# A Study of the Knee Cartilage Surface Features for the Custom-made Artificial Knee Joint Design

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**Abstract:** The soft tissue of human knee femur condylar is rather complex, the use of MRI images to construct the 3D images, and to provide the patient's geometry and physical characteristics are the primary goals of custom-made artificial knee joint design. In this study, the healthy patient's knee MRI images were provided by Taitung Mackay Memorial Hospital, through the slice with 1mm thickness as screening criteria to identify the available MRI images from DICOM data file and using Mimics software, via the discussion with orthopedic physician, to accurately construct knee femur condylar soft tissue 3D geometric model. Then, the obtained image data was converted to STL format as the input file for the CATIA software to analyze the surface curvatures of the knee femoral condyle soft tissue categorized by gender and age. 21 sets of MRI cases have been studied, the entire surface curvature radius were analyzed and summarized to provide custom-made artificial knee joint design reference basis.
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**Keywords:** Femur condylar soft tissue, Curvature radius, Mimics, CATIA, DICOM, Custom-made

## 1. Introduction

To provide patient's personalized anatomy real geometrical model and accord with patient's real geometrical and physiological characteristics are the primary goals for the design of artificial knee joint design. Since human knee joint tissue characteristic and femur condylar curvature vary with age and gender, the reconstruction of 3D knee joint model is the basis for artificial knee joint prosthesis related study. In this study, Mimics software and MRI images provided by Taitung Mackay Memorial hospital were used to collect and analyze human knee joint tissue characteristic and femur condylar surface curvature, and via the discussion with specialty physician to construct complete knee joint tissue 3D image, knee joint 3D geometry model and its related data base. Then, CATIA 3D engineering element was used for surface construction and measurement application, to build up the knee joint cartilage tissue surface curvature related data base.to provide press-fit design to fulfill the custom-made artificial knee joint design reference basis.

## 2. Literature review

There are many studies regarding the distal femoral shape variation and the induced knee joint function variations, degree of joint sickness and its prevention [1][2][3][4]. Female's intercondylar fossa shape, distal femur and posterior condylar curvature are much different from that of male and has higher tendency to suffer knee Osteoarthritis, higher relapse after surgical complication, and is not easy to recover. The curvature of medial and lateral femoral condyle and posterior condyle affect the stability of femoral rotating axis at bending as well as rotation of lateral compartment of tibiofemoral joint [5]. Currently, the majority of the artificial knee joint used is imported, and in addition to the variation of race and culture, frequently causes the size or shape unmatched as well as the lack of proprioception after the surgery. In Taiwan, there is no study related to gender and age variation of medial and lateral femoral condyle and posterior condylar soft tissue curvature radius. In view of this, this study focuses on the analysis of the domestic male/female medial and lateral femoral condyle center axis curvature radius and their characteristics. The results can be used as the basis when designing knee prosthesis.

Mimics is a set of highly integrated and easy to use 3D image generator and editing software. According to related literature, this software has a good reputation in the study of human tissue and/or bone structure and symptom[6][7][8][9][10][11][12]. The theory that Mimics use CT/MRI medical images data to construct 3D geometry model is based on gray threshold. Human tissue can be categorized into 2,000-4,000 density levels. Gray threshold, based on human density, is used as a base to identify tissue. Different gray scale can represent human tissue such as bone, ligament, muscle, and blood vessel [13]. Via the 3D geometry model, it is possible to inspect the exterior from different angle, and direction, such as locating CT layer that contains lateral epicondyle and medial epicondyle. Then 3D geometry model can accurately identify the characteristic location and dimension required for this study.

The study of knee joint reconstruct technique has been going on for many years. Between 1986 and 1996, David Siu [14,15] used AUTO to reconstruct human knee joint, and used 3D model to observe knee joint and obtain rich geometry measuring information, such as the description of femur condyle sagittal plane curvature radius, strike of the end of the medial and lateral condyles non coplanar and angle measurement of the 3D model.

