ACTA STEREOL 1996; 15/2: 193-200
ORIGINAL SCIENTIFIC PAPER

MEASUREMENT OF KNEE JOINT SPACE DEPTH USING IMAGE ANALYSIS METHODS

Leszek Wojnar[1], Edward Czerwiński[2], Janusz E. Badurski[3]

[1]Institute of Materials Science, Cracow Technical University of Technology, Al.Jana Pawła II 37, 31-864 Cracow, Poland
[2]Department of Orthopaedics, Med. Coll. Jagiellonian University, ul.M.Kopernika 19a, 31-501 Cracow, Poland
[3]Department of Medicine and Rheumatology, Śniadecki Hospital, ul.M.Skłodowskiej 26, 15-950 Białystok, Poland

ABSTRACT

Precise measurement of the joint space is very important in diagnosis of osteoarthritis and for the evaluation of treatment results. Classical analysis of radiographs, due to brightness and contrast variation, unsharp object boundaries as well as "human factor", enables getting results with precision not more than 0.5-0.7 mm. This is not nearly sufficient for evaluating progress in the rate of disease or its treatment. In order to improve accuracy of knee joint depth measurements, a new procedure based on image analysis methods, has been developed and tested. Control tests on a series of 60 real radiographs have shown that the image analysis based procedure gives highly repeatable results that agree well with other independent examinations. The precision of measurements has been estimated at a minimum 0.2 mm. Thus, application of image analysis enables getting results with precision approx. 3 times higher than in classical measurements. The analysis does not require very costly equipment - it is enough to use a PC computer and image analysis software. Measurements are relatively quick - one image requires approx. 5 mins to be analysed, including grabbing the image by a CCD camera.

Key words: image analysis, joint space depth, knee joint, radiographs.

INTRODUCTION

Due to increased mobility of the population and rotation in the hospital staff, one patient is frequently treated and investigated in different places by different specialists. It can be easily shown (compare Figs 3 and 6) that the same radiographs can be interpreted by various people in a significantly different way. The same problem arises in the case of sequential radiographs taken in different conditions (changes in the apparatus, films, development technique etc.) even if analysed by the same person. Thus, an inexpensive and quick method for rapid, repeatable, objective measurements is of high importance for clinical practice (Czerwiński 1993).

To solve the above mentioned problem, a new procedure, based of image analysis methods, was elaborated and tested. The method was tested on a series of radiographs of the knee joints of 15 patients. For every patient two radiographs were taken within a period of at least 12 months. Such a series of radiographs has the following advantages from the methodological viewpoint:

- Analysis of the knee joint space is relatively difficult. In case of positive results, the method can be adapted for other joints, which would be easier to analyse.
- Radiographs taken twice for every patient offer an opportunity for an analysis of joint space depth changes. This is of great importance in clinical practice and evaluation of the treatment results.
- A series of 60 similar radiographs allows a statistical analysis of the results.

In the following sections, the authors describe the analysis procedure, the obtained results and discussion thereof.

DETECTION AND MEASUREMENTS

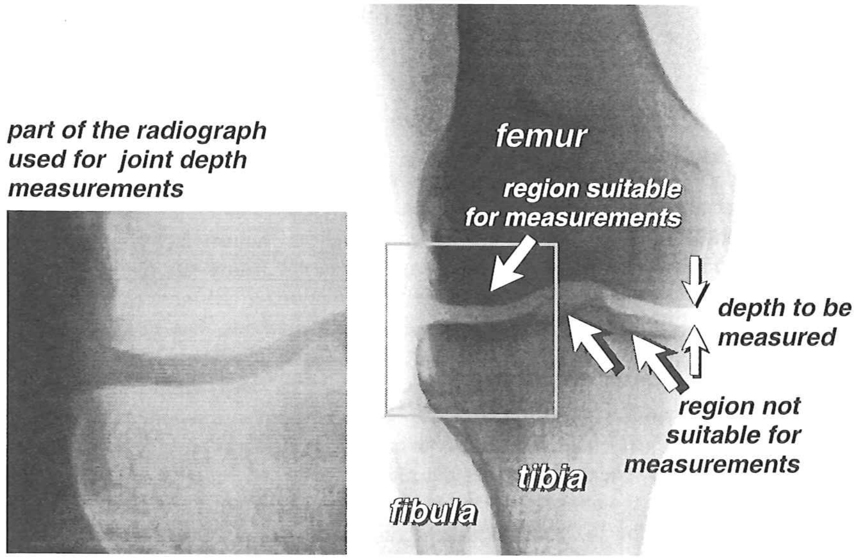

Fig.1. Schematic illustration of the radiograph region taken for measurements. Part of the joint space, indicated by arrows on the right, is useless for automatic analysis due to diluted or double edges.

