THE USE OF A RECONSTRUCTED 3-DIMENSIONAL SOLID MODEL FROM CT TO AID THE SURGICAL MANAGEMENT OF A TOTAL KNEE ARTHROPLASTY a case study.

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Abstract

The use of a rapid prototyping method was utilized to produce a pre-operative solid model of the proximal tibia in a patient with a massive defect of the medial tibial plateau. The solid model was reconstructed from aligned sequential CT images of the knee. This was then used to determine the level of bone resection of the proximal tibia for the optimum placement of the tibial component of a total knee replacement. This technique gives the surgeon both the three dimensional anatomical information needed to ascertain whether there is adequate bony support after cutting for the prosthesis, as well as a solid model on which to carry out the proposed surgery, before undertaking the procedure on the patient.

Keywords: Computerised tomography, knee prosthesis, bone modelling, Three-dimensional reconstruction

Introduction

Reconstructing the knee with the aid of a prosthesis in patients with gross degenerative changes and large bone loss presents many challenges to the Orthopaedic surgeon, therefore any aid in the preoperative planning would enhance the outcome of this form of surgery. Plane radiographs give little insight into the bone geometry in all three dimensions, especially the geometry of the cortex at the potential plane of resection.

The use of three dimensional reconstructed images from CT for the assessment and planning of complex hip pathologies has been investigated and is reported in the literature [1,2,3,4,5] and is has been shown to be helpful in the planning of surgery. More recently, the production of physical models of the bone-deficient or dysplastic acetabulum using data generated from CT scans has been used in the computer-aided design and manufacture of implants [6]. The successful production of custom-made femoral components in total hip replacements has been also been reported [7,8,9] as well as the use of three dimensional models in complex cranio-facial surgery. However, their use in the reconstruction of complex bone shapes around the knee has not been reported.

Materials and methods

The patient was a 60 year old lady with a long history of Rheumatoid Arthritis which first presented at the age of 15 with deformity of the fingers. She had a Benjiman's double osteotomy of the left knee at 27 because of the potential of subluxation, and a synovectomy of the right knee at 35. The left knee progressively became more varus and unstable and she presented at the age of 59, wheelchair bound with a grossly unstable and deformed left knee (figure 1). She was considered for total knee replacement and due to the gross deformity of the joint a CT was carried out. The scan was in the horizontal plane with her tibial axis aligned at right angles to the scanning plane on the machine's couch with soft firm padding. Slices in the horizontal plane at 1.5 mm intervals were taken to 30 mm below the joint line, producing 20 sections. The data was stored onto a magnetic/optical disc in DICOM format for processing and converting into the appropriate file system to produce a 3-D model in the computer (figure 2) and consequently a solid model to scale. The whole process to generate the solid model is shown in figure 3.

Figure 1. Pre-operative radiographs. A. Anteroposterior view, B. lateral view.

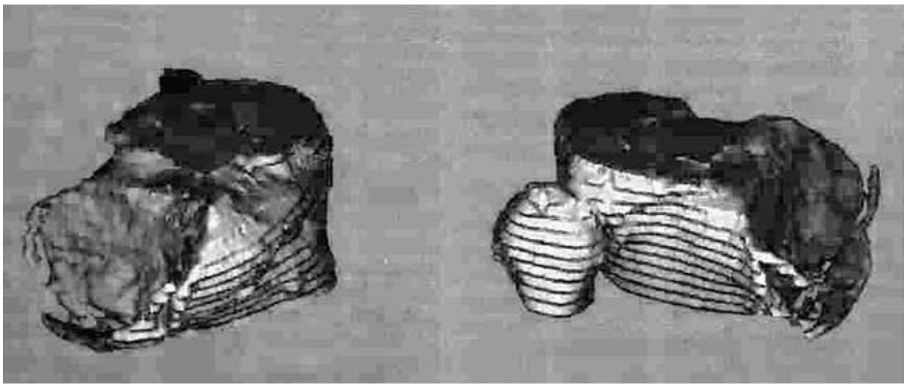

Figure 2. Reconstruction of the proximal tibia from the 1.5 mm sections.

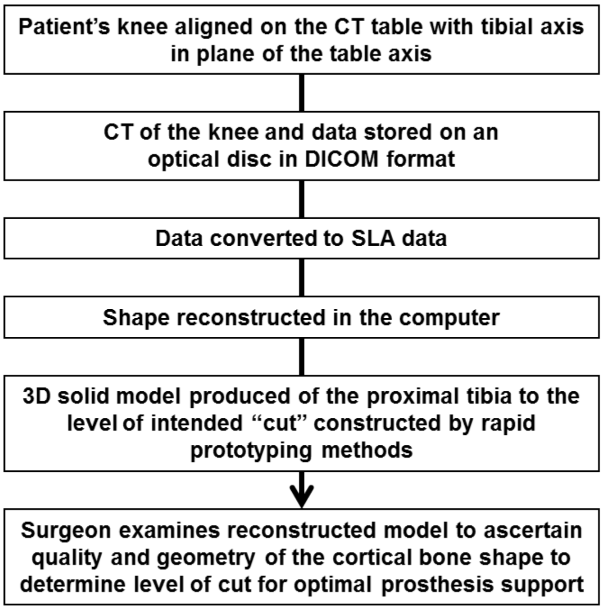

Figure 3. Flow diagram of the production process of the solid 3D model.