## 3. Study method

The study method is shown in Fig. 1 with the discussion as followed.

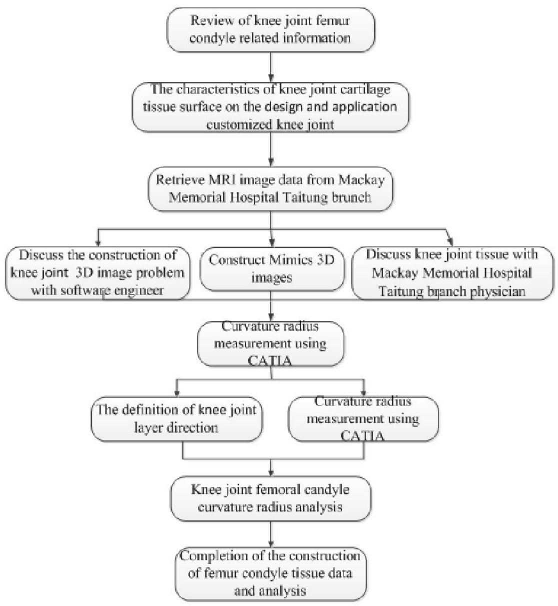



Fig. 1 Research flow chart

### 3.1 Mimics 3D image construction

Mimics can convert 2D planar medical images data obtained from CT or MRI into 3D images. Using the scanning portion (tissue, dimension, geometry complication etc.), pixel and cutting layer distance to build up the stacking 2D images and geometric property. However the quality of scanning image (such as pixel, cutting layer thickness etc.) has great effect on the total accuracy of the 3D image construct by Mimics. In general, Transaxial is used as main axis (MRI sometimes use sagittal as main axis) for image stacking. Through the build in function, Mimics automatically create the other two Orthogonal images：Coronal and Sagittal vision, as shown in Fig. 2.

In order to identify the correct position of CT or MRI radiographs scanning images, Mimics uses R-L axle (on Coronal Plane), A-P axle (on Sagittal Plane) and T-B axle (on Tansaxial Plane) as the coordinate system for the position of radiograph, as shown in Fig. 3.