The knee joint radiographs taken in a standing position were used in the experiments. The outer part of a radiograph (corresponding with fibula) was chosen for measurements (Figs 1, 2a). The first problem lies in proper detection of the joint for measurement. Due to variation in the bone thickness and structure, as well as the presence of soft tissues of the body, the image is highly nonhomogeneous that prevents any detection by simple thresholding (see Fig.2b). To avoid this effect an auxiliary image is built to remove the background and leave a sheer image of the bones. The auxiliary image is obtained by sequential linear erosions (VISILOG, 1992). Subsequent subtraction of the initial and auxiliary images yields the corrected image (Fig.2c). This image produces by itself an excellent subjective visualisation of the joint space. However, due to the high nonhomogeneity in the bone structure, this treatment is still insufficient for correct detection of the joint space.

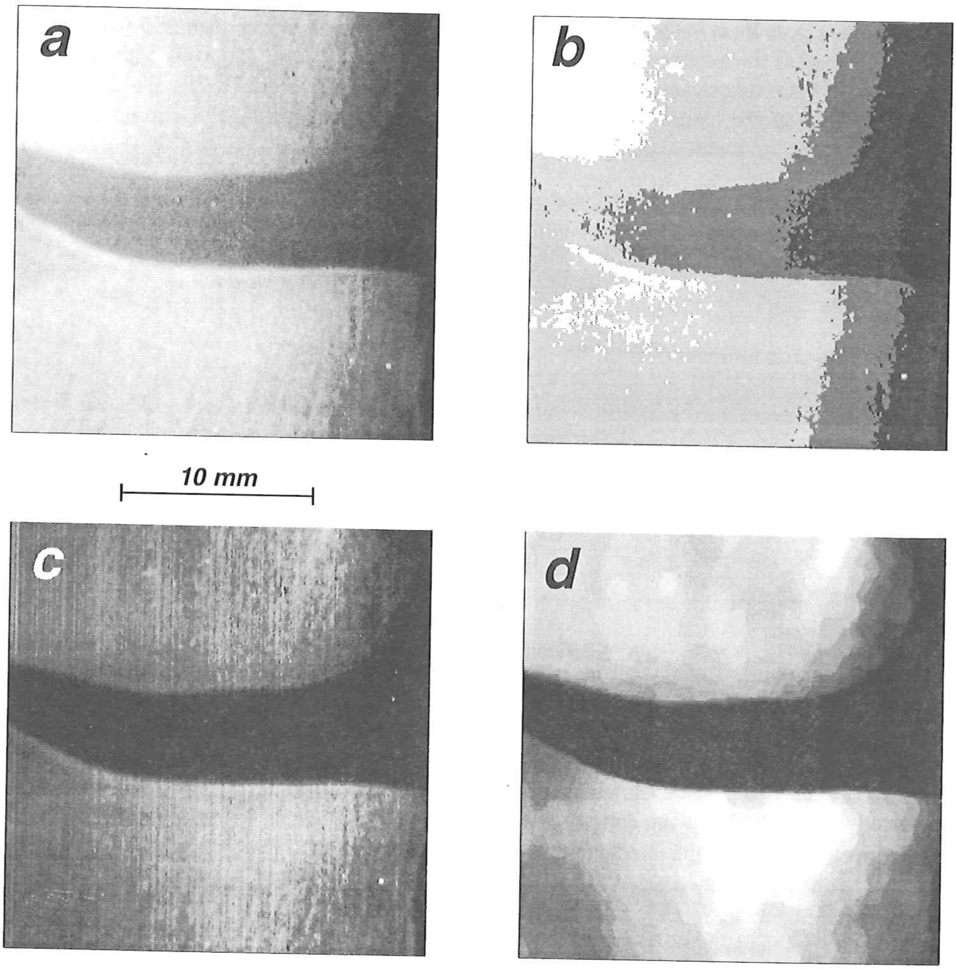

Fig. 2. Illustration of different stages of analysis. Initial radiograph (a), poor detection by thresholding (b), image with corrected background (c) and finally filtered image (d).

