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An Evaluation Method of EndoButton Position in MDCT Image After Anterior Cruciate Ligament Reconstruction.

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***Abstract*— ANTERIOR CRUCIATE LIGAMENT (ACL) reconstruction is performed to recover the injured knee which often happens in sports activity such as skiing, and basketball. The ACL reconstruction makes two bone tunnels in the femur and tibia. Then, the harvested graft passes the bone tunnels so that the femur and tibia are connected. The graft is fixed to the femur by using EndoButton. However, loosening of the fixation sometimes happens due to movement the EndoButton. It results in instability of the knee motion. Examination of frequency of occurrence of fixation loosening contributes to improve surgery procedure. This study set the goal to propose an evaluation method of EndoButton Position in MDCT image after ACL reconstruction. The proposal system was examined with this manually results. In the results, the error of anteromedial and posterolateral EndoButton were 1.88±1.03 and 1.78±1.19, respectively. As a result, the proposed method could detect automatically anatomical reference points and evaluate EndoButton positions.**

***Keywords*— medical image, image analysis, ACL rectionstruction, MDCT image**

I. INTRODUCTION

Anterior Cruciate Ligament (ACL) reconstruction is performed to recover the injured knee which often happens in sports activity such as skiing, and basketball. The ACL reconstruction makes two bone tunnels in the femur and tibia. Then, the harvested graft passes the bone tunnels so that the femur and tibia are connected. The graft is fixed to the femur by using EndoButton. However, loosening of the fixation sometimes happens due to movement of the EndoButton [1]. It results in instability of the knee motion. Although examination of frequency of occurrence of fixation loosening contributes to improve surgery procedure, no study has reported quantitatively evaluation of the EndoButton position. Therefore, this study set the goal to propose an evaluation method of EndoButton Position in MDCT image after ACL reconstruction.

In this study, MDCT image was used for evaluation of EndoButton position. The proposed method consists of six steps. The first step is localizing of gravity point of EndoButton. The second step is determining of proximal-distal axis. The third step is calibrating of searching area. The fourth step is detecting of the anatomical reference points. The fifth step is determining of the femur coordinate system. The last step is evaluation of EndoButton position. In this study, the proposal method was applied for 5 patients with the double bundle ACL reconstruction. For comparing the results, the anatomical reference points of medal and lateral epicondyles were manually indicated on the 3D viewer. The EndButton position based on manually reference points is regarded as truth value. The proposal system was examined with this manually results. In the results, the error of anteromedial and posterolateral EndoButton were 1.88±1.03 and 1.78±1.19, respectively. As a result, the proposed method could detect automatically anatomical reference points and evaluate EndoButton positions.

II. PRELIMINARY

A. ACL Reconstruction

The knee joint including the ACL is shown in Fig. 1. The knee joint consists of four parts: the femur, the tibia, the meniscus. Then, the ACL is attached to the femur and tibia

Fig. 1. Knee joint. PCL means the posterior cruciate ligament. The ACL consists of the AM and PL bundles. The AM bundle attaches on posterior position and anterior position in the femur and tibia, respectively.

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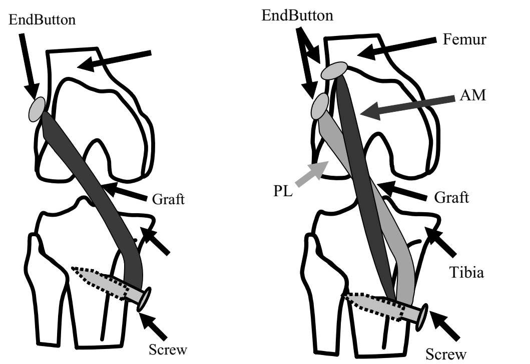


(a) (b)

Fig. 2. ACL reconstruction: (a) Single bundle reconstruction, and (b) double bundle reconstruction. The graft is fixed by EndoButton and screw on the femur and tibia, respectively.