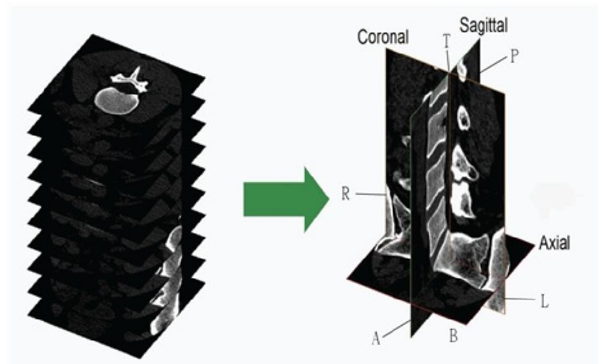



Fig. 2 The construction of 3D image by stacking 2D image data

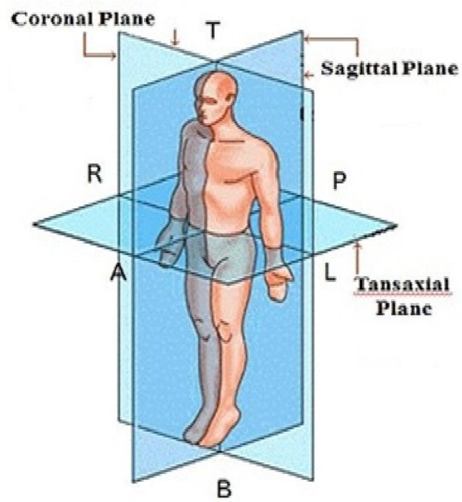



Fig. 3 The definition of radiography coordinate

After the input of MRI radiograph, a number (unit: mm) shows up on the right bottom corner of the Mimics windows. This number stands for the straight line coordinate position of this radiograph on the corresponding axle. Cross section and axle mentioned above can be used to position the individual layer of knee joint radiographs; For those radiographs that parallel to coronal plane, the position axis (A-P axle) coordinates increase from rear to front (P to A)；For those radiographs that parallel to Sagittal plane, the position axis (R-L axle) coordinates increase from right to left (R to L)；For those radiographs that parallel to Transaxile plane, the position axis (B-T axle) coordinates increases from bottom to top (B to T). In figure 4, the A-P axis coordinate for the radiography that is parallel to coronal plane is 118.61mm, the R-L axis coordinate for the radiography that is parallel to sagittal plane is 112.78 mm; the T-B axis coordinate for the radiography that is parallel to Transaxile plane is 63.00 mm.

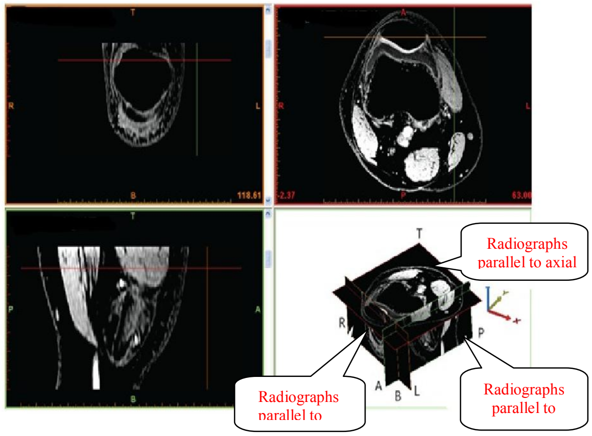



Fig. 4 Radiography's coordinate

### 3.2 Femur Condyle surface cartilage tissue 3D construction

Mimics is a software that utilizes 2D image data to perform transformation stacking and builds up 3D image data. This image processing technique can be used on the design of prosthesis, by via the data provided by visualize scanning system such as CT, MRI and confocal microscope to validate, measure and analyze human tissue structure. Its application has been proved to be accurate [16]. The process of using Mimics to build the knee joint femur condyle surface cartilage tissue 3D image is the following:

1. Contrast setting

Choose "Organized Images" function: this function is used to set up the contract of MRI and CT images. It can only perform preliminary contrast setting, as shown in Fig. 5. User can set the contrast manually, and base on the individual's visual recognition capability, to set the contrast in the clearest state. There are two parameters on the manual contrast setting screen.

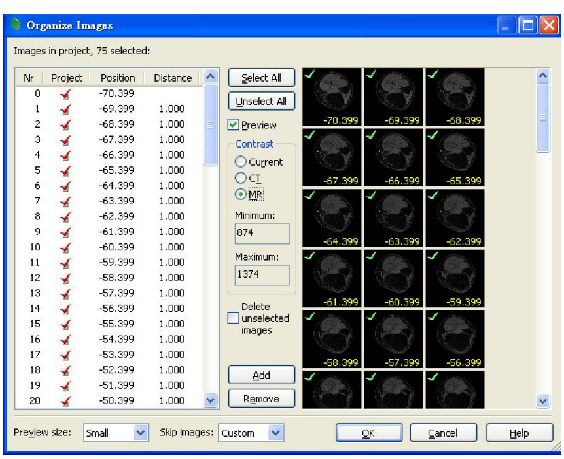



Fig. 5 Organize Images functions(Organize Images)

2. Threshold setting

Choose femur surface condylar cartilage tissue reconstruct portion and properly define its threshold value range to build the mask layer. There are two conditions when setup the threshold: minimum and maximum setting range.

3. Region growing

Before generating the image on the chosen structure, threshold chosen femur condylar cartilage tissue needs to connect with other soft tissue and muscle. It is necessary to segment those portions that do not belong to femur condylar cartilage tissue. After the segmentation, it is able to generate the chosen area and build up the structure tissue.