In order to prepare the image for final detection a proper filtering is necessary. Experimentally two independent methods of similar accuracy were developed:

- The first method is based on the filtering of the image by its opening and closing. The hexagonal grid and transformations of the size of at least 6 (in our case 1 pixel = 0.075 mm) are necessary to filter out local nonhomogeneity of the bone structure. The filtering procedure smoothes both bone and joint space but does not affect the cartilage-bone interface. Thus, this method enables detection of the joint space with very good accuracy. Unfortunately, it is sensitive to the grey level distribution in the image and requires careful control of the detection threshold in every case. So, it is not a good solution for a fully automatic analysis,
- the second method involved using the Gaussian filter (VISILOG, 1992) without automatic scaling of the image. Such a procedure changes significantly the grey level range in the

image. In other words; if the grey levels of the initial image are within the 0-255 range, the maximum grey level value in the filtered image can be much higher than 255 (for example 700), whereas the minimum value can even reach negative values. All pixels with grey levels above 255 are displayed as white, and all pixels with negative grey levels are displayed as black. Due to the nature of the Gaussian filter, this procedure enables correct automatic thresholding for a wide spectrum of radiographs.

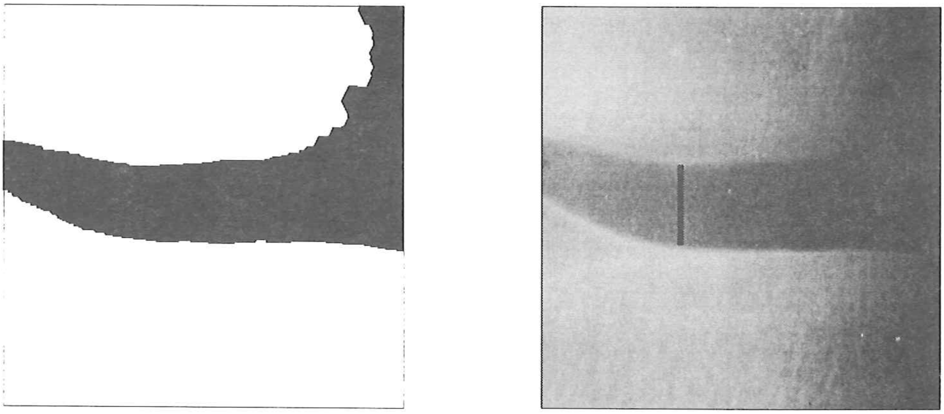

Fig. 3. Example of the detected space (it corresponds with the radiograph shown in Fig.2) - left and the measured space depth that is a height of the black bar overlaid initial image - right.

The space detected by thresholding has usually many defects, like small holes or saw-shaped edges. Therefore, a subsequent smoothing by opening and closing is necessary.

The next step in development of the measurement procedure is measurement of the detected space. The following concepts have been discussed:

- an average depth of the middle part of the detected space,
- the depth at precisely defined location, based on the shape of adjacent bones,
- the local minimum depth (based on the distance function) and
- the distance between the lowest point of the femur and the tibia.

Obviously, every solution has its own advantages and drawbacks. The first concept listed above (average depth) gives a kind of an integral measurement, not sensitive to local extremities or possible errors in detection. In spite of this promising feature an average depth is not a good solution for automatic image analysis since it is sensitive to sampling - taking various pieces of the radiograph one obtains various results. The next concept - measurements at a precisely defined location - are just as sensitive and be subject to even greater errors. A much better choice seems to be a local minimum depth since it is not sensitive to sampling. Preliminary tests have shown this concept to be very promising and corresponding well with manual measurements. Unfortunately, in numerous pathological changes in the joint, this local minimum has been not observed or detected at artificial locations. Thus, it always requires careful inspection during the analysis, and in such circumstances this concept cannot be used for automatic measurements.

Finally, the last concept (distance between the lowest point of the femur and the tibia as shown in Fig.3) was chosen for measurements. Neththeless, this concept exhibits three main drawbacks:

- The measurements can be sensitive to rotation of the image.
- In some cases multiple depths can be detected.
- Local errors in detection can affect the result.

In practice, these negative effects can be successfully reduced. Careful positioning of the radiograph, during image acquisition, can eliminate the rotation effect. In case of multiple depths, their mean value can be taken as a final result. And according to our experience, the third error, connected with local erroneous detection, has only theoretical meaning. Moreover, there exists a very simple solution for checking the correctness of the measurements. As a final step of analysis, a control image, as shown in Fig. 3 (right), is displayed. It enables a quick, visual control of the whole procedure.

On the other hand the procedure proposed (and finally implemented in our analysis) has some properties decisive for the needs of automatic analysis:

- It is not sensitive to sampling; thus the reproducible results can be obtained without any difficulty.
- Measurements can be easily performed in a fully automatic mode.
- Similar measurements can also be done manually.

