35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Curvature Analysis of Femoral shaft in Total Knee Arthroplasty Patient and Control group

Ki Seon Lim, Wang Kyun Oh, Ji Yun Shin, Byung Ki Cho, Tae Soo Lee

Abstract— **For some patients with joint illnesses such as rheumarthritis or varus deformity, the total knee arthroplasty (TKA) procedures are performed. However, when inserting metal cutting guide for the procedures, due to the femoral shaft bowing, complications such as the cortex of the femoral shaft damages or secondary fractures can be caused. If the central coordinate value of the femoral shaft is known, the metal cutting guide could be inserted into the anatomical center, so such complications can be prevented. In this study, CT images of femoral shafts of 10 individuals in the experiment group who are in need of receiving the total knee arthroplasty procedures and those of 10 individuals in the control group without illness in the femoral shaft have been utilized to locate the 3-dimensional coordinate values. Then, Matlab was utilized to identify the central coordinate value in order to obtain a graph reflecting the anatomical shapes as well as to acquire the 3-dimensional curvature values by section. As a result, the average curvature range of femoral shafts of the experiment group was determined to be 631.2 mm whereas the average curvature range of femoral shafts of the control group was determined to be 1430.4 mm. The statistical significant of the measured results was verified through ANOVA analysis. Based on these results, it was verified that the level of curvature of the femoral shaft of the experiment group was higher. If the anatomical central points are located and analyzed using this methodology, it would be helpful in performing orthopedic operations such as the total knee arthroplasty.**

I. Introduction

The Total Knee Arthroplasty (TKA) procedure is performed on patients with damaged cartilages at the knee joints, experiencing deforming changes of the joints and suffering arthritis deformanses due to various illnesses such as arthritis or varus deformities [1,3,6,9]. At this time, patients with deformed or bent femurs may experience complications such as damages of femur cortex or secondary fracture if severe due to the femoral shaft bowing when inserting synthetic objects during operation, so it is necessary to perform the templating procedure of the level of femoral shaft bowing [2, 3, 7].

For patients with TKA performed, sometimes a simulation program developed for predicting the results of inserting a synthetic object is utilized, but it is insufficient to predict the level of femoral shaft bowing [4]. Due to such reasons, various studies have been performed over the methodology to identify the level of femoral shaft bowing. For patients needing high tibial osteotomy (HTO) operation, the center points of the distal femur and the proximal tuberosity of tibia are connected to adjust for femoro tibial angle (FTA) in predicting the level of femoral shaft bowing [5, 10]. For patients needing total knee arthroplasty (TKA), sometimes the difference between mechanical axis connecting the head of the femur and the center of the knee joint and the anatomical axis connecting the center points of the femoral shaft is utilized to assess the level of femoral shaft bowing [5,6,7,10].

In this study, the CT images of femurs have been utilized to locate the 3-dimensional central coordinates in the x-, y-, and z-axes and connect their values in order to predict the anatomical shape of the femurs [7]. Further, the pixel analysis method has been utilized to propose an image processing based central coordinate measurement method, and also to compare the level of femoral shaft bowing in the experiment group and the control group [12, 13].

II. MATERIAL AND METHOD

A. *Subjects and Equipment*

Among the patients who visited "C" orthopedic clinic located at Cheongju, 14 patients with CT examinations performed for TKA were subjected. Among them, 4 patients with differing anatomic positions and algorithms were excluded to designate the CT images of a total of 10 patients (2 males, 8 females, average age 66) as the experiment group. For the control group for comparison, the CT images of 10 individuals without illness at the femoral shaft (4 males, 6 females, average age 77) from PACS images at "C" University Hospital were randomly selected, and an identical methodology was utilized to measure the central coordinate value. As for the number of images used in the study, it depended on the length of the femoral shaft of the experiment images. For "C" Clinic, the images were restructured to be 3mm to show a distribution of 79~95 counts, with an average length of 261 mm. For "C" University Hospital, the images were restructured to be 5mm to show a distribution of 40~59, with an average length of 255 mm. The general

This Research was supported by Basic Science Research Program through the National Research Foundation of Korea Funded by the Ministry of Education, Science and Technology (2012-0007523).