4. Image Edit

It is necessary to add or erase defect and boundary of the image built by Mimics to increase the accuracy of the reconstructed image. As seen in Fig. 6, the femur condylar cartilage tissue 3D model, built by Mimics, has holes on inner femur condyle. These holes were generated because when choosing the threshold, it is not possible to include the entire femur condylar cartilage tissue. It is necessary to patch these holes up manually. As shown in Fig. 7.

5. 3D calculation

The last step is to use Mimics 3D calculation capability to calculate and build up the mask image layers. 3D calculation uses five steps for result optimization. After the reconstruction, the surface of the femur condylar cartilage surface is more even, clear and smooth. Fig. 8 shows the final femur condylar cartilage tissue 3D model.

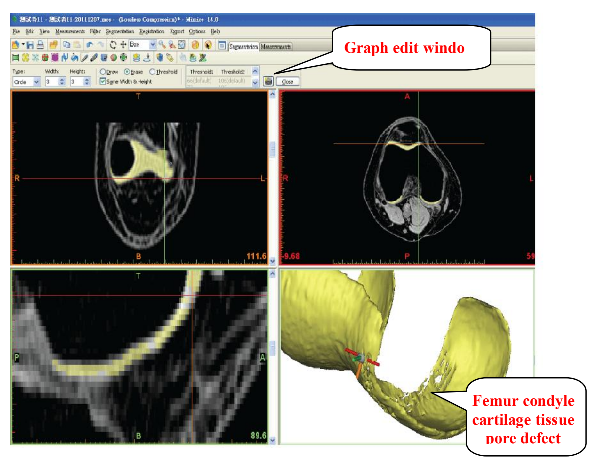



Fig. 6 Unpatched femur condyle cartilage tissue

### 3.3 Femur condyle soft tissue surface curvature measurement

The process of using CATIA to measure the femur condyle soft tissue surface curvature is the following:

1. Cutting direction setting

After the discussion with Taitung Markay Memorial hospital orthopedic physician, femur condylar soft tissue is generally trimmed to the ridge of knee joint femur condyle, as shown in Fig. 9. Therefore, the condyle soft tissue cutting layer direction defined for CATIA uses ridge line as the base for the layer setting, as shown in Fig. 10. Orange is the starting point of the layer.