RESULTS AND ANALYSIS

60 radiographs, as described in the introductory section, have been analysed. In fact we have no possibility of measuring the real space depth as all the patients are alive. Thus it is very difficult to verify the obtained results. In order to get this information, four series of measurements have been performed:

- Careful manual analysis was done by an experienced orthopaedic surgeon. The statistical error of measure, evaluated from repeated measurements, has been estimated as ±0.6 mm (0.05 significance level). These results have been taken as reference values for further analysis.
- Second manual analysis was performed by an independent physician of an average experience. These results, compared with the results by the experienced surgeon, give information on the precision and reproducibility of human measurements (see Fig.4).
- Image analysis based measurements were performed according to the procedure described in the previous section. The radiographs were introduced using a standard CCD camera. 8-bit grey level images of size 256x256 pixels were used for image analysis. The resolution of test images was 13.2 pixel/cm (33.5 dpi). The images were processed using a Pentium 100 MHz, 24 MB RAM computer, equipped with the VISILOG 4 system. Analysis of a single image on this apparatus takes approx. 50 seconds. If one adds time for grabbing and saving images, total time for a single analysis arises to 4-5 mins. Results obtained in this method are analysed versus the results by the experienced surgeon (see Fig.5),
- An independent image analysis was done on slightly different images (the region for analysis chosen independently). This analysis simulates measurements done in other laboratory. Results from this fourth source are in very good agreement with other measurements based on image analysis - the scatter does not exceed 0.23 mm. These results are not shown in the plots.

Analysis of the plots in Figs 4 and 5 gives us much information on the nature of obtained results. The results obtained by two physicians (Fig.4) are in a close agreement with each other. The best fit line can be described by the following equation: $(SP)=0.99*(ES)-0.054$.

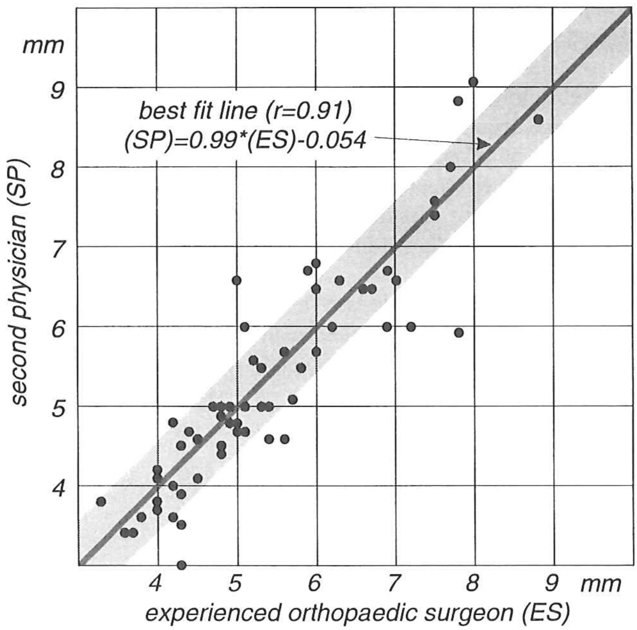

Fig. 4. Results obtained by a second physician (SP) versus results got by an experienced orthopaedic surgeon (ES). A light grey band denotes the error of (ES) measurements. The dark grey line is a best fit line obtained using the least square method.

The closer analysis of individual results shows, however, very large discrepancy. The difference between the results for the same radiograph reaches, in several cases, almost 2 mm. This scatter is surprisingly high and proves that manual analysis, especially, if performed by a few observers cannot give us assured, reliable results. A comparison of the results obtained by the experienced surgeon with the results obtained by image analysis (Fig.5) exhibits a different character. The best fit line *(IA)=0.799*(ES)+0.90* is not so close to the expected equation *(IA)=(ES)* but the maximum deviation from a perfect fit is clearly smaller than in the previous case. Moreover, considering the error of measurements, made by an experienced surgeon, image analysis gives no overestimated values. The existing undervalue can be a consequence of the poor quality of some radiographs. To summarise, the results obtained using image analysis, are in a better agreement than the results from the second physician. Moreover, image analysis offers repeatability of the results in subsequent analysis.

Exact values from measurements are important for correct diagnosis. However, even in the case of some scatter of such results correct diagnosis can be done provided the analysis will give proper trend estimation. In other words, in many cases it is sufficient for the measurements to reveal correctly the increased or decreased tendency in the analysed quantity. Such a case has been tested, and the results are summarised in Fig.6. It is clearly visible from this figure that image analysis is in almost perfect agreement with the experienced surgeon, whereas the analyses by two people gives unsure results. Simultaneously, one should stress that an image analysis requires relatively small training for getting correct result whereas manual analysis results are highly dependent from the operator's experience.