The stereolithography apparatus (SLA) creates models from a liquid resin that cures to solid when exposed to ultra violet light. An ultra violet laser scans the area of each slice to produce a solid layer. The build platform is lowered by one layer thickness and resin floods over the solidified layer. A recoating blade levels the resin and the next layer is scanned on top of the first, and so on until the model is complete. The preparation from CT data to machine-build files took less than 30 minutes, and the SLA machine produced the model in less than four hours.

Aligning the tibia during the CT scan was an advantageous to the planning of the resection of the proximal tibia in 3 ways. Firstly, as the optimal surgical cut through the tibia is perpendicular to the tibial axis this aligned approach means that the CT images could be visually inspected as sections through the tibia parallel to the plane of the intended surgical cut.

Secondly, it helps to maintain accuracy when building the physical model. CT data is captured as a series of planar images with a gap between them typically 1.5 mm, whilst the stereolithography process builds models at a layer thickness of typically 0.15 mm. Therefore interpolation is used to create intermediate sections between the original images. A cubic interpolation ensures that the intermediate sections are anatomically accurate and natural [10]. These sections then directly drive the rapid prototyping machine that builds the physical model. Aligning the CT images ensures that the layers that the model is built in, correspond to the plane of the planned surgical cut. This is a significant aid when viewing the stereolithography model as it ensured that that the layers visible in the finished model could be used to guide a level cut.

Thirdly, this two-and-half-dimensional format can be more accurate and less memory intensive than three-dimensional approximation formats such as the commonly used triangular faceted STL file.

The initial assessment of the CT sections (figure 4) suggested that the cut should be made 15mm below the lateral joint line. A solid model of the proximal 15 mm of the tibia was produced showing the cortical bone geometry to assess the size and shape of the supportive bone available after a cut at this level and compared with the under-surface shape and area of the tibial component. The model suggested that the bone shape and distribution would support a size small Minns™ meniscal bearing tibial component, the thickness of the cut bone removed by the oscillating saw was assumed to be 3 mm.

In theatre, following preparation of the distal femur the tibial cut was made as planned 15 mm below the lateral joint line, orthogonal to a line from the center of the knee to the center of the ankle in the sagittal plane. The CT generated model was seen to accurately represent the clinical findings at the time of surgery comfirmed when the removed bone was compared with the plastic model (figure 5), and a Minns™ meniscal bearing total knee was implanted as planned [8, 11]. (Corin Medical Ltd., Cirencester, England). A pair of 4mm thick meniscal bearings were found to be most appropriate in this case and the remainder of the procedure was carried out without incident.

Post operative management and follow up

Clinically the post operative period was uneventful, however, post operative check radiograph the following day did revealed a crack fracture of the shaft of the tibia which was thought to have occurred at some point during the peri-operative period and was felt to be most probably due to the marked rheumatoid arthritis and disuse as no traumatic event had been noted.

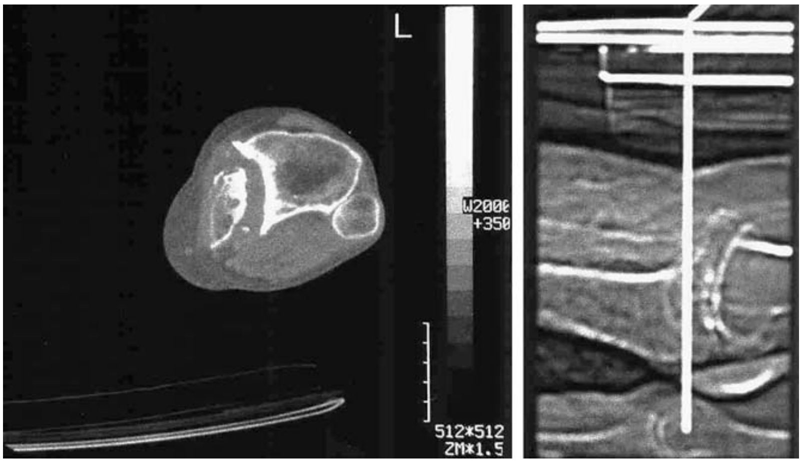

Figure 4. CT view at level of proposed resection of the proximal tibia.

