Integrated Computerized Database And Radiographic Image Analysis System For Total Knee And Hip Replacement

Suresh Lodha
Department of Computer Science
Rice University

Jeff Reuben
Division of Orthopaedic Surgery
UT Medical School at Houston

Abstract
An integrated computerized database and radiographic image analysis system for total knee and hip replacement is currently under development at University of Texas Medical School at Houston. The integration of clinical findings and parameters based on image analysis will be useful for statistical comparisons, several of which are of predictive value in determining the longterm success or failure of total joint replacement.

Introduction
A variety of prostheses are commercially available for total knee and hip replacement. Moreover numerous surgical procedures, techniques and instruments used for the exposure of the knee or the hip, preparation of the bone and insertion of the prosthesis have been developed. There is a need to determine the effects of these choices, exercised by the surgeon, on the outcome of the joint replacement surgery. Such information can be utilized as an aid to decision making for the surgeon.

Therefore, there is a need for standardized and systematic data collection of clinical findings and radiographs at different centers involving different treatment modalities. One of the basic requirements of such a system would be to perform flexible, automatic and reproducible measurements of several parameters from radiographs with different kinds of prostheses, and for such measurements to be written automatically to a database.
Background

The late John Charnley (1911-82) ushered the modern era of hip replacement in the early 1960s by using acrylic cement (polymethyl methacrylate) to bond implants to bone. The process of total hip replacement (THR) involves the replacement of the femoral head and pelvic socket with a femoral prosthesis and an acetabular cup component and wedging the implant into a surgically prepared cavity in the bone, as shown in figure 1.

Although commonplace, THR remains a major surgical procedure and is not always successful [2]. The success of THR is determined by a combination of component fixation, and ability to transfer loads from prosthesis, through the cement, to the host bone. For normal biological growth, bone requires adequate mechanical stimulus. If the stimulus is small, such stress-shielding of the femur can lead to bone resorption. Stress analysis and experimental models indicate that the prosthetic stem changes the normal stress pattern in the proximal femur, e.g. for a fully bonded stem the stress in the proximal medial region can be reduced upto 30 percent of the normal stress [5]. The process results in aseptic loosening of the stem, which has emerged as possibly the most significant cause of failure of THR.

Subsequent refinements in component design, choice of materials, prosthesis
fabrication, and surgical techniques have led to a multitude of THR systems. The selection of an appropriate THR is a problem for the contemporary surgeon with a huge diversity of cemented and noncemented prostheses. It is not clear why a surgeon should prefer one procedure over another or one prosthesis over another. For example, regional traditions would appear to have a strong influence upon the adopted practices[4]. Therefore there is an immediate need to outline a scientific procedure for selecting one THR over the other. Such a procedure depends upon correlating the outcome of a total joint replacement with the different treatment modalities adopted. This in turn depends upon automatic reproducible measurement of several parameters from radiographs of patients following total joint replacement surgery.

**Computer Materials**

In this section, we first describe the computer hardware and software materials used in building an integrated computerized database and image analysis system for total knee and hip replacement.

**Hardware**

The system is based on an IBM-XT-compatible computer (Omnitech Corporation Ltd., St. Louis), the Lumisys DIS 1000 film digitizer, and the IMLOGIX (Microtech Inc., St. Louis) image viewing station. A PC-based system provides a relatively inexpensive means of having an integrated database and image analysis system.

The PC has an Intel 80386 main processor and runs at 25 MHz. It has 1 Mb of RAM, one 8 Mb 3-1/4" floppy disk drive and a 80 Mb hard disk drive. The mother board has one RS-232 serial, one parallel interface, a keyboard connector, a virtual display adapter and eight expansion slots. One expansion slot (SCSI interface) is used to communicate with the digitizer and the floppies. Another is used to communicate with the IMLOGIX workstation. The RS-232 serial I/O port is used for a PC Mouse. The 12" VDU has 80 character per line by 25 line display.

