

Design and Manufacturing of Knee Joint by Cad/Cam and Rapid Prototyping

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A custom approach of CAD/CAM was presented for the concurrent development of custom made femoral component of knee prosthesis. The femoral component is developed on a prescription basis and is unique for each patient. The medical image of the knee joint obtained according to the patient CT scan and MRI. The necessary constraints based on surgical experience were integrated into the CAD system. The rapid prototype model was built as the reference for review. Through the application of CAM software, the interference-free toolpath and the cutter location file for multi-axis NC machining are generated.

Keywords : CAD/CAM; Rapid prototyping; Knee joint; CNC machine; biomechanics

INTRODUCTION

Presently in India, hip replacements and other joint replacements are carried out using standard sized replacement parts selected from a range provided by manufacturers based on anthropometric data of western population. Possible complication due to this includes infection, blood clotting, loosening, wear dislocation, prosthesis breakage, nerve injury. Apart from above mentioned problems that are present universally with the implantation of these prostheses worldwide, use of these in Indian populations suffer from additional problems.

Osteosarcoma is the most common type of bone cancer and the sixth most common type of cancer among children. The total knee prosthesis must cater to the required range of motion (flexion-extension and rotation). The task is to evolve with different concepts which satisfy the intended purpose. Technologies in CAD/CAM and rapid prototyping are very effective in designing and manufacturing of total knee prosthesis.

Design and development of modern mechanical components are the result of advancement of manufacturing technology and the investigations carried through in different scientific areas. The biomedical engineering has great advancements in the health care of patient. One of these is related to artificial knee replacement. Artificial knee replacement surgery is becoming more common as the population of the world. Each year over two million osteoarthritis joints are replaced with artificial joints worldwide. The main reason for replacing any arthritic joint

with an artificial joint is to stop the bones from rubbing against each other. A primary concern of these devices for the hip and knee is to eliminate pain and improved mobility.

A knee is a hinge joint where the end of the thigh bone (femur) meets the top of the large bone in the lower leg (tibia). A healthy knee has smooth cartilage that covers the ends of the bones. The two bones glide smoothly as the bend of knee. The muscles and ligaments around the knee joint support weight and help move the joint smoothly when walk. The anatomy of a knee joint is shown in Figure 1.

CAD MODEL OF KNEE JOINT

A patient wanting a knee replacement can now get the knee cut in such a way, that the new knee (the implant) fits exactly to the bone. With the help of patient specific cutting block, a patient's joint blocks, a patient's joint bone is cut so it is exactly the inside shape of the implant fits like building blocks. With the help of the patient X-rays, CT scans, MRI, a three dimensional image of the joint is transferred to a computer software which marks the bone image at places where it needs to be cut. A block is then made in CAD software, which when fitted at the joint during surgery, saves all measurements and the bone can be directly sawed through the gap in block.

Artificial knee replacement is made up of three main parts. The femoral component (top portion) replaces the bottom surface of the femur and the groove where the patella fits. The tibial component (bottom portion) replaces the top surface of the tibia. The patella component (kneecap portion) replaces the surface of the patella where it glides in the groove on the femur. To develop the implant, the surgeon and the engineer determine the basic requirements and design criteria use either patient X-rays, the computer tomography (CT) scans or magnetic resonance image (MRI). With the help of these design criteria, the design parameters are transferred to the CAD software. To provide

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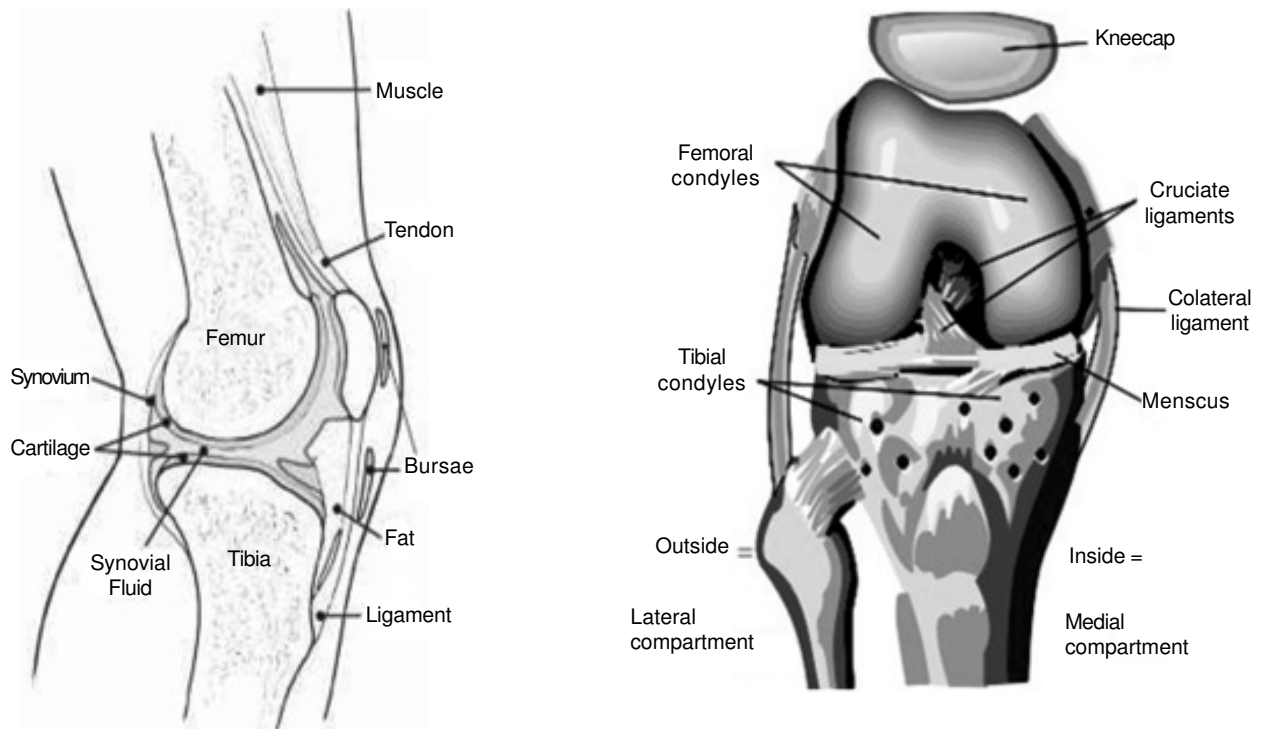