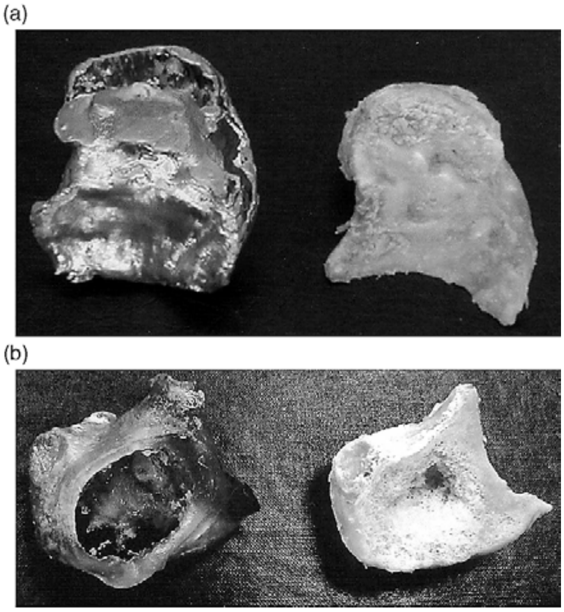

Figure 5. Comparison of the plastic model reconstruction at the proposed level of resection (left) with the actual resected bone (right). The resected bone sample is 3 mm thinner than the plastic model because of bone removed by the saw. A. Upper surface, B. lower cut view.

This did alter the normal post operative regime of early mobilization and was treated with 6 weeks in a full leg length splint prior to mobilization thereafter. The patient went home on the 10^{th} post operative day mobilizing non - weight bearing with a pulpit frame and using a wheelchair. At 6 weeks the fracture had united and the patient allowed to mobilise. At 12 weeks there was a good range of knee movements the patient walking without support, pain free with much improved gait and is delighted with the result (Figure 6).

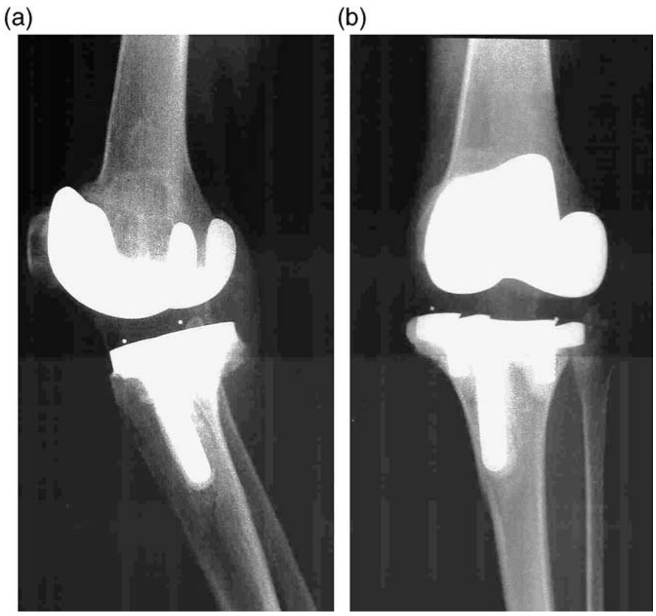

Figure 6. Three months post-operative radiographs showing good coverage of the proximal tibia and positioning of the prosthesis. (a) Anteroposterior view, (b) lateral view.

Discussion

The technique described above provides detailed information of the bone morphology in the region of the intended surgery and facilitated prediction of the level of transection of the deformed tibia at a level best suited to supporting the prosthesis. In addition, it provided a model on which the planned surgery could be carried out, before ever reaching the patient. This degree of pre-operative information is extremely useful, and should there have been insufficient bone at the proposed level of the tibial cut, the size of any required wedge could be accurately predicted.

The fracture of the tibia may have been due to an inability of the bone to resist ordinary per-operative handling as a result of her long-standing arthritis and subsequent disuse, or possibly due to the inadvertent cortical contact of one of the trephines used to prepare the proximal tibia.

The authors recognise that although it is still small, there is an increased radiation dose to the patient associated with the use of a CT scan in this technique when compared to plain radiographs normally used. A scan of the knee, being an extremity does not put any other radiosensitive structures in the field. In addition to the tomograms produced, there is also the opportunity, as was done in this case, for 3D reconstruction both virtually, and now as a physical model, which can be compared to the proposed prosthesis pre-operatively. The technique can be used on any tissue that can be clearly distinguished in either CT or MR images.

Whilst we do not suggest this technique is required for any joint replacement which is anything other than "straightforward" however this case has demonstrated the value of this technique in knee arthroplasty in cases with complex anatomy where the bone shape and quality was difficult to predict from plain films. The creation of a three dimensional model facilitates pre-operative planning in difficult cases and provided valuable information prior to surgery.

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