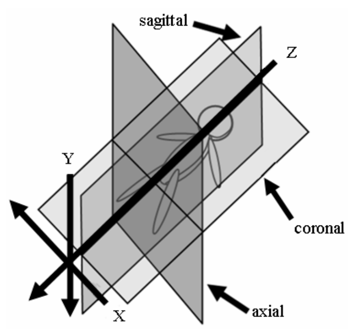
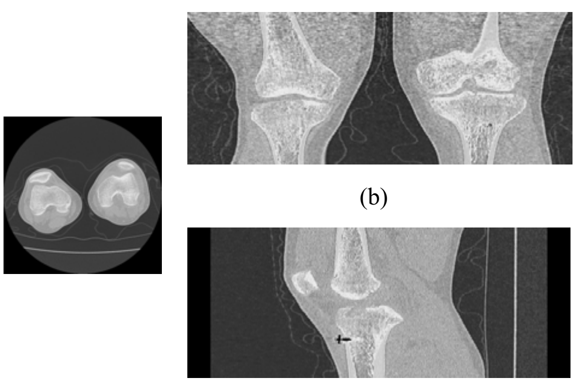


Fig. 3. Coordinate System of MDCT Image.



(a) (b) (c)

Fig. 4. An Example of MDCT Image. (a): Axial (X-Y plane), (b):Coronal (X-Z plane), and (c): Sagittal (Y-Z plane).

for controlling knee movement, and running from posterior of the femur to anterior of the tibia. The fiber of the ACL is roughly classified into Anteromeidal (AM) bundle and Posterolateral (PL) bundle.

The ACL is one of the most injured parts of human body. In general, women has higher possibility of having the ACL injury more than men. When the knee is rapidly twisting or over extending in sports activities, the ACL is injured. After

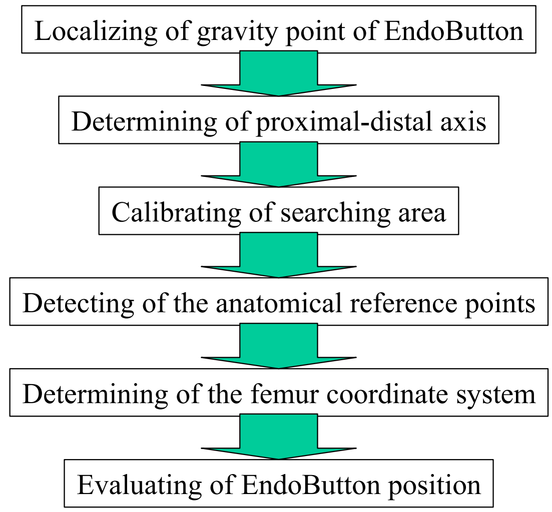


Fig. 5. Procedure of Proposal Method.

the ACL completely tears, the following three symptoms happens: A. pain and swelling, B. blood fulfilled in the knee, C. feeling of instability of the knee.

ACL reconstruction is performed under arthroscopy to recover sports activities. ACL reconstruction has two types of surgeries: single bundle reconstruction and double bundle reconstruction. The difference is the number of reconstruction graft (one or two) as shown in Fig. 2. The graft is attached to the femur and tibia through the bone tunnel which is prepared by drilling [2]-[4].

B. MDCT Image

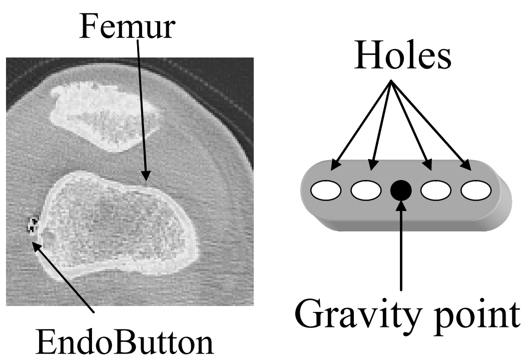
MDCT Image was obtained for patients who have ACL reconstruction. One slice consists of 512x512 (XxY) voxels. The number of slice (Z) and resolutions differ from patient to patient. The range of image was 5 cm proximal from the femur epicondyle and 5 cm distal from the tibial tubercle. The coordinate system is shown in Fig. 3. Then, an example of MDCT of the ACL injure knee is shown in Fig. 4. It has been reported that diameter or area of bone tunnel is analyzed in 2D slice as the conventional method [5]-[9].