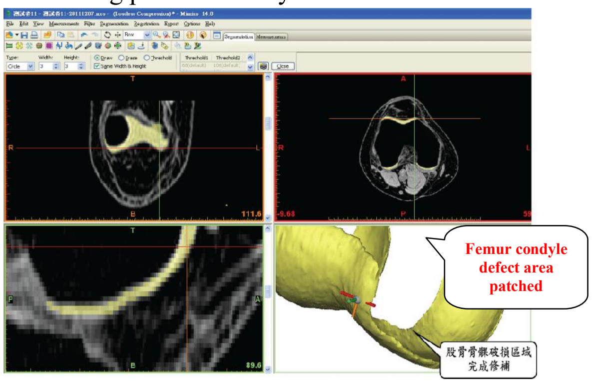



Fig. 7 Patched femur condyle cartilage tissue

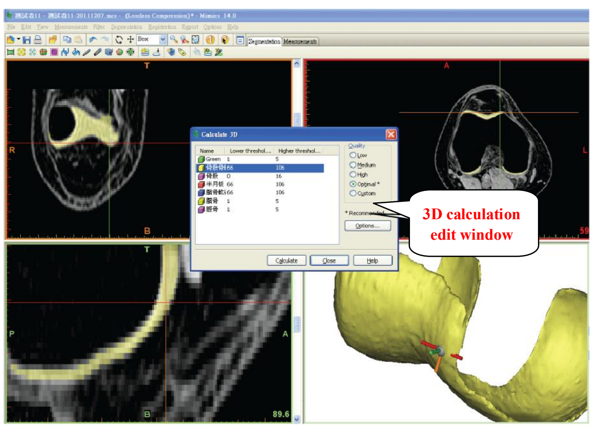



Fig. 8 Femur condyle cartilage tissue 3D model

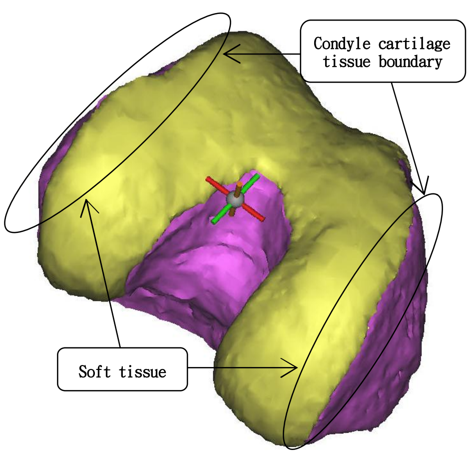



Fig. 9 Femur condyle soft tissue boundary and condyle ridge trimmed line

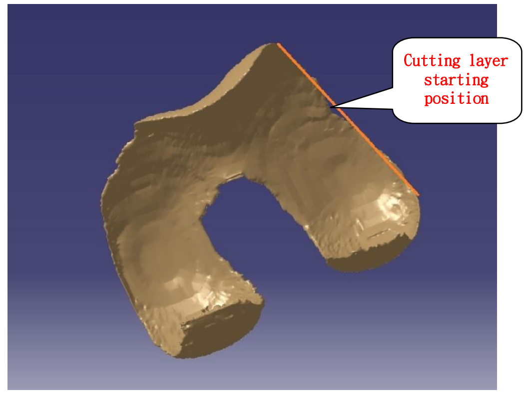



Fig. 10 Condyle soft tissue layer starting position

2. Femur condylar soft tissue layer

The planar section layer can be any thickness. Since the thickness of MRI radiography is 1mm, femur condyle soft tissue layer is set at 1mm.

Curve form scan function in CATIA is used to scan and compute the layered soft tissue. These scanned curves are used as basis for the single condylar axis.

3. Definition of the single condylar axis

Take right femoral condyle as an example, compute its layer scanned curve data, and use middle position of femur/lateral condylar width (WM/LFC) to locate single condylar axis, as shown in Fig. 11. And choose the layer where single condylar axis is located, see Fig. 12. The reason is that, this single condylar axis is the location that suffers the force the most when it exercises. Therefore, in this study, this axis is chosen to for the femoral condyle soft tissue curve surface curvature measurement and analysis, then, use generative shape design model to continue the curvature measurement.

4. Layer cross section rebuild

Before measuring the curvature, it is necessary to use the “Project 3D elements” function in CATIA under sketch model to rebuild layer cross section curve. Then, we are able to edit and measure the cross section curve.