Ki Seon Lim is with the department of Biomedical Engineering, Chungbuk National University, Cheongju, South Korea (e-mail: lks7491@ naver.com).

Wang Kyun Oh is with the department of Biomedical Engineering, Chungbuk National University, Cheongju, South Korea (e-mail: ojwoo1@ naver.com).

Ji Yun Shin is with the department of Biomedical Engineering, Chungbuk National University, Cheongju, South Korea (e-mail: lion0344@gmail.com).

Byung Ki Cho is with the department of Orthopaedic Surgery, Chungbuk National University Hospital, Cheongju, South Korea(e-mail: titanick25@naver.com).

Tae Soo Lee is with the department of Biomedical Engineering, Chungbuk National University, Cheongju, South Korea (corresponding author to provide phone: +82-43-269-6332; fax: +82-43-272-6332; e-mail: tslee@chungbuk.ac.kr).

characteristics noted for the experiment subject images have been organized and shown in below TABLE I.

TABLE I. GENERAL CHARACTERISTICS OF THE EXPERIMENT IMAGES

		General Characteristics	
		Experiment Group	*Control Group*
Sex	Males	2	4
	Females	8	6
Average Age		66	77
Average length of the femoral shaft [mm]		261	255

The imaging equipments used for the experiments were the 16-channel Multi Detector (Somatom, Siemens, Germany) and 64-channel Multi Detector (Brilliance, Philips, the Netherlands) CT scanners. From the anatomic position, the entire femur areas including the femoral shaft's heads and the knee joints were scanned. The scanned width of the images taken was 3~5 mm. The region included for scanning is shown in the following Figure 1.

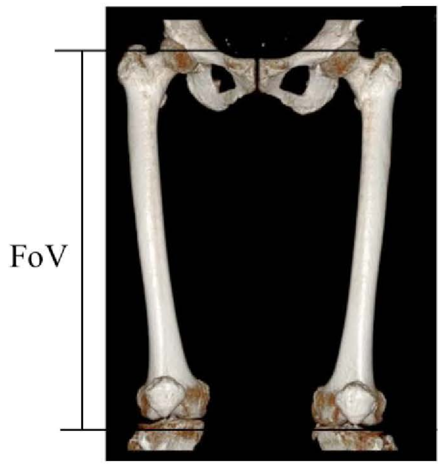


Figure 1. Example of image scope taken

B. Conversion and Analysis of the Images

DICOM images located at PACS servers have been transported to PC for analysis, and converted to jpeg format using the Osirix DICOM viewer. The converted images were pre-processed by adjusting the window widths and window levels. The outcome is presented in Figure 2.

The pre-processed images have been loaded as 8-bit grey images on Matlab to be analyzed, and the following processes have been undertaken to locate the central coordinate values.

1) Each experiment image included both right and left femoral shafts. As the central coordinates exist at both left and right, the images have been divided as 1/2 for analysis.
2) The grey scale values were adjusted to maximize the contrast between the femur including the medulla and other femoral shaft's organs, and threshold values were applied to detect the medulla area.
3) The center of gravity for the detected medulla was calculated to locate the central coordinate. The central coordinate value is presented at below Figure 3.

