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# Short-term functional outcomes of computer assisted navigated high tibial osteotomy

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ABSTRACT

*Purpose:* High tibial osteotomy (HTO) is a surgical procedure performed on patients with knee osteoarthritis (OA). Computer assisted navigated high tibial osteotomy (CAN-HTO) may result in improved outcomes for patients undergoing this procedure.
*Methods:* Retrospective study involving patients undergoing CAN-HTO.
*Results:* Surveyed thirty-three patients. Average follow-up: 2.3 years. 97% patients reported they would have this procedure performed again, if indicated. Re-operation rate: 6.1% and complication rate: 12.1%. Patients had decreased KOOS for symptoms when compared to non-navigation based HTO ($p = 0.000$).
*Conclusion:* There may be merit with the use of CAN-HTO, with demonstrated patient-reported benefits at 2-year follow-up.

## 1. Introduction

High tibial osteotomy (HTO) is a surgical realignment procedure performed on patients with medial compartmental knee osteoarthritis (OA) and varus deformity, who, after a period of conservative management, continue to report pain, decreased function, and decreased quality of life.[1–5] It is an effective way of treating OA in a younger active patient population who are not ideal candidates for a total knee replacement.[3,6,7] HTO's have demonstrated significant alleviation of symptoms and improved function if proper mechanical alignment is attained.[3,8] With traditional surgical technique, it is challenging to obtain proper alignment,[9,10] with low reproducibility and high intra-operator variability in balancing the alignment.[11–13]

Under or over correction of the deformity does not produce adequate outcomes and compromises the success of HTO.[7,14–18] Under-correction of the deformity will result in persistence of symptoms and possibly more rapid progression of arthritis, which would in turn elevate the patient's symptoms. Over-correction into more valgus alignment leads to other issues, such as patellar mal-tracking.[19,20] HTO can also result in alteration of the tibial slope and this can lead to instability of cruciate ligaments causing further pain and functional impairments.[16,18,21–23] It is noteworthy that anterior cruciate ligament reconstruction is prone to failure in the setting of significant varus mal-alignment[24] and it is recommended to correct the varus mal-alignment prior to ACL reconstruction with an HTO.[24]

Computer assisted navigated high tibial osteotomy (CAN-HTO) has been used and reported to have improved outcomes. CAN-HTO assists with obtaining more accurate alignment in the coronal plane, which has enhanced the reproducibility and success of HTO.[12,25–31]

This study reports the functional outcomes of CAN-HTO and compares them to other functional outcomes reported for HTO not assisted with navigation, pre-operative to HTO, pre-operative to TKA and post TKA.

## 2. Materials and method

This is a retrospective study involving thirty three patients, who, between October 2010 and June 2015, had undergone a computer navigated HTO. The surgeons in this study performed CAN-HTOs on all their patients. This study was approved by the institutional review board of the Halton Healthcare Services Research Ethics Committee.

The Stryker eNact Precision Knee Navigation System (Stryker; Kalamazoo, Mitch) was utilized intraoperatively to obtain preoperative and final intraoperative alignment and the change in alignment in the coronal plane. Measurements were obtained prior to and subsequent to soft tissue balancing. Our operative technique has been described in

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detail previously.[32]

Patients were contacted by telephone between one and five years postoperatively. Patients were asked to complete the outcome survey: Knee injury and Osteoarthritis Outcome Score (KOOS). Additional survey questions that were included were as follows: patient satisfaction, whether they would have this procedure again, smoking status, and current pain level on the visual analogue scale (VAS). Two authors (JB, NS) recorded the results during the telephone conversation. Statistical analyses of descriptive and analytical tests were done using Minitab 17 as well as Microsoft Excel 2007.

