td>1</td>
<td>2.4</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>100.0</td>
<td>42</td>
<td>100.0</td>
<td>13</td>
</tr>
<tr>
<td>Balancing in extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balanced knees b</td>
<td>35</td>
<td>100.0</td>
<td>42</td>
<td>100.0</td>
<td>13</td>
</tr>
<tr>
<td>Nonbalanced knees</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>100.0</td>
<td>42</td>
<td>100.0</td>
<td>13</td>
</tr>
</tbody>
</table>

Abbreviations: deg, degrees; LLMA, lower limb mechanical axis; TKA, total knee arthroplasty.

*Results of likelihood ratio analysis.

bDifference between the medial and lateral gaps less than 3 mm.
formation varying from 0° to 3° (group 1\textsubscript{varus}), 46.1% (n=42) from 3° to 9° (group 2\textsubscript{varus}), and 14.4% (n=13) greater than 9° (group 3\textsubscript{varus}) (Table 2).

To establish the effectiveness of navigation and the difficulty in achieving alignment and balancing relative to the degree of deformity, the success rate of these parameters was calculated in each experimental group. Regarding balancing in flexion in the varus condition, 97.2% of the knees were found to be well balanced (difference less than 3 mm between the medial and lateral gaps) in group 1\textsubscript{varus}, 97.6% in group 2\textsubscript{varus}, and 100% in group 3\textsubscript{varus}; the success rates of balancing in flexion did not exhibit significant differences among the groups (P=.728). Similar results were observed in the case of balancing in extension where all 3 groups exhibited 100% effectiveness, with no significant difference between groups (P=.524) (Table 2).

Regarding the varus condition, group 1\textsubscript{varus} exhibited 100% neutral alignment (up to 3° of deviation on the coronal plane), group 2\textsubscript{varus} exhibited 88%, and group 3\textsubscript{varus} exhibited 84.6%; the difference between the latter 2 groups relative to the former group was significant (P=.022) (Table 3).

Conversely, regarding valgus deformity, significant differences among the subgroups were not found relative to balancing in flexion (P=.18), as adequate results were observed in 100% of the participants in group 1\textsubscript{valgus}, 88.9% in group 2\textsubscript{valgus}, and 100% in group 3\textsubscript{valgus} (Table 4).

<p>| Table 3 | Balancing After TKA as a Function of the LLMA Deviation: Distributed According to the Degree of Deformity Before TKA–Varus\textsuperscript{a} |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>0-3 (Group 1)</th>
<th>4-9 (Group 2)</th>
<th>Greater Than 9 (Group 3)</th>
<th>Total</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aligned knees\textsuperscript{b}</td>
<td>36</td>
<td>100.0</td>
<td>37</td>
<td>88.0</td>
<td>11</td>
</tr>
<tr>
<td>Nonaligned knees</td>
<td>0</td>
<td>0.0</td>
<td>5</td>
<td>12.0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>100</td>
<td>42</td>
<td>100</td>
<td>13</td>
</tr>
</tbody>
</table>

Abbreviations: deg, degrees; LLMA, lower limb mechanical axis; TKA, total knee arthroplasty.
\textsuperscript{a}Results of likelihood ratio analysis.
\textsuperscript{b}Deviation of LLMA on the coronal plane up to 3°.

<p>| Table 4 | Balancing After TKA as a Function of the Flexion and Extension Gaps: Distributed According to the Degree of Deformity Before TKA–Valgus\textsuperscript{a} |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>0-3 (Group 1)</th>
<th>4-9 (Group 2)</th>
<th>Greater Than 9 (Group 3)</th>
<th>Total</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balancing in flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.180</td>
</tr>
<tr>
<td>Balanced knees\textsuperscript{b}</td>
<td>15</td>
<td>100.0</td>
<td>16</td>
<td>88.9</td>
<td>8</td>
</tr>
<tr>
<td>Nonbalanced knees</td>
<td>0</td>
<td>0.0</td>
<td>2</td>
<td>11.1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>100.0</td>
<td>18</td>
<td>100.0</td>
<td>8</td>
</tr>
<tr>
<td>Balancing in extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.432</td>
</tr>
<tr>
<td>Balanced knees\textsuperscript{b}</td>
<td>15</td>
<td>100.0</td>
<td>17</td>
<td>94.4</td>
<td>8</td>
</tr>
<tr>
<td>Nonbalanced knees</td>
<td>0</td>
<td>0.0</td>
<td>1</td>
<td>5.6</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>100.0</td>
<td>18</td>
<td>100.0</td>
<td>8</td>
</tr>
</tbody>
</table>

Abbreviations: deg, degrees; LLMA, lower limb mechanical axis; TKA, total knee arthroplasty.
\textsuperscript{a}Results of likelihood ratio analysis.
\textsuperscript{b}Difference between the medial and lateral gaps less than 3 mm.
and 100% in group 3_valgus, which was the group with the greatest deformity. Similarly, significant differences were also not found (P=.432) relative to balancing in extension among the groups (Table 4), as this was achieved in 100% of the participants in group 1_valgus, 94.4% in group 2_valgus, and 100% in group 3_valgus (Table 4).

Regarding alignment, the knees were aligned in 87.5% of the participants in group 1_valgus, 77.8% in group 2_valgus, and only 25% in group 3_valgus; the difference between the latter group relative to the former 2 groups was significant (P=.006) (Table 5).