Figure 2. Femoral CT image with calibrated window width and level

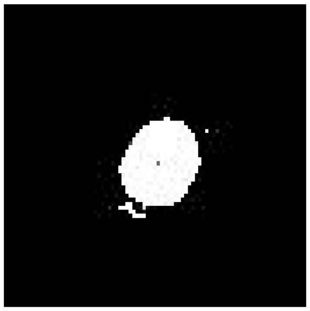


Figure 3. An Example of the central coordinate on a femoral shaft of the CT images

C. Curvature and Radius of Curvature

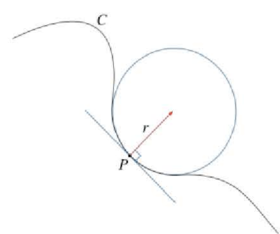


Figure 4. Radius of curvature in a curve

On a curved surface or at each point of a curve, the value displaying the degree of the bowing is defined as the radius of curvature. The larger the radius, the flatter the curve, and the value is infinity for a straight line. The radius of curvature in a circle is the radius of the circle, with a constant curvature value. As shown on Figure 4, the radius of curvature on a given point "P" of curve C is the radius r of the circle fitted along the circumference; therefore, the radius of the circle equals the radius of curvature. The center of the circle which is tangent to the curve is the center of the curvature. The curvature is the reciprocal of the radius of the internally tangential circle.

$$K = 1/r \quad (1)$$

D. Curvature Formula of the Central Coordinate

As for the 3-dimensional central coordinate, the 3-dimentional coordinate values of (x, y, z) have been identified using 3mm and 5mm intervals from the z-axis in femoral CT scan images. As each coordinate represents a function with a certain slope, a tangent straight line can be drawn as shown in Figure 4 to determine the derivative value. Also, as the 3D curvature of the femoral shaft must simultaneously reflect the level of curvature in the lateral direction as well as the anteroposterior directions, a 3-dimensional curvature formula was applied. The below is the formula applied.

$$K=\frac{\sqrt{(z''y'-y''z')^2+(x''z'-z''x')^2+(y''x'-x''y')^2}}{(x'^2+y'^2+z'^2)^{3/2}} \quad (2)$$

III. RESULT

The 3-dimensional coordinate values of CT images of the experiment group and the control group have been utilized to obtain the approximated curves and 3D radii of curvature. The statistical significance was verified through ANOVA analysis.

A. 3D Radius of Curvature

The radii of curvature of the experiment group had a distribution of 403.2~945.0 mm at the femoral shaft, while the distribution for the control group was 928.8~2,506.7 mm.

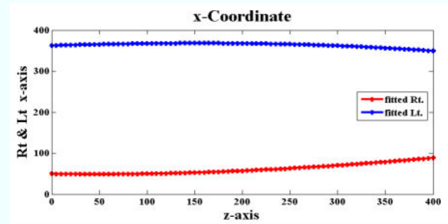
Based on the results of performing ANOVA to discriminate the average radii of curvature value between the two groups, the p-value was less than 0.001, indicating that the difference was statistically significant. We believe this provides the evidence that the bowing level of the femoral shaft from the images of the experiment group was more severe. The results are shown below in Table II.

TABLE II. RADII OF CURVATURE AND STANDARD DEVIATION

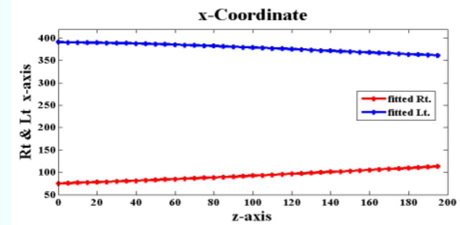
	Experiment group	*Control group*
Mean ± SD [mm]	631.2 ± 145.4	1430.4 ± 434.9

B. Graph approximated by curve fitting method

All central coordinate values of femoral shaft CT images used for the study can be displayed. For coordinate values dispersed with 3mm and 5mm intervals, the curve fitting function utilizing 3-dimensional formulas was used to be shown as a graph in reflecting the shape of the femoral shaft. The results are presented in Figures 5 and Figure 6. The left side of the graph is the proximal part of the femoral shaft whereas the right side is the distal part. The level of curvature of the x-axis and the y-axis shown at the graphs of the experiment group and the control group tend to coincide with the value of the curvature radius presented in Table 2. Such results could be applied in all images of the CT scans of the femoral shafts for the 20 individuals.