The KOOS scores obtained for the study population were compared to KOOS scores in comparable populations found within the literature. Four different studies were chosen, which allowed for a comparison between this study to: (1) pre-operative and operative patients for TKA,[33] (2) general population matched to age,[34] post-operative TKA and patients treated non-operatively[35] and patients undergoing HTO without navigation pre and post-operatively.[36] Given that they had different variance, two-sample *t*-test was applied to statistically compare and conclude the two means were different. Two-sample equivalence test was conducted in the scenario were the p-value > 0.05 for the difference of two means. It was performed to compare two means and conclude they were similar statistically. In cases where p-values for both difference and equivalence were > 0.05 further testing was performed to see if one mean was greater than the other statistically.

## 3. Results

The survey was performed on thirty-three patients. The average follow up was 2.3 years. Average age at the time of surgery was 47.6 ± 6.5 years. Thirty-two (97%) patients reported that after knowing the outcome of the surgery, they would have this procedure if indicated. The post operative VAS pain score was reported to be 3.3 ± 2.1, with 0 being no pain and 10 being maximum pain. The re-operation rate was 6.1% and complication rate was reported as 12.1%. Smoking was found to be present in 15.2% of the patients. The data is summarized in Table 1.

The average values of various domains of KOOS questionnaire are attached in Table 1. Statistical analysis of KOOS questionnaires with previously reported KOOS scores for non-navigation assisted HTO, pre-operative to HTO, general population, pre-operative to TKA and TKA were performed and are attached in Tables 2–5 with their respective p-values.

The KOOS score was found to be higher for the patients in this study when compared to the cohort of patients awaiting TKA with all p-values = 0.000. When compared to TKA patients, the KOOS scores are similar in the domains of pain, symptoms, ADLs and quality of life. The KOOS scores were found higher for sports/recreational activities when compared to TKA with p = 0.000. The HTO patients scored lower scores in all domains when compared to general population of the same age group with p-values less than 0.08.

In comparison to the KOOS scores of the non-navigation based HTO, the CAN-HTO had higher KOOS score for symptoms with p = 0.000. The scores in pain, ADL, sports/rec and quality of life were similar.

**Table 1**
Computer assisted navigation - high tibial osteotomy survey results.

| | |
|---|---|
| Number of Patients | 33 |
| Mean Follow up | 2.3 years |
| Average age of patient at surgery | 47.6 ± 6.5 years |
| Average VAS pain currently | 3.3 ± 2.1 |
| Average KOOS Pain | 77.8 ± 15.7 |
| Average KOOS Symptoms | 74.5 ± 17.0 |
| Average KOOS ADL | 82.8 ± 13.5 |
| Average KOOS Sport/Rec | 48.3 ± 29.5 |
| Average KOOS QOL | 46.8 ± 24.3 |
| Re-operation rate (Any procedure on same knee) | 6.1% |
| Complications | 12.1% |
| Smokers | 15.2% |
| Will you recommend others to have this procedure to others, or will you have had this procedure knowing the outcome you had? | 97% say yes |

## 4. Discussion

The results state the KOOS scores for patients undergoing CAN-HTO at two year follow-up and demonstrate: 1) decreased symptoms when compared to non-navigation based HTO, 2) increased sports and recreational activities when compared to TKA, 3) increased KOOS scores when compared to pre-operative patients for HTO and TKA and 4) increased KOOS scores when compared to patients deemed for non-operative management of knee arthritis.

The ideal patient for an HTO is a young, thin and active patient who has isolated medial compartment arthritis. If not treated, this has the potential to progress to severe osteoarthritis possibly requiring a total knee arthroplasty. Comparing the KOOS scores for our patients to the cohort studied by Paradowski et al. (with pre-operative KOOS for patients selected for TKA),[33] KOOS score in all five domains was significantly higher (p = 0.000 in all five domains). Similarly, when comparing to the cohort of patients studied by Ornotti et al. for patients selected for TKA,[35] pre-operatively the KOOS score in all five domains was significantly higher (p = 0.000) in the HTO cohort studied in this study. These results suggest and further affirm that the CAN-HTO patients fair well compared to non-operative arthritic patients. This procedure changes the coronal alignment of the knee and shifts the weight bearing axis towards the healthy lateral compartment thereby reducing the patient's pain and thus improving performance of their ADLs, sports/recreation, and overall quality of life.[37–39]

