Computerised measurement of tibiofemoral alignment

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Tibiofemoral alignment has a direct correlation with the survival of total knee arthroplasty. Traditionally, it has been measured using a goniometer on radiographs. We describe new software which measures this alignment on scanned radiographs by automatically detecting bones in the image.

Two surgeons used conventional methods and two clerical officers used the computerised routine to assess 58 radiographs of the knee on two occasions. There were no significant differences between any of the paired comparisons. The largest mean difference detected was 1.19°. Across all comparisons, the mean correlation was 0.755. A standardised routine for measuring tibiofemoral alignment was the greatest factor in reducing error in our study.

These results show that non-medical staff can reliably use the software to measure tibiofemoral alignment. It has the potential to measure all the parameters recommended by the Knee Society.

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In total knee arthroplasty (TKA), tibiofemoral malalignment is a major cause of loosening of the implant.¹⁻⁶ Consequently, objective radiological assessment is vital. The radiological evaluation and scoring system presented by the Knee Society in 1989 recorded various measures of alignment and scored the quality of fixation after TKA.¹ They proposed that radiological features should be converted into numbers which could be stored in a computerised database, and encouraged the adoption of a universal scoring system which would allow comparison of

results from different centres and using different designs of implant.

Tibiofemoral alignment is usually recorded manually, using non-standardised routines. Lonner, Laird and Stuchin⁷ found good interobserver agreement when seven orthopaedic surgeons recorded alignment on short films with varying degrees of rotation and flexion of the knee. Laskin,⁸ however, reported intra- and interobserver errors as great as 7°. In order to reduce these errors, non-standard routines should be avoided, particularly when the measurement may determine the survival of a knee implant.

To date, little attention has been given to the measuring

Fig. 1

The manual method for measuring the tibiofemoral angle on radiographs.

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Fig. 2a

Fig. 2b

Fig. 2c

The computerised image (a). The white lines represent the grey level values of a horizontal line in the image approximately located and drawn over the original image. The isolated signal contains information regarding the anatomical features, as illustrated for the femur (b) and the tibia and fibula (c).

tools or to defining the radiological parameters.⁹⁻¹¹ The positioning of the longitudinal axis of the bone is subject to the perception of the examiner. The 2°-scale of normal clinical goniometers makes it impossible to reduce the error any further.

Our aim was to assess and compare the precision of conventional and computerised measurements. We describe a method of automating definition of the longitudinal tibiofemoral axis and determining tibiofemoral alignment.

Materials and Methods

We randomly selected 65 radiographs taken on 30 × 40 cm films before and after TKA showing at least 15 cm of tibia and femur. Two orthopaedic surgeons (OS-A and OS-B) and two clerical observers (CO-A and CO-B) independent-

ly measured the tibiofemoral alignment on the same set of anteroposterior (AP) films. They all repeated the exercise two weeks later blinded to their first set of readings.

We used the paired *t*-test and Pearson's correlation to analyse the results.

Manual routine. The orthopaedic surgeons used a manual routine similar to that described by Petersen and Engh¹² (Fig. 1). By joining two points in the mid-shaft, one 10 cm above the knee and the other as far proximally as the radiograph allowed, they established the true anatomical axis of the femur which closely follows the centre of the shaft.^{4,7,8} The anatomical axis of the tibia was established by joining two points in the mid-shaft, one 10 cm below the knee and the other as far distally as the radiograph allowed. The angle subtended by these two lines was recorded as the tibiofemoral angle.

Fig. 3a

Fig. 3b

The edge-finding algorithm. The conventional edge-finding algorithm determines the grey-level gradient for each point. When the difference between bone and soft tissue is greatest, the boundaries appear as peaks as shown for the femur (a) and for the tibia and fibula (b). The mid-point used for the calculation of the best-fit axis is shown for the tibia (b).

Fig. 4

A screen print of the actual software shows how the edges of the bones are clearly identified, offering visual feedback for the operator.

Computerised routine. The clerical observers used a computerised routine. The computer stores images as numbers on a grey scale. A common system uses 256 variations, with zero representing black, 255 representing white and the intermediary numbers shades of grey between these values. The precision of measurements depends on the degree of resolution used when the images are taken. All the images were acquired with a Sharp (Japan) JX-610 flatbed scanner, initially as 24-bit colour images, and then converted to an 8-bit grey scale. The optical resolution of 300 dots per inch yielded a pixel size of 80 μm . Figure 2a shows a digitised radiograph with the grey values arrayed over the image. Measurements can be taken between any two points along these lines. If we subtract the underlying image, the plotting of the grey levels, as illustrated in Figures 2b and 2c, is equivalent to any other signal, such as an acoustic or electrical one. The anatomical features of the image can still be identified in this signal.

Our routine is based on well-established algorithms used for the automatic identification of boundaries between bone and soft tissue (Fig. 3). Within the area of interest (shown as squares S1 and S2 in Figure 4), the computer program detects the bony edges which border on soft tissue and determines both the width of bone at that level and the midpoint of the bone in the particular segment. The resolution is the same in the horizontal and vertical planes. Therefore for a longitudinal distance of 5 cm, the program will carry out the same measurement 600 times and determine 600 midpoints. To determine the line which best represents the midpoints, a best-fit algorithm is used. Standard algebraic equations¹³ are then used to calculate the tibiofemoral alignment.

Fig. 5

A faulty measurement. The white arrows indicate the mis-measured points. The staples superimposed on this particular image are as yet not recognised by the software. Other routines are being developed to deal with these situations.