Figure 1 Anatomy of knee joint

the exact and best fit and fit of knee joint to each individual patient, the shape is of major concern. By patient CT scan or MRI, the CAD software marks bone image according to the shape of joint. That image of each knee joint component then converted into the CAD model as shown in Figure 2. The goal for the knee joint design was to define a product that met manufacturing requirements and surgical expectations. The first step is computer aided design (CAD).

RAPID PROTOTYPING OF KNEE JOINT

ProtoCAM specializes in medical rapid prototyping and medical stereo lithography, providing medical devices prototypes, medical models, medical prototypes and

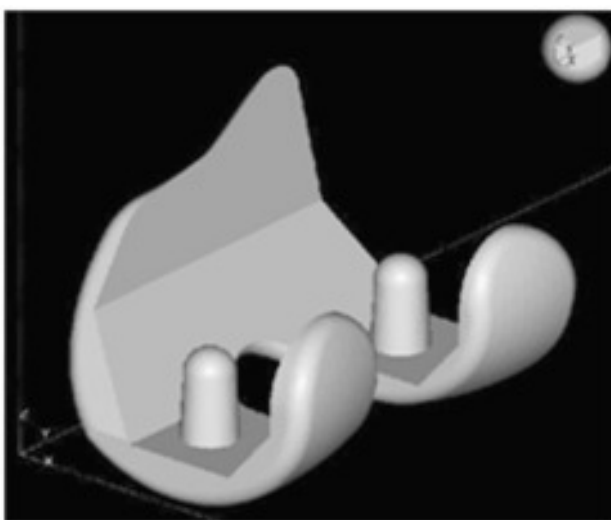


Figure 2 Three-dimensional structure of knee joint

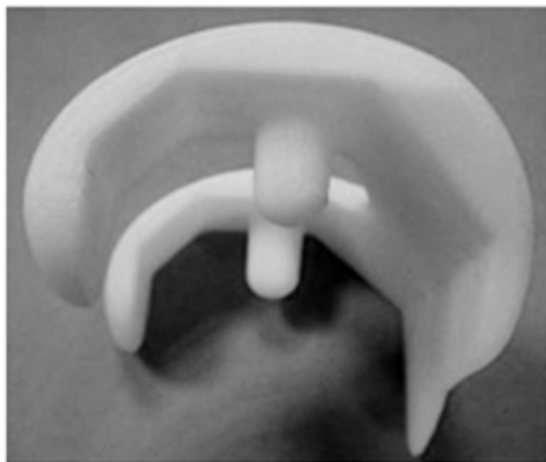
physical prototypes of anatomical parts for medical applications. The use of rapid prototyping (RP) technologies in medical applications is relatively new and very innovative, so that designers, doctors, or others can generate a physical, tangible medical prototype to work with. The parts produced by rapid prototyping systems are used for several purposes in engineering, including testing of form, fit and function. Form testing allows a designer to verify the CAD design, evaluate manufacturability, and to get reactions from potential users and customers. Fit testing verifies that the designed part mates accurately with adjoining portions of the final assembly. Form and fit testing are also frequently and collectively referred to as 'concept modeling'.

The physical model of a part is made directly from a three-dimensional CAD model by rapid prototyping. The materials used include liquid resin, fusing powdered thermoplastic materials, ceramics, ABS, investment wax, etc. The layer creation techniques comprise liquid-layer curing, extrusion of melted plastic, binder-droplet deposition onto powder layer, laser-driven, electron-beam, etc. The RP primitives provided actual full-scale models that can be handled, analyzed, and used for future development.