TKA has been an acceptable treatment option for severe knee osteoarthritis and has well documented outcomes in the literature. Comparing our results to the cohort of patients by Paradowski et al. the KOOS scores are similar with regards to pain (p = 0.024) and symptoms (p = 0.058). In terms of ADLs and Quality of life, statistics were inconclusive. Regarding KOOS score for sports/recreational activity, our patients have a score that is double that of the TKA patient (P = 0.000). This supports the theoretical advantage of better range of motion and sports related activities in the setting of HTO when compared to TKA.[39–41] This could also be due to the population cohort in the HTO group being younger compared to TKA and thus more involved in sports and recreational activities compared to the older age group.

When comparing the CAN-HTO population to the general population in Paradowski et al.[34] (both populations of a comparable age group), the normal population does better than the surgical group in all domains of KOOS (P < 0.08).Thus the HTO does help the patient when compared to pre-op TKA or TKA patients but is not the same as the general population.

Osteoarthritis of the knee has varying degree of severity, and based on the severity, a particular treatment option is offered, such as TKA for more severe osteoarthritis. Comparing the results of this study with the cohort of patients studied by Ornetti et al.[35] which were treated non-operatively for osteoarthritis as their arthritis was not severe enough for TKR, the HTO patients did better in all domains of KOOS (P < 0.06).

McNamara et al.[36] studied a group of patients prior to HTO and then subsequently non-navigation based HTO. Comparing our study results to their cohort of patients pre-operatively, the navigation based HTO patients studied in our study had KOOS scores in all five domains significantly higher (p = 0.000).

Comparing the results of navigation based HTO to non-navigation based HTO (as studied by McNamara et al.[36]) the KOOS score for ADLs were comparable statistically (p < 0.05). Differences in scores in the domains of quality of life, sports/recreational activities and pain were not statistically significant. In terms of symptoms, the KOOS score in the navigation HTO cohort were significantly higher. (p = 0.000). This further supports the proposed advantage of navigation based HTO over

**Table 2**
Comparison of KOOS data from the study to the data from Pradowski et al., 2015 for the patient population prior to undergoing total knee arthroplasty and post total knee arthroplasty (TKA).

| | Current Study | Pradowski et al., 2015 – Pre op TKA | Difference in Means | p-value |
|---|---|---|---|---|
| **Number of Patients** | 33 | 68 | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 35.7 ± 17.3 | 42.1 ± 6.9 | **0.000** |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 35.3 ± 22.6 | 39.2 ± 8.0 | **0.000** |
| **Average KOOS ADL** | 82.8 ± 13.5 | 33.0 ± 17.1 | 49.8 ± 6.2 | **0.000** |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 7.2 ± 13.6 | 41.1 ± 10.9 | **0.000** |
| **Average KOOS QOL** | 46.8 ± 24.3 | 16.8 ± 13.3 | 30.0 ± 9.1 | **0.000** |

| | Current Study | Pradowski et al., 2015 – Post- op TKA | Difference in Means | p-value | p-value (equivalence) | p-value (Greater) |
|---|---|---|---|---|---|---|
| **Number of Patients** | 33 | 68 | | | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 78.7 ± 17.4 | −0.9 ± 6.9 | 0.795 | **0.024** | |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 76.3 ± 17.8 | −1.8 ± 7.3 | 0.625 | 0.058 | |
| **Average KOOS ADL** | 82.8 ± 13.5 | 78.1 ± 16.0 | 4.7 ± 6.1 | 0.127 | 0.155 | 0.064 |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 24.6 ± 29.9 | 23.7 ± 12.6 | **0.000** | | |
| **Average KOOS QOL** | 46.8 ± 24.3 | 53.7 ± 19.4 | −6.9 ± 9.7 | 0.160 | 0.623 | 0.080 |

Difference in means = Current study – Comparative study; KOOS = Knee injury and osteoarthritis outcome score; ADL = Activities of Daily Living; Sport/Rec = Sports/Recreational activities; QOL = Quality of Life; p-value (equivalence): 2-sample equivalence test was performed if the values were within 10% of each other; p-value (Greater) – 2-sample *t*-test was performed to see if the greater of the two means was statistically greater than the other.