**DISCUSSION**

Poor implant alignment resulting in early failure of TKA is a noteworthy and well-documented fact in the medical literature. Within that context, navigated CAS has been shown to add objective measurement methods to the surgeon’s experience. Although the patient benefits afforded by this technology concerning the radiographic alignment were confirmed by Ishida et al in a meta-analysis, the type of study with the highest level of evidence, the clinical impact of this technique remains to be established.

Ishida et al followed patients for a minimum of 5 years and reported better clinical and radiographic results in the group treated with CAS in comparison to the traditional technique. Similar results were demonstrated by Longstaff et al because these authors were able to correlate appropriate alignment with better clinical outcomes and earlier rehabilitation. However, a large number of studies have also reported the lack of any correlation between alignment improvement and clinical outcomes, and such discrepancy points to the need for new studies of better quality with longer follow-up periods to assess the clinical results.

Computer-assisted surgery is performed to improve the precision of bone cuts, implant position, and ligament alignment. In addition to affording greater cut precision, computer navigation also contributes to ligament balancing. The ligament balance in extension and flexion together with the tibial and femoral bone cuts generates the flexion and extension gaps that will be filled by the corresponding prosthetic components, including the tibial and femoral components and the polyethylene spacer.

To achieve appropriate balancing, which is manifested by a rectangular rather than trapezoidal space, balance between the medial and lateral spaces is needed in both flexion and extension. Such balance is achieved by means of ligament equalization, which generally involves medial release in varus knees and lateral release in valgus knees. Resection of the posterior cruciate ligament is typically associated with these types of release, and it was performed in all of the authors’ cases. Moreover, rotation of the femoral component is an important factor relative to the flexion space because external rotation is associated with the opening of the medial compartment and closure of the lateral one, and vice versa in the case of internal rotation. Therefore, in addition to ligament release, rotation of the femoral component could be performed to achieve balance in the flexion space.

Regarding balancing on the coronal plane, Bathis et al applied the conventional technique in 80 patients and achieved appropriate alignment in 78% of cases. Similarly, Martin et al achieved ideal alignment in 76 of 100 prostheses placed using the conventional technique, and Tingart et al performed 500 TKAs and achieved appropriate alignment in 74% of the cases using conventional guides. Therefore, in comparison to the literature, the authors’ results concerning alignment were superior to those reported for the use of conventional instruments, as the authors achieved ideal alignment in 92.2% of the 132 TKAs performed.

Regarding balancing, good balance was achieved in all groups, also in flexion and extension, without significant difference regarding type or degree of deformity. Balancing was considered to be within

### Table 5

<table>
<thead>
<tr>
<th>Deviation of LLMA Before TKA, deg</th>
<th>0-3 (Group 1)</th>
<th>4-9 (Group 2)</th>
<th>Greater Than 9 (Group 3)</th>
<th>Total</th>
<th>%</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aligned knees</td>
<td>14</td>
<td>87.5</td>
<td>14</td>
<td>77.8</td>
<td>2</td>
<td>25.0</td>
</tr>
<tr>
<td>Nonaligned knees</td>
<td>2</td>
<td>12.5</td>
<td>4</td>
<td>22.2</td>
<td>6</td>
<td>75.0</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>100</td>
<td>18</td>
<td>100</td>
<td>8</td>
<td>100</td>
</tr>
</tbody>
</table>

**Abbreviations:** deg, degrees; LLMA, lower limb mechanical axis; TKA, total knee arthroplasty.

*Results of likelihood ratio analysis.

aDeviation of LLMA on the frontal plane up to 3°.
the normal range when it exhibited up to 3 mm of medial and/or lateral opening in the flexion. Regarding limb alignment as a function of the mechanical axis in the group with varus deformity, the greater the deformity, the greater the malalignment—a finding already demonstrated in other studies that used the conventional technique.  

It is generally known that greater deformities are associated with greater technical difficulty in achieving appropriate alignment and balancing. It is also worth noting that the authors do not believe that an alignment of ±3 mm is ideal for all patients. According to some reports, a large fraction of the overall population exhibits constitutional varus deformity greater than the level considered to be ideal (±3°), which is neither pathologically nor represents a clinically unfavorable condition. However, surgeons should be careful with this type of assertion and do not mean to convey to less experienced surgeons the idea that poor alignment is not a question of wear: a review of different theories.

In the current study, TKA was performed as established with the gap technique, and the balance of both gaps was achieved in 96.4% of the cases. In the current study, the ideal ligament balancing did not result in neutral coronal alignment in all cases, but appropriate alignment was only achieved when ligament balancing was symmetric. Therefore, under specific conditions, it is possible to intentionally sacrifice alignment for the sake of balancing, and this is particularly true in the case of large deformities, where the recovery of the neutral mechanical axis is a matter of controversy. In addition, the persistence of slight residual deformity may provide the means to achieve symmetric gaps; therefore, balanced ligamentous tension improves the dynamic alignment of TKA, and navigation contributes to achieve this goal.

The authors believe that with increasing numbers of studies reporting on the use of CAS, as well as with improvements in the development of navigation technology, more precise results will be obtained in terms of the position, balancing, and alignment of knee components in TKA.

**CONCLUSION**

Computed-assisted total knee arthroplasty could attain proper flexion and extension balance regardless of coronal plane malalignment magnitude. Severe valgus and varus knees are more difficult to align using navigation. No difference was found in the balance of flexion or extension gaps in valgus or varus knees, independent of the severity.

**REFERENCES**


