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Construction of a database of average cross-sections in Chinese proximal femurs

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Abstract: The process of constructing a database of average cross-sections in Chinese proximal femurs is described. The main goal of creating the database is for designing hip stems for Chinese patients. Methods for constructing the database are introduced. According to some existing software and programs developed by the authors, a database of average cross-sections in Chinese proximal femurs was built based on CT images of eighty femur-specimens. 3-D shape of a patient's proximal femurs can be reconstructed according to the database and X-ray radiographs. Theoretical analyses and results of clinical application indicate that the database can be used to design hip stems for Chinese patients.

Key words: database; average; femur; cross-section

Hip stems, currently used in China, are mostly made in Europe or America. However, differences in bone geometries are obvious among different ethnic groups[1]. Many Chinese scholars have reported that hip stems usually cannot fit Chinese femoral cavities well[2]. However, the degree to which a hip stem fits the corresponding femoral cavity has great effects on load transfer and stability of the prosthesis[3-6]. In recent years, many scholars have investigated Chinese thighbones using X-ray radiographs to obtain some sizes related to the design of hip prostheses[7,8]. Although these sizes are helpful in improving design of hip stems for Chinese people, they also have some limitations. These sizes cannot reflect the shapes of femoral cross-sections. In some cases, hip prostheses, designed according to these sizes, are also not suitable for the patient's bone geometries. In order to solve this problem, a database of average cross-sections in Chinese proximal femurs was built.

Although different femurs have different shapes, shapes of cross-sections (in corresponding places) of different femurs are similar. The database is mainly for designing hip stems. A hip stem is implanted into the upper-side of a femur. In addition, some parts of the femur (caput femoris, collum femoris, etc.) are cut off during the operation. Thus, the database was built in the area of proximal femurs, and the area is under the intertrochanteric fossa. There are mainly five kinds of cross-sections in this area (see Fig. 1). From Fig.1, it can be seen that these figures are not very complicated. Thus, it is possible to create a database of average cross-sections in the proximal femurs.

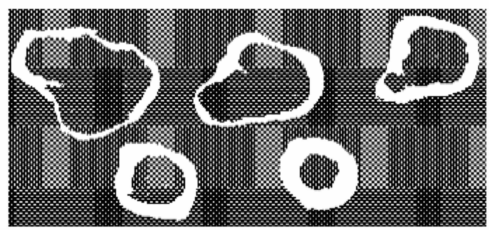

Fig.1 Five main cross-sectional shapes of proximal femurs

1 Process of Constructing the Database

The construction of the database requires a multi-stage process, which includes CT scanning, image processing, defining locations of cross-sections, obtaining the required data and the statistics of these data (see Fig.2).

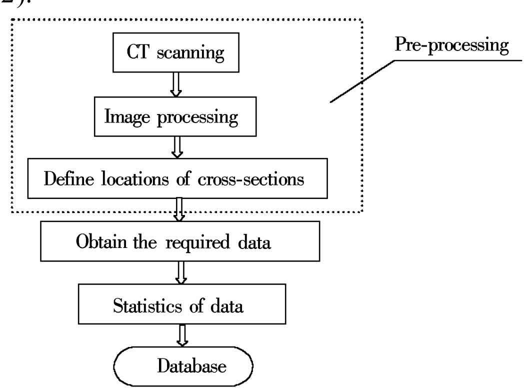

Fig.2 Flowchart of creating a database

1.1 Pre-processing

In this study, eighty femur-specimens, which were obtained in Shanghai, China, were scanned on a spiral CT machine. Among these femur-specimens, fifty-three are male adults', and the others are female adults'. The slice thickness was 0.625 mm. CT image

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information was saved into files of digital imaging and communications in medicine (DICOM) format.

A CT image is a grey-scale map. The grey level of a point reflects bone density in this point. When creating a database of average cross-sections in proximal femurs, only the inner and outer edge lines are concerned. It is necessary to detect the contours of femoral sections. Fig. 3 shows two cross-sections that belong to two different femurs. Contour lines of the cross-section on right side have been detected. Information of each femur-specimen contour lines was saved into a separate IBL file. The above course was carried out using a software developed by our institute. The software was developed to deal with files of the DICOM format. After several operations, DICOM images can be processed and an IBL file with information on a femur can be automatically created.