**Table 3**
Comparison of KOOS data from the study to the data from Pradowski et al., 2006 for the general population segregated by sex with age between 35 and 54 years.

| | Current Study | Pradowski et al., 2006 –Women | Difference in Means | p-value |
|---|---|---|---|---|
| **Number of Patients** | 33 | 80 | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 88.8 ± 18.7 | −11.0 ± 6.9 | **0.002** |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 89.5 ± 14.6 | −15.0 ± 6.4 | **0.000** |
| **Average KOOS ADL** | 82.8 ± 13.5 | 88.6 ± 19.7 | −5.8 ± 6.4 | 0.075 |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 79.3 ± 27.7 | −31.0 ± 12.0 | **0.000** |
| **Average KOOS QOL** | 46.8 ± 24.3 | 83.4 ± 22.0 | −36.6 ± 9.8 | **0.000** |

| | Current Study | Pradowski et al., 2006 - Male | Difference in Means | p-value |
|---|---|---|---|---|
| **Number of Patients** | 33 | 78 | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 87.4 ± 17.9 | −9.6 ± 6.8 | **0.006** |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 86.5 ± 16.7 | −12.0 ± 7.0 | **0.001** |
| **Average KOOS ADL** | 82.8 ± 13.5 | 89.1 ± 17.6 | −6.3 ± 6.1 | **0.044** |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 76.0 ± 29.5 | −27.7 ± 12.3 | **0.000** |
| **Average KOOS QOL** | 46.8 ± 24.3 | 77.7 ± 25.4 | −30.9 ± 10.2 | **0.000** |

Difference in means = Current study – Comparative study; KOOS = Knee injury and osteoarthritis outcome score; ADL = Activities of Daily Living; Sport/Rec = Sports/Recreational activities; QOL = Quality of Life.

**Table 4**
Comparison of KOOS data from the study to the data from Ornetti et al., 2008 for the patient population prior to undergoing total knee arthroplasty and post total knee arthroplasty (TKA).

| | Current Study | Pradowski et al., 2015 – Pre op TKA | Difference in Means | p-value |
|---|---|---|---|---|
| **Number of Patients** | 33 | 68 | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 35.7 ± 17.3 | 42.1 ± 6.9 | **0.000** |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 35.3 ± 22.6 | 39.2 ± 8.0 | **0.000** |
| **Average KOOS ADL** | 82.8 ± 13.5 | 33.0 ± 17.1 | 49.8 ± 6.2 | **0.000** |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 7.2 ± 13.6 | 41.1 ± 10.9 | **0.000** |
| **Average KOOS QOL** | 46.8 ± 24.3 | 16.8 ± 13.3 | 30.0 ± 9.1 | **0.000** |

| | Current Study | Pradowski et al., 2015 – Post- op TKA | Difference in Means | p-value | p-value (equivalence) | p-value (Greater) |
|---|---|---|---|---|---|---|
| **Number of Patients** | 33 | 68 | | | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 78.7 ± 17.4 | −0.9 ± 6.9 | 0.795 | **0.024** | |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 76.3 ± 17.8 | −1.8 ± 7.3 | 0.625 | 0.058 | 0.313 |
| **Average KOOS ADL** | 82.8 ± 13.5 | 78.1 ± 16.0 | 4.7 ± 6.1 | 0.127 | 0.155 | 0.064 |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 24.6 ± 29.9 | 23.7 ± 12.6 | **0.000** | | |
| **Average KOOS QOL** | 46.8 ± 24.3 | 53.7 ± 19.4 | −6.9 ± 9.7 | 0.160 | 0.623 | 0.080 |

Difference in means = Current study – Comparative study; KOOS = Knee injury and osteoarthritis outcome score; ADL = Activities of Daily Living; Sport/Rec = Sports/Recreational activities; QOL = Quality of Life; p-value (equivalence): 2-sample equivalence test was performed if the values were within 10% of each other; p-value (Greater) – 2-sample *t*-test was performed to see if the greater of the two means was statistically greater than the other.