The RP process begins with a CAD model. A preferably solid modeling CAD system is a key component of success (Figure 3). Most popular solid model CAD systems require translated processors to create the stereo lithography (STL) file for a RP system. The degree of resolution for the model surfaces must be specified by entering a quality value in the interface of CAD system. This step assures that the CAD data is input to the RP machine in the tessellated STL surfaces of the object are represented as numerous tiny



(a) Front View



(b) Side View

Figure 3 Rapid prototype model of knee joint

triangles. After creating STL model files, the next step is to simulate the process of build prototype via Catalyst software (pre-process). The simulation software automatically slices, calculates support structures, and creates tool paths.

CAM FOR KNEE JOINT

Manufacturing of total knee prosthesis is a very difficult job to perform due to the uneven curvatures and intricate shapes which are necessary to mimic the natural knee shape. Also, modular knee prosthesis contains different sizes of components to suit according to the age of the patient. This adds another factor to complicate the prosthesis manufacturing. These different components are usually in different materials, and the manufacturing process must be planned to achieve the desired geometric fidelity, internal properties, tolerances, and surface finish.

The femoral component has to be machined on multi-axis CNC machine tools because of their complex shapes. Machining sequences and cutter location (CL) files can be created in the manufacturing module of UniGraphics NX software, which is the same CAD/CAM environment that the solid model was created in. In order to clamp and

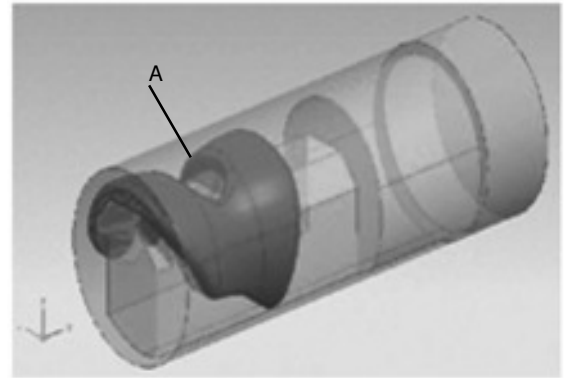
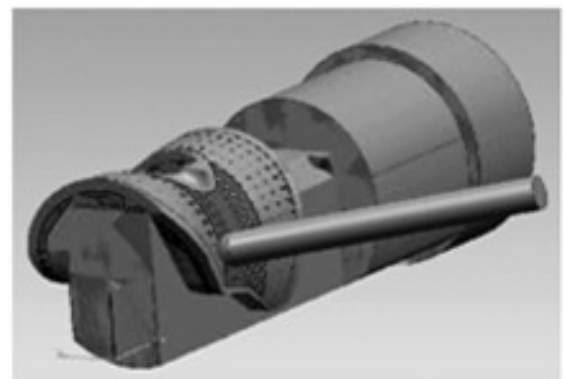
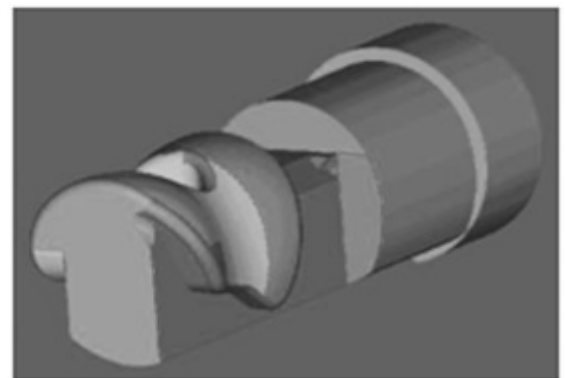


Figure 4 Manufacturing model is assembled with the work piece model



(a)



(b)

Figure 5 Cutting simulation of finish machining for the knee joint

manufacture the femoral component, the design model was modified to become the work piece model for cutting simulation.

In the set up environment of manufacturing module for the femoral component, an alike femoral component work piece (marked as A) is built first and then assembled with the manufacturing model, as shown in Figure 4. The operation of multi-axis milling is used to machine the multi-axis machining within CAD/CAM software, two constraints, *ie*,

collision and gouging, are the major consideration. The generated CL file can be verified through the function of solid cutting simulation built in this module. Figure 5 shows the cutting simulation of finish machining by multi-axis machining operation.

CONCLUSION

This paper presents the integrated approach of computer-aided design and computer-aided manufacturing for the design and manufacture for femoral component of

knee prosthesis. The system implemented is from surgeon requirements to the completion of manufacturing. The solid modeling, rapid prototype and virtual machining are used in the system to establish the interface among conception, design and manufacture. The CAD/CAM techniques are applied to fulfill the design of complicated surface and multi-axis NC machining. The NC programs are verified through solid cutting simulation and virtual-cut. The results are useful for the development of the femoral component.