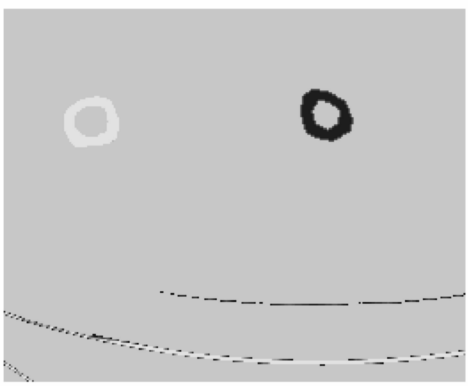

Fig.3 Detecting the edges of femoral cross-sections

After one of these IBL files was imported into Pro/ENGINEER software, a model of a femur-specimen was built. Based on the model, locations of intertrochanteric fossa and the vertex of the trochanter minor can be defined. Locations of twenty-six cross-sections (see Fig.4) were defined on the model in succession. The vertex of trochanter minor and the intertrochanteric fossa are in the 16th and the 26th cross-sections, respectively. In the range of the first cross-section to the 6th one, the distance between two adjacent cross-sections is four times the distance between the next/

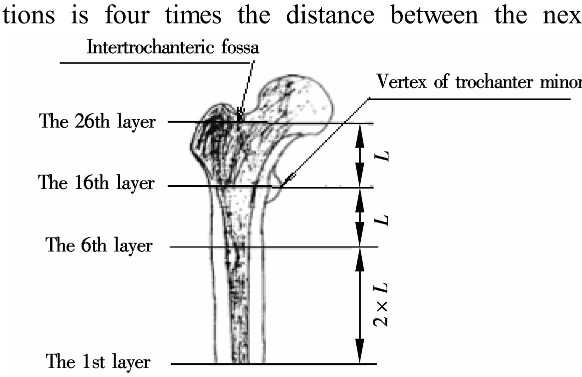

Fig.4 Locations of cross-sections

other two adjacent cross-sections. Information of the inner and outer edge lines on these cross-sections was saved into IGES files, respectively.

1.2 Obtaining the required data

After one of these IGES files was input into Unigraphics software, the edge lines were smoothed. Then, according to the principle that the curve-length between two adjacent points should be equal on the same edge line, each edge line was divided into many segments (see Fig. 5). The number of segments on every edge line is equal. At last, 3-D coordinates of extreme points of these segments were acquired and saved into TXT files.

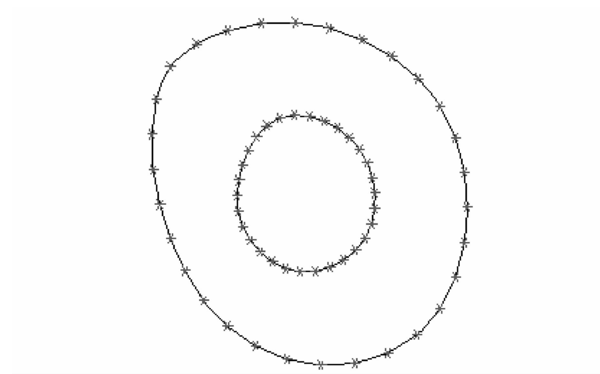

Fig.5 Positions of sampling points

1.3 Statistics of data

According to the general theory of statistics, average coordinate values of corresponding 3-D points on these eighty femur-specimens were calculated and saved into a TXT file. After statistic points were translated, the database of average cross-sections in proximal femurs was formed. Based on the database, a Chinese average proximal femur can be reconstructed (see Fig.6).

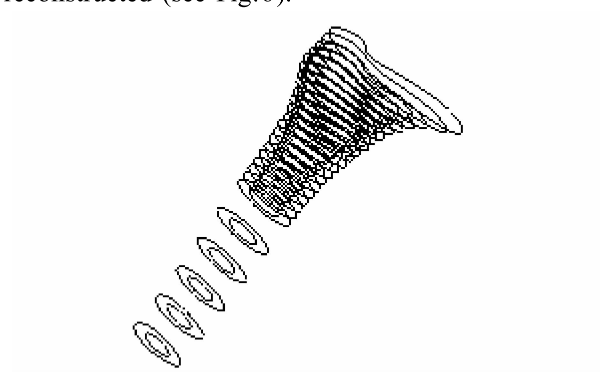

Fig.6 Average cross-sections in proximal femur

2 Clinical Application

Using the database of average cross-sections, the authors developed a software to design hip stems only based on X-ray images. The methods of designing hip stems based on X-ray films will be introduced in another article. Several hip stems, designed by the software, have been used in hip joint replacement cases. Fig. 7 shows an X-ray image that was taken after one of these operations. Orthopedic surgeons have analyzed clinical results. These surgeons concluded that these implants matched corresponding femoral cavities well. This indicated that hip stems designed based on X-ray radiographs could fit corresponding femoral cavities well by using the database of average cross-sections.