III. PROPOSED METHOD

The proposed method consists of six steps as shown in Fig. 5. The first step is localizing of gravity point of EndoButton. The second step is determining of proximal-distal axis. The third step is calibration of searching area. The fourth step is detecting the medial and lateral epicondyles. The fifth step is determining of the femur coordinate system. The last step is evaluation of EndoButton position.

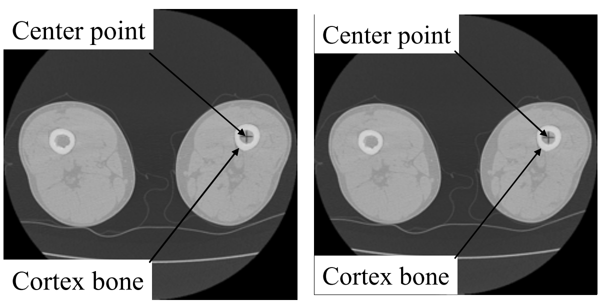
A. Localizing of gravity point of EndoButton

A region of EndoButton can be extracted by simple thresholding processing, because EndoButton is depicted with outstanding high intensity due to metallic composition as shown in Fig 6 (a). Then, gravity point $p_g(x_g, y_g, z_g)$ is calculated from



(a) (b)

Fig. 6. EndoButton: (a) EndoButton on MDCT image, and (b) gravity point of EndoButton. EndoButton has four holes.



(a) (b)

Fig. 7. Center points: (a) a center point of *j*-th slice, and (b) a center point of *j*+*m*-th slice.

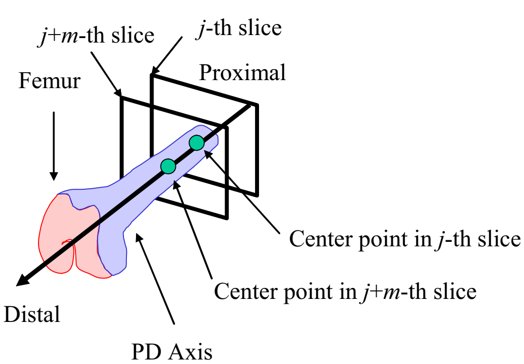
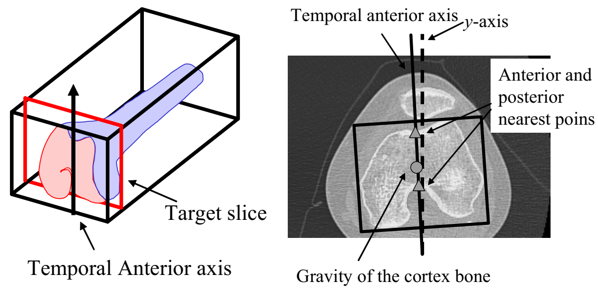


Fig. 8. Proximal-Distal Axis

$$x_g = \frac{\sum_{i=0}^{n} x(i)}{n}, \quad y_g = \frac{\sum_{i=0}^{n} y(i)}{n}, \quad z_g = \frac{\sum_{i=0}^{n} z(i)}{n} \quad (1)$$

where n is the number of voxel of the EndoButton, $x(i)$, $y(i)$, and $z(i)$ are coordinate values of i-th voxel of the EndoButton, respectively. The gravity point is regarded as Endopoint position (Fig. 6(b)).



(a) (b)

Fig. 9. Temporal anterior axis: (a) a target slice, and (b) anterior and posterior nearest points.