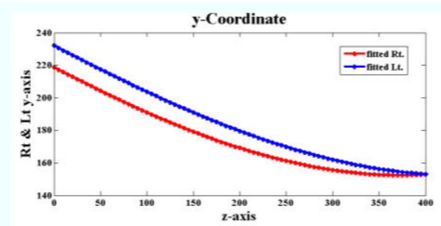


(a) Example of x-coordinate plot of the experiment group

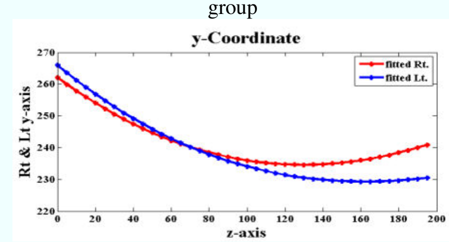


(b) Example of x-coordinate plot of the control group

Figure 5. Example of x-coordinate plot



(a) Example of y-coordinate plot of the experiment group

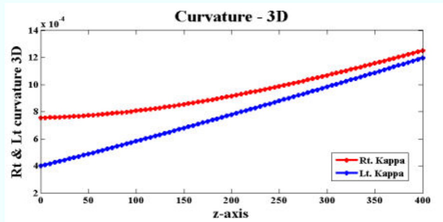


(b) Example of y-coordinate plot of the control group

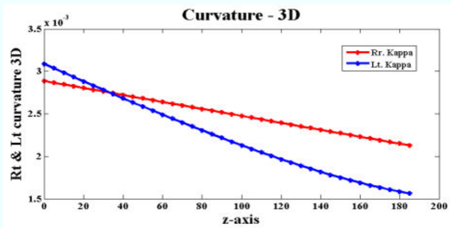
Figure 6. Example of y-coordinate plot

C. Curvature graph

The curvature by section with the z-axis as the reference is one measure to reflect the degree of bowing in the femoral shaft with objective data, and its results are presented in Figure 7. The radii of curvature between proximal and distal parts of the right femoral shaft in presented experiment group's graph showed the distribution of 754.2~1250.6 mm, and the left side showed the distribution of 399.6~1195.1 mm. Therefore, the radii of curvature values at the distal part were greater. On the other hand, the radii of curvature between proximal and distal parts of the right femoral shaft in the control group's graph showed the distribution of 2,887.3~2,128.5 mm, and the radii of curvature at the left side showed the distribution of 3,088.6~1,563 mm. Therefore, we could see that the radii of curvature values at the distal part are smaller.



(a) Example of experiment group's 3-dimensional curvature graph



(b) Example of control group's 3-dimensional curvature graph

Figure 7. 3-dementional curvature graph

IV. DISCUSSION AND CONCLUSION

In this study, CT scan images were utilized to locate 3-dimensional central coordinates. The pixel analysis method was then utilized to determine the value of the center of the gravity of the images and obtain central coordinates as well as the curvature by section.

In previous studies, L. W. Ehmke et al. have discussed that femoral nailing techniques utilizing the Remer method had high usability for operations as a preconfigured spiral-shaped path is formed along the center of the femoral shaft [8]. Further, Karakas et al. have utilized planar x-ray images to determine the femur curvature angles of Caucasians [11]. The differences between this study and previous studies include the fact that curvatures by section have been measured to analyze the degree of curvature at femoral shaft in a more detailed way, as well as the fact that 3-dimensional coordinate values have been utilized to simultaneously reflect not only the degree of curvature of anteroposterior directions but also the degree of curvature of lateral directions. As the count of images used for the study is small, it cannot be generalized, which presents a limitation of the study.

In conclusion, the central coordinate measurement method utilizing Matlab as presented in this study reflects the degree of curvature at the femoral shaft more objectively. As such, it presents a good method for assessing the central coordinate value in the analysis of clinical images. We believe that taking measurements of the radii of curvature for more cases of experiment and control groups and analyzing their differences in the future will provide great help in orthopedic operations including the total knee arthroplasty.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2012010951), a grant of the Korea Healthcare Technology R&D Project, Ministry of Health & Welfare, and Republic of Korea (A100054).