The Lumisys DIS 1000 film digitizer has many features that make it the ideal choice for a low cost, simple and reliable means to digitize X-ray images on film. The major features are: (i) high resolution: the DIS 1000 can digitize up to 4K by 5K resolution images. The maximum film size is 14" by 17". (ii) high positional accuracy, (iii) precision optics, and (iv) proprietary light collection
The IMLOGIX image viewing station displays images up to 1024x1024 pixels by 12 bits with full spatial resolution and 256 grey scale levels. The pixel display area is 10" by 10" on a 16" monitor. The station supports the proprietary interactive zoom and pan features and real-time contrast manipulation. The display function is supported within a PACS (Picture Archiving and Communication System) configuration using a thin-wire Ethernet (IEEE 802.3, 10 BASE2). The station is controlled using a three-button mouse.

Software

The software consists of the database Dbase IV, the application development system Objectvision, in-house image analysis software, windows interface and communication protocols.

Dbase IV (Ashton Tate Inc.) is selected as the database because of its popular uses in microcomputers. Dbase brings SQL (Structured Query Language) to PC and can be supported on a network.

Objectvision (Borland International Inc.) is a software tool for creating applications that gather and manipulate information. The applications can use external links to data as an alternative to requiring user input or computing a value in a decision tree. The supported data file types include ASCII, Paradox, Dbase, Btrieve, and Dynamic Data Exchange (DDE) to other Microsoft windows applications. DDE links provide the advantage of transferring the data automatically whenever the information source file receives a new value. Objectvision is chosen because it allows convenient creation of applications that present a familiar forms interface to users in Windows environment. The applications can also automate any task that requires user to follow complex procedures and accurately capture data, thus rendering the task relatively effortless.

Computer Methods

Database

The objective of the database is to record clinical findings of a patient over several visits including pre- and post-surgery visits. The challenging part in designing the database has been to accommodate several different formats and
functions used by different organizations. We illustrate the point by taking the example of the variety of knee rating systems that are being used [3]. The Knee Society (KS), Mayo Clinic (MC), Hospital for Special Surgery (HSS), and British Orthopaedic Association (BOA) use different knee rating systems. To evaluate the pain, different scoring systems are used by these organizations, as illustrated in figure 2.

This example illustrates that pain has been categorized with respect to activity such as resting, walking, climbing stairs, walking and climbing stairs, with respect to time such as day or night, with respect to frequency such as occasional or continual, and with four different intensities such as none, mild, moderate and severe. The numerical scores used are also different. Although it is possible theoretically to record 4 different intensities of pain, depending upon 4 different functions, 2 different time zones, and 2 possible frequencies, it may be difficult or even unnecessary to elicit such elaborate responses from the patient. In this case, for example, we have chosen the format used by the Knee Society. This format is general enough to compute the score of pain at rest as evaluated by any of the four organizations However it ignores the details of pain at walking or pain at night. Of course, such details can be added to the existing database with a minimum effort at any time, if desired.

Another example is the evaluation of the functionality of walking. Four differ-

<table>
<thead>
<tr>
<th>BOA</th>
<th>HSS</th>
<th>MC</th>
<th>KS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>Points</td>
<td>Pain</td>
<td>Points</td>
</tr>
<tr>
<td>None</td>
<td>4</td>
<td>None</td>
<td>15</td>
</tr>
<tr>
<td>Mild</td>
<td>3</td>
<td>Mild</td>
<td>10</td>
</tr>
<tr>
<td>Moderate</td>
<td>2</td>
<td>Moderate</td>
<td>5</td>
</tr>
<tr>
<td>Severe</td>
<td>1</td>
<td>Severe</td>
<td>0</td>
</tr>
</tbody>
</table>

|         |               | Moderate       | 5             | Occasional   | 5      |
|         |               | Continual      | 6             | Severe       | 7      |

|         |               | Pain (at walking) | 15            | None         | 1      |
|         |               |                  | Mild / Occasional | 2 |
|         |               |                  | Stairs Only     | 3      |
|         |               |                  | Walking & Stairs | 4      |
|         |               |                  | Occasional      | 5      |
|         |               |                  | Continual       | 6      |
|         |               |                  | Severe          | 7      |

|         |               | Pain (at night)  | 10            | None         | 1 |
|         |               |                  | Mild / Occasional | 2 |
|         |               |                  | Moderate       | 3 |
|         |               |                  | (Awakens)      |       |

|         |               |                  | Severe         | 4 |

**Figure 2** Knee Rating Systems: Evaluation Of Pain
different scoring systems are being used, as illustrated in figure 3. In this case we have chosen the system used by the Knee Society and Mayo Clinic because of its simplicity. In addition, we accommodate the format of British Orthopaedics Association by specifying the distance and the time information, which is consistent with the six-category format used by these three organizations.