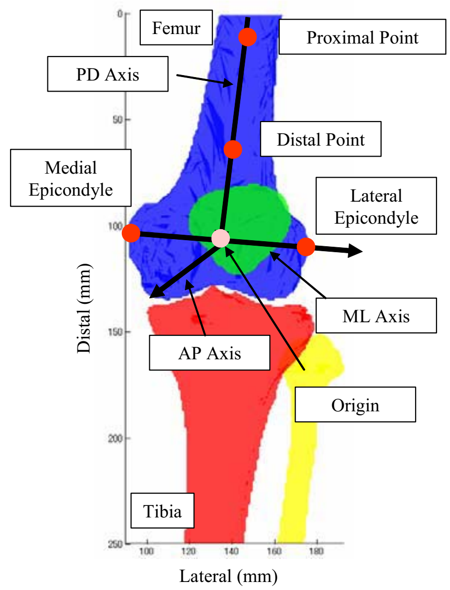


Fig. 10. The bone coordinate system of the femur bone.

B. Determining of proximal-distal axis

The proximal-distal (PD) axis is along with the bone axis. Here, j-th slice and $j+m$-th slice sufficiently above knee joint. Because the cortex bone is clearly depicted in both images, the region of the cortex bone is extracted 2-Dimentionally as shown in Fig. 7. Then, the center of the cortex bone is determined with similar calculation as equation (1). The PD axis is determined as a line connecting the obtained center points as shown in Fig. 8. Here, j = 0, and m = 10 were used, respectively.

C. Calculating of temporal anterior axis

A temporal anterior axis which is required for next processing is determined in this section. The target slice, that has the largest area of the cortex bone, is selected as shown in Fig. 9 (a). In the slice, the gravity point of the cortex bone is calculated with equation (1). The nearest anterior- and posterior points from the gravity point are detected. A temporal anterior axis is calculated by connecting the both points as shown in Fig. 9 (b).

D. Detecting of the anatomical reference points

The lateral-medial axis is determined based on anatomical reference points. The medial and lateral epicondyles are employed as the anatomical reference points. Both of the points are detected as the farthest points from temporal anterior axis. The lateral-medial (LM) axis is calculated by connecting both of the points as shown in Fig. 10.

E. Determining of the femur coordinate system

The bone coordinate system of the femur is determined from the information obtained by the previous processing. The origin is determined as the center point of the medial and lateral points. The anterior axis is determined as a cross product of the PD and ML axis as shown in Fig. 10.

F. Evaluating of EndoButton position

The EndoButton position was calculated by using the bone coordinate system of the femur. The position consists of anterior, lateral and distal positions.

IV. Experiments

The proposed method was applied for five persons (one female and four males) after double bundle ACL reconstruction that has informed consent. For comparing the results, the anatomical reference points of medal and lateral epicondyles were manually indicated on the 3D viewer. The EndButton position based on manually reference points is regarded as truth value. The proposal system was examined with this manually results.

V. Results

Error of AM and PL EndoButton Position are tabulated in Table I and II, respectively. Each value is difference between the proposed method and manual. In these results, the total error of AM and PL EndoButton position were 1.88±1.03 and 1.78±1.19, respectively.

TABLE I. ERROR OF AM ENDOBUTTON POSITION.

	Anterior	Lateral	Distal	Error
#1	0.47	-0.30	-1.10	1.23
#2	-0.91	-0.91	-2.30	2.64
#3	0.55	-0.09	0.11	0.57
#4	-1.81	0.33	-0.22	1.86
#5	-1.24	-0.44	2.82	3.11
mean	-0.59	-0.28	-0.14	1.88
SD	1.06	0.46	1.90	1.03

Unit: mm

TABLE II. ERROR OF PL ENDOBUTTON POSITION

	Anterior	Lateral	Distal	Error
#1	0.14	-0.14	-1.10	1.12
#2	-1.79	-0.50	-2.30	2.96
#3	0.23	-0.01	0.11	0.25
#4	-1.34	0.77	-0.22	1.56
#5	-0.90	-0.42	2.82	2.99
mean	-0.73	-0.06	-0.14	1.78
SD	0.89	0.51	1.90	1.19

Unit: mm

VI. Conclusion

This study is a pilot study for examining a displacement of EndoButton in time course. The proposed method could detect the medial and lateral epicondyles and EndoButton. As a result, the EndoButton position could be localized from the results. Future work is to apply the proposed method for MDCT images of two different periods.

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