Results

The computer program takes a few seconds for each reading and adequately measures the tibiofemoral angle. When metal artefacts such as skin staples overlying the cortex interfered with the readings there were sometimes gross discrepancies, as shown in Figure 5. Radiographs of such poor quality that they could not be enhanced by the software also gave misleading results. We excluded these radiographs thus leaving 58 images.

We classified the difference between the first and second readings ($n = 116$) of all observers into four groups, as described by Laskin⁸ (Fig. 6). To analyse the intra-observer, interobserver and intersystem variability, we drew 12 sets of paired readings. Table I gives the numerical results.

The sample size of 58 in each group resulted in a power of 81% for detection of a clinically significant difference of 2° assuming a common SD of 3.750° and a p value of 0.05 (two-tailed paired t -tests). There were no significant differences between any of the paired comparisons. The largest mean difference, detected between OS-A and CO-A, was 1.19° . Correlations ranged from 0.553 to 0.873, and across all comparisons the mean correlation was 0.755.

Fig. 6

Percentage variations. The pie charts show intra- and interobserver variability of the manual and the computer readings. The key indicates the magnitude of disagreement.

Table I. Results of paired readings (degrees) for intraobserver, interobserver and intersystem variability in the 58 images

Pair number	Mean	SD	SEM	Correlation between two series	Mean difference
Intraobserver					
1. OS-A1	5.0000	3.75	0.4931	0.792	0.1034
OS-A2	5.1034	3.22	0.4229		
2. OS-B1	5.0259	3.44	0.4528	0.873	0.0086
OS-B2	5.0172	3.65	0.4804		
3. CO-A1	5.6808	3.70	0.4865	0.829	0.0782
CO-A2	5.7590	3.83	0.5037		
4. CO-B1	6.2244	3.65	0.4794	0.827	0.2220
CO-B2	6.0024	4.17	0.5482		
Interobserver					
5. OS-A1	5.00	3.75	0.49	0.782	0.0259
OS-B1	5.02	3.44	0.45		
6. OS-A2	5.10	3.22	0.42	0.712	0.0862
OS-B2	5.01	3.65	0.48		
7. CO-A1	5.68	3.70	0.48	0.810	0.5436
CO-B1	6.22	3.65	0.47		
8. CO-A2	5.75	3.83	0.50	0.779	0.2434
CO-B2	6.00	4.17	0.54		
Intersystem					
9. OS-A1	5.00	3.77	0.49	0.595	0.6808
CO-A1	5.68	3.70	0.48		
10. OS-B1	5.02	3.44	0.45	0.809	1.1986
CO-B1	6.22	3.65	0.47		
11. OS-A2	5.10	3.22	0.42	0.553	0.8990
CO-B2	6.00	4.17	0.54		
12. OS-B2U	5.01	3.65	0.48	0.706	0.7418
CO-A2	5.75	3.83	0.50		

Discussion

In the absence of agreement in the literature on the definition of the tibiofemoral axis,¹⁴ computer analysis offers the possibility of reliable and reproducible measurements. This may affect the evaluation of multicentre studies by greatly reducing errors arising from the subjective component of conventional readings.

Only a few studies have compared the conventional measurement of various knee angles and distances with measurements obtained by digitising images.^{9,11} To our knowledge, most digitising systems still have a subjective component in that they rely on the operator to select manually the reference points on a computer screen or digitising device. By automatically determining the axis of a long bone, our system reduces the subjective element. While we do not know the cost of other systems, we are aware that many call for sophisticated equipment and workstations. Using only standard radiographs and a personal computer, our system is likely to be more cost-effective.

On radiographs of the lower limbs, several factors may influence the measurement of angles and distances. These include the positioning of the limb, morphological variations in the femur and tibia, the quality of radiographs and the use of long or short films.^{7,9,10,12,14-18} Lonner et al⁷ concluded that limb rotation and knee flexion of 10°, either alone or in combination, significantly affected radiological measurements of anatomical alignment. Wright et al,¹⁶ however, showed that the effect on axial alignment was

minimal within 10° of rotation and that radiological measurement was reliable. In order to reduce the possibility of such errors, we take care to ensure that radiographs of the knee are taken with the patient standing and the patellae facing forward.

Because metal artefacts such as staples and implants may result in errors, it is important to have visual feedback as shown in Figure 5. Grossly abnormal values should alert the examiner to study the image carefully and if necessary to measure the radiograph manually.

The clear definition of the anatomical axis of the femur and tibia contributed significantly to the reduction of errors. Laskin⁸ reported that when 50 surgeons used a non-standardised routine to measure the tibiofemoral angle on two occasions, 6% of the readings showed a variability greater than 7°. Wright et al¹⁶ found mean inter- and intraobserver differences of 1.4° and 0.7°, respectively. In both manual and computerised readings in our study only 1% showed a variability greater than 7°. Furthermore, the largest mean interobserver difference was 0.5° and the largest mean intraobserver difference 0.2°.

Since many orthopaedic units now hold special clinics to audit their joint replacements, it may be useful to be able to rely on non-medically qualified staff to measure the tibiofemoral alignment on digitised radiographs. The computer provides scope for storing preoperative and postoperative images. Our department is currently investigating the possibilities of analysing fractures and the positioning and migration of components. Shaver et al¹⁹ have already

described the digital measurement of polyethylene wear. The software is presently being expanded to include all the parameters recommended by the Knee Society.¹

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