**Table 5**
Comparison of KOOS data from the study to the data from McNamara et al., 2014 for the patient population prior to undergoing standard high tibial osteotomy (HTO) and twenty four months post HTO.

| | Current Study | McNamara et al., 2014 – Pre op HTO | Difference in Means | p-value |
|---|---|---|---|---|
| **Number of Patients** | 33 | 138 | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 51.1 ± 17.5 | 26.7 ± 6.3 | **0.000** |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 45.5 ± 12.8 | 29.0 ± 6.4 | **0.000** |
| **Average KOOS ADL** | 82.8 ± 13.5 | 60.7 ± 19.0 | 22.1 ± 5.7 | **0.000** |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 26.1 ± 21.0 | 22.2 ± 11.0 | **0.000** |
| **Average KOOS QOL** | 46.8 ± 24.3 | 25.0 ± 18.0 | 21.8 ± 9.1 | **0.000** |

| | Current Study | McNamara et al., 2014 – Post HTO | Difference in Means | p-value | p-value (equivalence) | p-value (Greater) |
|---|---|---|---|---|---|---|
| **Number of Patients** | 33 | 138 | | | | |
| **Average KOOS Pain** | 77.8 ± 15.7 | 73.3 ± 20.5 | 4.5 ± 6.5 | 0.170 | 0.193 | 0.085 |
| **Average KOOS Symptoms** | 74.5 ± 17.0 | 58.8 ± 16.6 | 15.7 ± 6.6 | **0.000** | | |
| **Average KOOS ADL** | 82.8 ± 13.5 | 80.6 ± 19.2 | 2.2 ± 5.7 | 0.445 | **0.022** | |
| **Average KOOS Sport/Rec** | 48.3 ± 29.5 | 51.9 ± 27.3 | −3.6 ± 11.4 | 0.526 | 0.390 | 0.263 |
| **Average KOOS QOL** | 46.8 ± 24.3 | 52.7 ± 24.8 | −5.9 ± 9.5 | 0.218 | 0.553 | 0.109 |

Difference in means = Current study – Comparative study; KOOS = Knee injury and osteoarthritis outcome score; ADL = Activities of Daily Living; Sport/Rec = Sports/Recreational activities; QOL = Quality of Life; p-value (equivalence): 2-sample equivalence test was performed if the values were within 10% of each other; p-value (Greater) – 2-sample *t*-test was performed to see if the greater of the two means was statistically greater than the other.

standard HTO and may be attributed to more accurate alignment correction with navigation.[42–45]

The purpose of this study is to determine our outcomes of the novel technique of navigation assisted high tibial osteotomy. Complication rates have been reported with a range from 0 to 47% in the literature.[46] Our complication rate of 12.1% and re-operation rate of 6.1% is within the range. The re-operation consisted of patients requiring a revision high tibial osteotomy or conversion to a TKA. 15.2% of the patients were smokers and most complications are among the smoker sub-group. The total number of complications was too small for statistical analysis and further studies are needed to compare smoking and other factors with complication rates. However smoking is a known risk factor non union and wound complications.[47] Ninety-seven percent of patients report that they would have this procedure done again, knowing their outcome. This study demonstrates the success of navigation assisted high tibial osteotomy in short term (two year) follow up. Long-term outcomes of HTO depend on accuracy and precision of the alignment.[27,39,40,44,48] Prospective studies are necessary to further demonstrate the success of CAN-HTO.

## 5. Conclusion

This study states the KOOS scores for CAN-HTO at two year follow-up. It shows patients have decreased symptoms when compared to non-navigation based HTO. Patient self-reported scores for sports and recreational activities were higher when compared to post TKA. The study also demonstrates increased KOOS scores when compared to pre-operative patients for HTO and TKA as well as increased KOOS scores when compared to patients deemed for non-operative treatment for knee arthritis.

## Conflicts of interest

None.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jor.2019.02.016.

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