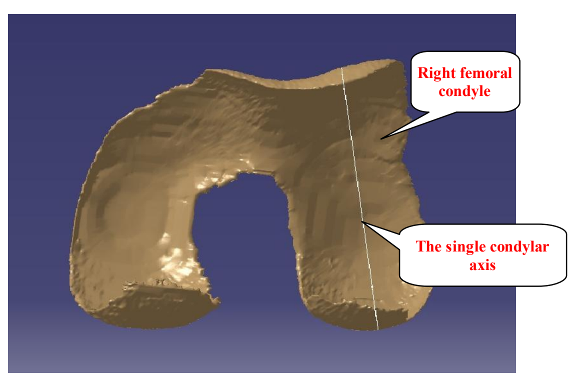



Fig. 11 the single condylar axis of the right femoral condyle

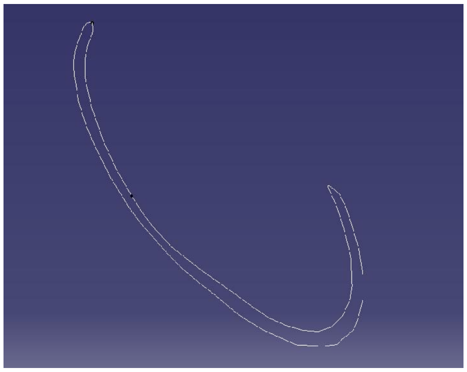


Fig. 12 The tissue layer cross section located at the single condylar axis

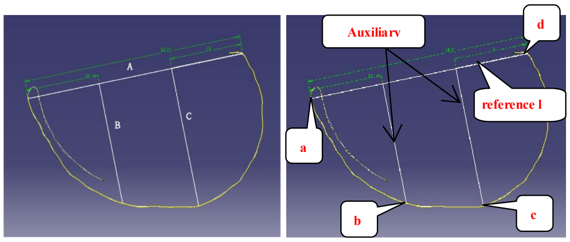



Fig. 13 Definitions of reference axis and auxiliary line

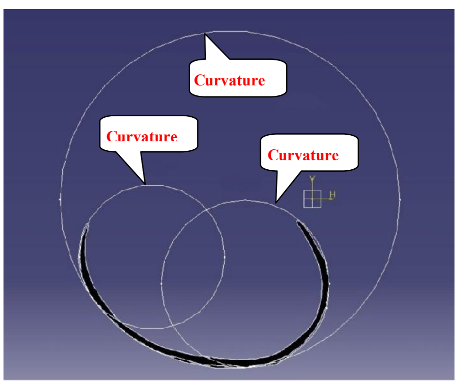



Fig. 14 The tissue layer cross section curvature assembly located at the single condylar axis

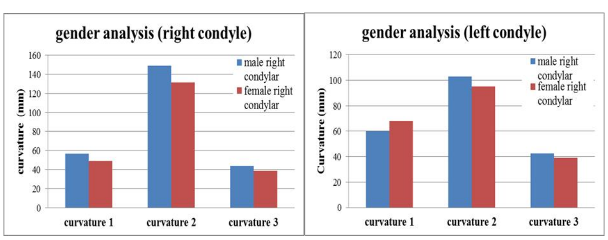



Fig. 15 The gender differentiation of femoral condyle soft tissue curvature

5. Defined reference axis and auxiliary line

In order to obtain characteristics of femoral condyle soft tissue curvature, it is necessary to define reference axis and auxiliary line for the measurement. Reference axis is defined as the axis (A) that along the longest length of the femur front/rear joint cross section (FAP). Auxiliary line is defined as the axis that is perpendicular to reference line and located on the FAP line at 1/3 (B) and 2/3 (C) locations respectively. Reference and auxiliary intersect with layer curve at points a, b, c and d. By measuring arcs ab, bc and cd, we can obtain the curvature of this cross section, as shown in Fig. 13. With this curvature information, we can further understand the curvature characteristics of femoral condylar soft tissue. In femoral condylar soft tissue curvature measurement, we used three circle curvatures to do the analysis. The constructed right femoral condyle single condylar layer cross section curvature assembly is shown in Fig. 14. Among them, curvature not only has to sustain human weight, but also absorbs the impulse caused by human exercise.

## 4. Results and Discussion

In this study, 21 sets of MRI data were used to analyze and induct femur condyle left/right condyle curvature information and were categorized by gender and age. Results are shown and discuss in the following:

1. Gender analysis

From data analysis, it clear shows that the mean value of male femur condylar soft tissue curvature is larger than that of female's. This means, gender consideration affects the femur condyle soft tissue curvature data; the difference is especially large in curvature 2, as shown in Fig. 15.

