Hip surgery planning from preoperative radiographs

S. Burrezo†, A. García‡, F. Vico‡, G. García-Herrera‡, J. Garrido‡ & J. Farfán‡

‡ Group of Studies in Biomimetics
University of Málaga
Technology Park of Andalusia
E-29590 Campanillas (Málaga – Spain)
‡ Hospital General de Antequera
Servicio de Traumatología
Antequera - Spain

ABSTRACT: During hip surgery planning the physician makes decisions on the type and size of the prosthesis according to visual and clinical information. We present a rule-based system that evaluates preoperative radiographs to assist the surgeon. The proposed computer system approximates the precise implant by supplying the surgeon with the tools to obtain the proper measurements on the radiographs. This information, combined with clinical data about the patient, feeds a knowledge database. This article describes in detail the structure of the program and its functioning.

INTRODUCTION

Total hip arthroplasty (substitution of several bones of the hip with a prosthesis) is a very complex process, in which a correct planning is critical [1,2]. It is necessary to estimate the dimensions and state of the bones to determine the type of prosthesis that better fits the patient. Frequently, this preoperative process is made according to the information provided by the study of radiographs. This process involves complex and highly specialized vision-based tasks: segmentation of structures, characterization of features, recognition of pathologies, etc. The results of this analysis feeds a decision making system that outputs a tentative schedule for the surgery: type of prosthesis and precise positioning in the patient’s hip. The physician makes use of these two modules (trained visual system and expert knowledge) in surgery planning.

Computer systems can reproduce these functions by applying techniques from the fields of artificial vision and knowledge engineering [3]. This work presents a software tool (Proteo-Hip) that helps in the analysis of the visual information, and makes decisions according to a knowledge database.

The following section describes in detail the structure and functioning of the proposed system. Further sections reports on the main advantages of Proteo-Hip, as a tool that has been implemented in medical services. We conclude by outlining the future lines of work that have scheduled for the next period.

DESCRIPTION OF THE SYSTEM

Proteo-Hip consists of two main modules:

1. a graphical interface, to perform in an monitored or automatic way, the appropriate measurements on the antero-posterior radiography of the preoperative hip.

2. a rule-based system, that captures the knowledge used in surgery planning. Proteo-Hip makes decisions on the methodology and type of prosthesis that better fits the patient, based on clinical data and the measurements obtained from the radiographs.

Graphical interface

We first describe the functioning and importance of the graphical interface (figures 1, 2 and 3). This module is of great importance, since the decisions are made based on the radiographic data. The traditional methodology to perform these measurements involves the use of a rule and templates of different forms. This procedure introduces a considerable human error in the process. Despite methodological aspects, there are some measurements that are intrinsically complex (like those based on irregular structures), and the physician approximate values based on personal experience. Furthermore, the bad quality and different scales and formats of the radiographs also contribute to magnify the overall error in the process of measurement.

The main role of the graphical interface is to minimize this error, that affects seriously the decision making process. Figure 2 shows how this methodology has been implemented.

1 send correspondence to sbg@geb.uma.es
in a software tool, simplifying the procedure in a way that only a few number of points have to be identified in the image to obtain the measurements with high precision. The values on the screen are scaled to a real magnitude according to a ratio previously computed by the program.

The radiographs are introduced in the system by means of a scanner, or directly, loading a graphical file (for the case of digital radiography). Special peripherals (drawing board, high resolution display, etc.) and basic image manipulation (zooming, contrast and brightness adjustment, and cropping) are applied to help in the measurement process. To obtain the necessary references and measurements, the system helps the user describing every step of the process.

The effort invested in this graphical interface directly affects accuracy in data acquisition, and it is worth, since around 70% of the knowledge necessary for surgery planning is directly obtained from the preoperative radiography. The 30% remaining comes from qualitative clinical data.

Regarding these clinical items (like sex, age, clinical history, pathology, state of the bone, etc.), an interactive interface (figure 1) has been designed to display the clinical fields in a single window. This eases database updating: introduction of new patients and revisions, and changes in existing clinical data; with all this information, Proteo-Hip can calculate a score that indicates the state of the patient for each revision. Also informs about the evolution of the patient’s score in a graphical way. These skills makes Proteo-Hip a complete database manager.

**Figure 1.** General aspect of Proteo-Hip’s graphical interface. Three main blocks can be distinguish: (1) clinical data (top-left) and prosthesis data (bottom-left), (2) patient’s follow-up (center), and (3) details of a particular follow-up (right).
Figure 2. Measurements on the graphical interface. The preoperative hip is digitized and displayed. Special measurements are done by clicking on key points, identified by the surgeon. Distances and angles are then computed automatically.

Figure 3. Post-operative follow-up. The interface allows also the performance of many other measurements that determine the score of the patient. These measurements consist of distances, angles, and also areas of the image, necessary to estimate how well the implant fits the patient’s hip after some time.
Proteo-Hip is also applied for the patient’s follow-up. After the surgery, it is necessary to perform a follow-up of the patients for many years. Total hip arthroplasty involves a protocol of measurements on several radiographs. This protocol is based on some 60 measurements. The analysis of these measurements indicates whether the prosthesis is placed correctly, or whether the bone is reacting in contact with the prosthesis. This pathology is rather common, since the bone-prosthesis junction produces the erosion of the bone tissue, and the redistribution of the body weight, affecting the structure and the overall equilibrium.