Fig.7 X-ray film after operation

3 Discussions

Differences in shapes and dimensions of cross-sections in the upside of a femur are noticeable. When creating a database of average cross-sections, it is necessary that the number of cross-sections chosen here should be relatively high. Moreover, cross-sections midway the length of a femur, are almost elliptical or round. The number in this area can be relatively few. This will reduce the number of cross-sections treated, and lessen computational effort. The number of points chosen on a contour line should not be too few or too many. Too few points will lead to an inaccurate simulation; too many points will increase the required computational effort.

For the convenience of implanting, the upside of a hip stem should not cling to the compact bone[9]. Moreover, bone is a living tissue that continuously rebuilds its structure according to the direction of loads exerted on it. After insertion of a metal prosthesis into the medullary canal, the load equilibrium in the bone is disturbed — the tissue remodels itself and, where there is a lack of stresses due to the stress-shielding activity of the implant, which is stiffer, the bone atrophies. Reduction of stresses in bone with respect to the natural state causes it to adapt to the new conditions manifested by changing mass (external remodeling) or changing bone density (internal remodeling). The latter is especially dangerous because it can cause aseptic loosening of the implant[10]. Engh found that although the stress-shielding effect may be obvious, even if the hip stem matches the upper part of a femur well, the hip stem volume may be too large[11]. Thus, a hip stem should not fill the upper part of the femoral cavity fully, and a certain thickness of cancellous bone should be set aside. Although X-ray radiographs cannot provide accurate anatomical shapes of femoral cross-sections, rough shapes of some femoral cross-sections can be predicted based on the database of average cross-sections. According to X-ray radiographs, through translating and stretching or compressing these average cross-sections, the designer can reconstruct a rough proximal femur of the patient. After creating the database, the authors compared two kinds of proximal femur models of several femur-specimens. One kind of model was simulated according to the database; the other kind was simulated on the basis of CT data. The authors found that the corresponding models were close. For the reasons mentioned above, it can be concluded that hip stems can be designed based on rough proximal femur models simulated according to the database.

The place where X-ray radiographs are taken should approach the highest standard, and amplification ratios of X-ray radiographs should be accurate. Thus, the proximal femur model, simulated according to the database, can be very close to the real one. Professor Hua, et al.studied the accuracy of prediction of 3-D femoral canal shape from plain X-ray radiograph. They concluded that the femoral canal, reconstructed based on plain X-ray radiographs and a database of average cross-sections could be used to design custom hip stems for patients[12, 13].

A model simulation based on CT images is usually more accurate than that of a reconstruction based on X-ray radiographs and the database. However, in some clinical cases (such as hip implant repair cases), CT images are not available, thus the proximal femur cannot be reconstructed based on CT data. However, X-ray radiographs can be taken in any situation. Using the database, a rough proximal femur of the patient can also be reconstructed.

4 Conclusion

This paper presents the construction of a database of average cross-sections for designing hip stems. Through treating eighty femur-specimens, the authors have built a database of average cross-sections in Chinese proximal femurs. Through clinical applications and analyses, it can be concluded that the database can be used to reconstruct proximal femurs for designing hip stems for Chinese patients. The database of average cross-sections in Chinese proximal femurs is very useful in designing hip stems for Chinese patients.

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中国人股骨近端平均截面数据库的建立

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摘要: 描述了在股骨近端构建一个平均截面数据库的过程. 建立这个数据库主要是为中国人设计髋关节假体. 同时, 介绍了构建数据库的方法. 根据现有的软件及开发的程序, 建成了一个中国人股骨近端平均截面数据库. 该数据库是根据 80 根股骨样本的 CT 图像建成的. 根据该数据库及 X 线片, 可以重建中国患者股骨近端 3-D 形状. 理论分析和临床结果表明, 利用该数据库可为中国人设计髋关节假体.

关键词: 数据库; 平均; 股骨; 截面

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