REFERENCES

[1] B. J Chung, Y. G. Kang, C. B. Chang, S. J. Kim, and T. K. Kim, "Differences between Sagittal Femoral Mechanical and Distal Reference Axes Should Be Considered in Navigated TKA," *Clinical Orthopaedics and Related Research*, vol. 467, Issue 9, pp. 2403-2413, Sep. 2009.

[2] Z. H. Lu, J. K. Yu, L. X. Chen, X. Gong, Y. J. Wang, and K. K. Leung, "Computed Tomographic Measurement of Gender Differences in Bowing of the Sagittal Femoral Shaft in Persons Older Than 50 Years," *The Journal of Arthroplasty*, vol. 27, Issue 6, pp.1216-1220, June 2012.

[3] E. Leibowitz, S. Logan, G. Schmidig, J. Schinski, M. Kester, and A. Patel, "Femoral Anterior Bow and Its Influence on TKA Femoral Placement and Size," *British Editorial Society of Bone and Joint Surgery*, 2011.

[4] S. K. Hwang, D. H. Kang, T. Y. Cho, and C. H. Lee, "Comparison of Conventional and Digital Templating Technique in Total Hip Arthroplasty" *J Korean Hip Soc*, vol. 22, no. 1, pp. 73-78, 2010.

[5] R. Nagamine, S. I. H. Miura, S. Matsuda, and Y. Iwamoto, "Femoral shaft bowing influences the correction angle for high tibial osteotomy," *Journal of Orthopaedic Scienc.*, vol. 12, pp. 214-218, 2007.

[6] S. Panyachare, and P. Udomkiat, "The Coronal Angulation of the Femur in Thai Osteoarthritic Knee Patient with Varus Deformity" *Siriray Med J*, vol. 63, no. 5, Sep.-Oct. 2011.

[7] J. H. Jun, S. M. Kim, and S.Y. Park, "A study of lateral curve angle estimation for femoral IM nail design," *Key Engineering Materials*, vol. 326-328, pp. 807-810, 2006.

[8] L. W. Ehmke, B. M. Polzin, S. M. Madey, and M. Bottlang, "Femoral Nailing Through the Trochanter: The Reamer Pathway Indicates a Helical Nail Shape," *Journal of Orthop Trauma*, vol. 20, no. 10, Nov. 2006.

[9] R. Niimi, M. Hasegawa, A. Sudo, and A. Uchida, "Unilateral stress fracture of the femoral shaft combined with contralateral insufficiency fracture of the femoral shaft after bilateral total knee arthroplasty," *Journal of Orthop Sci* , vol. 13, pp. 572-575, Dec. 2008.

[10] A. Unnanuntana, P. Toogood, D. Cooperman, and R. E. Grant, "Evaluation of Proximal Femoral Geometry Using Digital Photographs," *Journal of Orthopaedic Research*, vol. 28, no. 11, pp. 1399-1404, Nov. 2006.

[11] H. M. Karakas, and A. Harma, "Femoral shaft bowing with age: a digital radiological study of Anatolian Caucasian adults," *Turkey Society of Diagn Interv Radiol*, vol. 14, pp. 29-32, Mar. 2008.

[12] J. Kordelle, M. Millis, F. A. Jolesz, R. Kikinis, J. A. Richolt, "Three-dimensional analysis of the proximal femur in patients with slipped capital femoral epiphysis based on computed tomography," *J Pediatr Orthop*, vol. 21, no. 2, pp. 179-182, Mar.-Apr. 2001.

[13] K. S. Lim, W. K. Oh, J. Y. Shin, E. J. Cha, and T. S. Lee, "Three Dimensional Analysis Algorithm of Femoral Shaft Bowing" *IFMBE Proceedings*, vol. 39, pp. 854-857, May 2012.