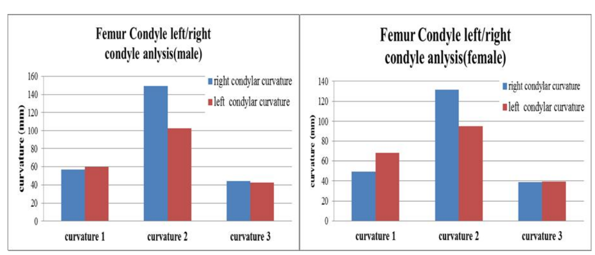
2. Femoral condyle left/right differentiation analysis

(1) Male femoral condyle

In male femoral condyle left and right condylar soft tissue curvature analysis, we found out that male right condyle curvature is large than that of left condyle. However, the difference decreases with age, as shown in Fig. 16a.

(2) Female femoral condyle

In the case of female, it right condylar curvature apparently larger than that of left condyle, as shown in Fig. 16b.




(a) (b)

Fig. 16 Gender femoral condyle left/right condyle soft tissue curvature differentiation analysis

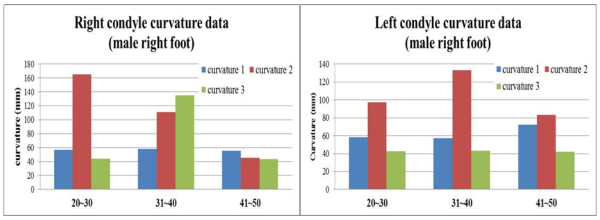


Fig. 17 Male age group condyle soft tissue curvature variation analysis

3. Age group analysis

The effect of age on the male and female right femoral condylar soft tissue analysis was also analyzed in this study. In male case, femoral condylar soft tissue curvature data variation is large except for curvature 1. Curvature 2 decreases with as the age increases. In the case of female, femoral condyle soft tissue variation is small, especially curvature 3, as shown in Fig. 17 and 18.

## 5. Conclusions

1. The purpose of this study is to increase the accuracy of the identification of femoral condylar soft tissue range. Via the discussion with Taitung Markay Memorial Hospital orthopedic physician to confirm that femoral condyle ridge line is used as the basis to identify femoral condyle soft tissue boundary.

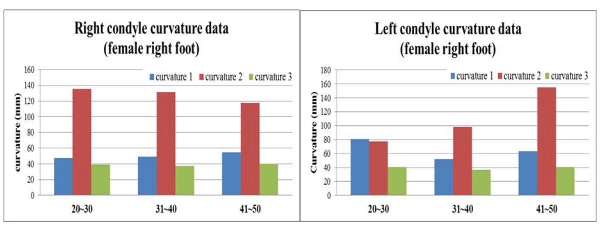


Fig. 18 Female age group condyle soft tissue curvature variation analysis

2. Since femoral condyle soft tissue structure is complicate and tissue volume is thin and small, the critical point of using Mimics to reconstruct condyle soft tissue using MRI images is the setting of contrast and gray threshold. We found out, the threshold value between 48 and 81 can obtain better 3D model. During the construction, it is necessary to perform manual pixel patching, however the discussion with physician is necessary in order to obtain tissue boundary information.

3. Through the use of CATIA, the definition of single condylar axis, and the setting reference axis and auxiliary line, three curvature radii were used to complete left/right condylar single axis layer curvature assembly analysis. This measuring model can be used to analyze other layer cross section, and eventually complete the data setting of the entire femoral condyle soft tissue curvature data.

4. This research studied femoral condyle left right condyle curvature data. The data was analyzed and inducted based on gender and age. In gender analysis, it is discovered that male femoral condylar soft tissue curvature mean value in general is larger than that of female. In the analysis of femoral condyle left/right condylar curvature, regardless of gender, right condylar curvature is larger than that of left condylar curvature. By looking at the age group comparison, male femoral condyle soft tissue curvature data has larger variation than that of females'.

5. The setup of femoral condyle soft tissue measuring and analysis model can further collect MRI image data, build up more condylar soft tissue curvature comparison and analysis database to increase the data accuracy and reliability, and achieved the goal of the artificial knee custom-made design.

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