Rule-based system

Concerning the second module, the rule-based system integrates in a symbolic way the knowledge of the surgeon to plan hip surgery. A number of items have been selected to determine the type and size of the implant (table I). Some of them represent clinical information, and others are obtained from the measurements, according to rather complex equations. Since the goal of this article is not to describe the details of the surgery planning process, we will mention only a few of these items.

Table I. Data required for surgery planning.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>age</td>
<td>&lt; 60, 60–70, &gt; 70</td>
</tr>
<tr>
<td>sex</td>
<td>male, female</td>
</tr>
<tr>
<td>Singh’s index</td>
<td>1 – 2, 3 – 4, 5 – 6</td>
</tr>
<tr>
<td>morphological-cortical index</td>
<td>&lt; 2.3, 2.3 – 2.6, &gt; 2.6</td>
</tr>
</tbody>
</table>

While age and sex are obtained directly from the patients database, the Singh’s index and the morphological-cortical index are estimated from measurements on the preoperative radiograph. The Singh’s index is computed by visually estimating the state of the bones, and the morphological-cortical index involves the completion of two distances. According to these items a number of rules (table II) can be designed to determine the type of implant to be used in the surgery. Similarly, some other items (clinical or radiographic) are used to configure the whole knowledge database.

Table II. Example of rules used in surgery planning. These rules are based on values of the sex, age, Singh’s index and morphologic-cortical index.

<table>
<thead>
<tr>
<th>sex</th>
<th>age</th>
<th>Singh’s index</th>
<th>morphologic-cortical index</th>
<th>type of implant</th>
</tr>
</thead>
<tbody>
<tr>
<td>male</td>
<td>&lt; 70</td>
<td>5, 6</td>
<td>≥ 2.6</td>
<td>cemented</td>
</tr>
<tr>
<td>male</td>
<td>&lt; 60</td>
<td>3, 4, 5, 6</td>
<td>≥ 2.6</td>
<td>cemented</td>
</tr>
<tr>
<td>male</td>
<td>&lt; 60</td>
<td>5, 6</td>
<td>≤ 2.3</td>
<td>cemented</td>
</tr>
<tr>
<td>female</td>
<td>&lt; 60</td>
<td>5, 6</td>
<td>≥ 2.6</td>
<td>cemented</td>
</tr>
<tr>
<td>male</td>
<td>60 - 70</td>
<td>3, 4</td>
<td>≥ 2.6</td>
<td>cementless</td>
</tr>
<tr>
<td>male</td>
<td>60 – 70</td>
<td>5, 6</td>
<td>2.3 – 2.6</td>
<td>cementless</td>
</tr>
<tr>
<td>male</td>
<td>&lt; 60</td>
<td>3, 4</td>
<td>2.3 – 2.6</td>
<td>cementless</td>
</tr>
<tr>
<td>female</td>
<td>60 – 70</td>
<td>5, 6</td>
<td>≥ 2.6</td>
<td>cementless</td>
</tr>
<tr>
<td>female</td>
<td>&lt; 60</td>
<td>3, 4</td>
<td>≥ 2.6</td>
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<td>female</td>
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<td>cementless</td>
</tr>
</tbody>
</table>

At this time of development, the running version of Proteo-Hip performs surgery planning by matching current input data with the antecedents of the rules, what means a very simple method to obtain the configuration of the implant to be used. Future versions will include an expert system based on the available knowledge database.

CONCLUSIONS
Proteo-Hip has been tested in the Hospital General de Antequera (Málaga – Spain) for several months, and will be used in the next future in some other hospitals in Spain and France. Its main purpose is to perform surgery planning, the patients’ follow-up, and also to administrate clinical and radiographic data. Apart from this non-predictive functionality, the proposed system has been showed to perform accurate surgery planning, what means a considerable reduction of time and costs in total hip arthroplasty. This system helps in the automation of surgery planning, that indeed has been shown to yield very good results [1].

Since Proteo-Hip implements a standard protocol for measuring preoperative radiographs, its interest in training students is also very relevant. The overall functioning of the system helps in showing how to perform measurements on the radiographs, as well as to estimate the state of the hip, and the type and size of the fitted implant.

FUTURE WORK

Two lines of research are of interest at this point: (1) the design and implementation of an expert system to handle big knowledge databases, and (2) using neural networks and genetic algorithms to perform data mining on the preoperative data. While the first one is rather straight-forward, the second one involves the development of a large database of clinical cases, where standard and non-standard data is measured on the preoperative radiographs of patients. This ambitious project involves a wide distribution of the program and building a unified database from local databases, what can be done through the Internet. The results of the proposed knowledge discovery is expected to enrich the knowledge database for surgery planning, adding non-standard rules, extracted from the analysis of statistical significance, instead of direct medical experience.

ACKNOWLEDGMENTS

This work has been funded by DePuy Ibérica, S.A. (a Johnson & Johnson’s company), that is also in charge of its worldwide distribution. This work has also been funded by the Spanish Ministry of Science and Technology (project number 1FD1997-0413(TIC)).

REFERENCES