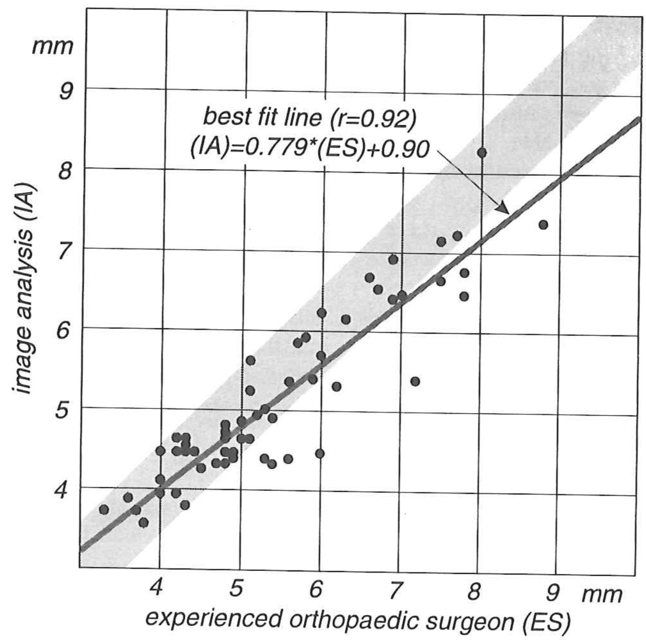

Fig. 5. Results obtained using image analysis technique (IA) versus results obtained by an experienced orthopaedic surgeon (ES). A light grey band denotes the error of (ES) measurements. The dark grey line is a best fit line obtained using the least square method.

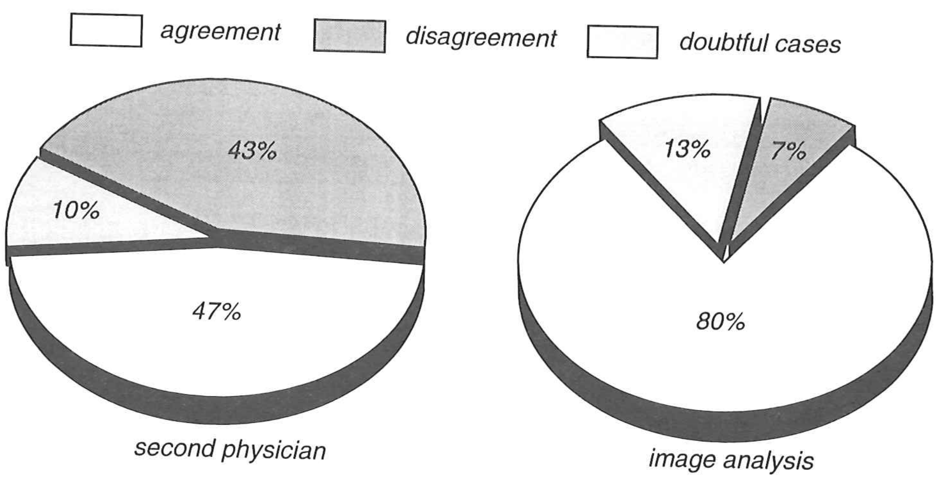

Fig. 6. Qualitative analysis of the trend assessment (joint space depth increase, decrease or no alteration), obtained by second physician and image analysis, compared with the results produced by an experienced specialist.

CONCLUSIONS

From the above experiments and analysis, the following conclusions can be drawn:

1. Measurement of the knee joint space depth, using image analysis methods, can give the same results irrespective of the operator and his experience. On the contrary, manual measurements are very sensitive to the human factor and results obtained by various people are in often not comparable.
2. The agreement between results obtained by an experienced orthopaedic surgeon and via image analysis are in a fairly good agreement. Moreover, both methods give very similar results when the direction of the space depth changes is analysed for individual patients. This observation is of great importance for possible clinical application of the method proposed.
3. The measurement criterion, used in image analysis, causes that manual measurements seeming to be overestimated in comparison with the image analysis methods. However, a good linear regression can be found between these two types of measurements.

REFERENCES

Coster M, Chermant JL. Precis d'Analyse d'Images. Presses du CNRS, 1989: 1-560.

Czerwiński E. Ilościowa ocena zmian występujących pod wpływem fluoru w kości korowej i gąbczastej oraz ich znaczenie diagnostyczne. Cracow: Jagiellonian University, 1994: 1-136.

VISILOG 4. Reference Guide. Velizy: Noesis, 1992: I-1-III-5-22.

Wojnar L, Majorek M. Komputerowa analiza obrazu. Cracow: Fotobit-Design, 1994: 1-159.

Presented at the 9th International Congress for Stereology, Copenhagen, August 20th to 25th, 1995.