The raw data stored in the database can be utilized to compute the knee rating as evaluated by any of the four different organizations. A comparison of these scores may eventually lead to the standardization and simplification of these evaluation systems.

**Image Analysis System**

A radiographic image analysis system for total hip replacement using standard Charnley prostheses was developed by Jones [4]. This system used a PCVision frame grabber and the programs were written in Lattice C with graphic generation subroutines from the Halo Library. Since then these programs were documented and partly rewritten by Omnitech Corporation for transferring the system to the modern hardware. The major issues involved in the transfer of the system are: (i) creating an integrated windows interface (using only one mouse for the VDU and the IMLOGIX workstation), (ii) creating a working ethernet communications protocol, (iii) creating a structure for user-defined
procedures, built on simple primitives.

The system identifies a set of primitives that can be implemented in a mod-
ular fashion to enhance flexibility, portability and extensibility of the system. The set of primitives include a sobel-type edge detection routine, a region-
growing contour detection routine, a least squares-fit routine, and an adaptive
histogram equalization routine. The desirable functionality includes precisely
defined, automatic (with minimal user input), reproducible measurements of
several parameters including the alignment of the prosthesis, distribution of
the cement, surrounding bone thickness, subsidence, migration or loosening for
different kinds of knee and hip prostheses.

The challenge of the system is to overcome the problem of the standardization
of radiographs: automatic correction or rejection of the radiographs for differences
in magnification, apparent shape, size, apparent position and contrast arising
due to variation in the alignment of the radiographs, variation in the distance
between the X-ray tube and film, variation in the exposure of the X-ray film,
inter-patient biological variability or intra-patient biological change.

This problem is tackled by making the measurements relative to reference
points and lines, rather than at absolute positions within the image. The
radiographic features, which are selected for reference generation are (i) less
sensitive to radiographic alignment, (ii) less prone to change and instability,
(iii) definable and consistently recognizable features. The references for THR
include the center of the head of the femoral component, the midline of the
femoral component system, the distal tip of the femoral component stem, and
the midline of the femoral medulla. Additional references for supplementary
measurements to follow any stem bending or stem subsidence include the mid-
line of the femoral component neck and the midpoint of the lesser trochanter.
The measurements provide information about the valgus or varus inclination
of the femoral component stem, (ii) retroversion/anteversion of the femoral
component neck, retroflexion/anteflexion of the femoral component stem, and
the medial/lateral displacement of the femoral component stem. Other mea-
surements, which depend upon the anatomy of the proximal femur, include
the cortical bone thickness, the medullary width, and the extra-cortical width.
Measurements related to the surgical technique include the stem alignment and
position, width of cement-bone demarcation, and the medullary filling. Most
of the measurements are automatic or semi-automatic. Interactive measure-
ments include the determination of the midline of the medulla, which is hard
to determine reliably by an automatic method. There is a great need to make
these measurements automatic by first using image enhancement techniques to highlight the features that need to be extracted followed by automatic measurements.

Discussion

An integrated computerized database and radiographic image analysis system has been described for obtaining quantitative information from radiographs of patients who have undergone total joint replacement surgery. Measurements are made rapidly and accurately for a wide variety of prostheses. The results are automatically stored in a database for statistical comparisons. Further development is in progress. The system will prove valuable in postoperative care. However the most significant contribution of the proposed system would be to compare the measured parameters from the radiographs of the patients with the predicted outcome based on the stress analysis of the preoperative configuration with the designed prosthesis in place. Such a study would provide necessary feedback to justify or modify the stress analysis models, which are utilized in designing the prostheses [1]. The eventual goal is to construct an integrated prosthesis design, stress analysis and radiographic image analysis system.

References


