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COMPUTER ASSISTED SURGICAL PLANNING IN THR AND FABRICATION OF HIP PROSTHESES VIA ADDITIVE MANUFACTURING TECHNOLOGIES

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Abstract: *The aim of this study is to describe a novel methodology on application of virtual reality (VR) techniques and additive manufacturing technologies in pre-planning and improving total hip replacement (THR) surgery. VR techniques and computer assisted surgical planning enables the simulation of the THR operation and virtual implantation of hip prostheses. Considering important parameters such as fill and fit criteria, CCD and anteversion angles, and femoral offset, that affect prosthesis durability and efficiency, virtual implantation helps to select the proper prosthesis. In order to demonstrate the importance of the novel methodology, a case study on virtual implantation of standard cementless hip prosthesis and a custom-made hip prosthesis is compared and presented.*

Key words: *Medical RP, Virtual reality, Hip prosthesis*

1. INTRODUCTION

With respect to the design and fabrication, cementless THR is divided into two category of standard cementless and non-standard cementless, which is also known as custom-made prosthesis. Application of such prosthesis includes advantages and disadvantages for the patients. The aim of this study is to present a novel methodology that helps to select proper prosthesis (standard or custom-made), which may lead to the maximum benefit of the patient. It may also lead to the most comfort of the patient, extended durability of prosthesis and lessening need to revision surgery and less cost of surgery and treatment. Other advantage of using proposed methodology is to utilize virtual reality (VR) techniques for surgery simulation and preplanning. In order to demonstrate the importance of the methodology, a case study of virtual implantation of standard cementless prosthesis versus a custom-made hip prosthesis, is presented and compared. To the best of our knowledge, there is no comparison between standard hip prosthesis and custom-made hip prosthesis in the literature in viewpoint of virtual implantation and surgical planning using VR techniques.

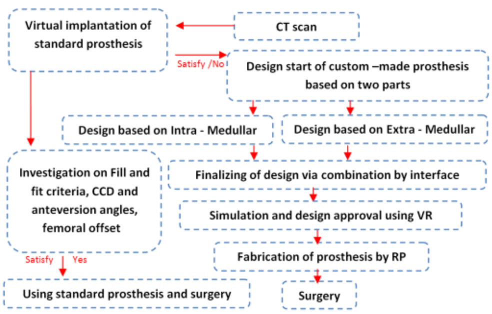

Fig. 1. Proposed methodology

2. METHOD

The proposed methodology of planning, surgery simulation and prosthesis design, begins using BIO-CAD modeling of hip joint via non-invasive data acquisition by CT scan (Fig. 1). In this methodology, the CT images were acquired with 1mm slice thickness and a resolution of 512×512 pixels and 0° gantry tilt. After data acquisition, CT data were exported as DICOM format into the MIMICS software. MIMICS which has the capability of creating 3D virtual environment based on VR techniques, is used for simulation of standard prosthesis in femoral canal. The Parameters which may affect prosthesis efficiency, and must be investigated at virtual environment, before actual implantation include (Jun& Choi, 2009; Abbaszadeh et al., 2009): Fill (the percentage of the cross-sectional area of the femoral canal occupied by the prostheses stem), Fit (surface area of prosthesis stem in direct contact with the endosteal surface), CCD angle (it was measured between the hip prosthesis neck axis and hip prosthesis stem axis), Anteversion angle (it was measured from projected line of the hip prosthesis neck axis to the transverse plane), Femoral offset (distance between femoral head center and prosthesis stem axis).Based on the proposed methodology, surgeon imports the standard prosthesis into the virtual environment in order to investigate the above mentioned parameters. As shown Figure 2, while the satisfaction of these parameters are investigated and approved by surgeon, the standard prosthesis with specific size is acceptable to be utilized. In case of disapproval (in particular for patients with abnormal hip such as dysplasia), second part of the methodology is applicable. In other words, in case of incompatibility of standard prosthesis with patient's CT scan, surgery approach may be modified accordingly in advance. It means the design of custom-made prosthesis is preferred versus standard prosthesis.

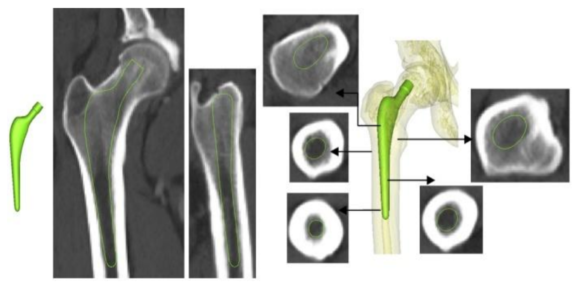

Fig. 2. Investigation on fill and fit criteria and other important parameters in standard prosthesis in view of lateral and frontal and five critical cross-sections

In this methodology, custom-made prosthesis is designed in two portions (Figure 3), and eventually are combined using interface plane (plane that is aligned with cutting plane of femoral neck) in the surgery. The first part of design is related to the intra-medullar portion of the prosthesis which is aimed to achieve optimal fit and fill for stabilizing bone tissue in the distal and proximal femur. The second part of design is related to the extra-medullar portion, which is aimed to restore geometrical and biomechanical parameters of designed prosthesis neck such as CCD and anteversion angles, and femoral offset. During the custom-made prosthesis design as well as during process of standard prosthesis selection, it is possible to simulate surgery operation in virtual environment such as resection of femoral neck (Fig. 4). After prosthesis design completed (Fig4), the simulation of prosthesis in the femoral canal begins and important parameters such as anteversion and CCD are extracted (Fig5).

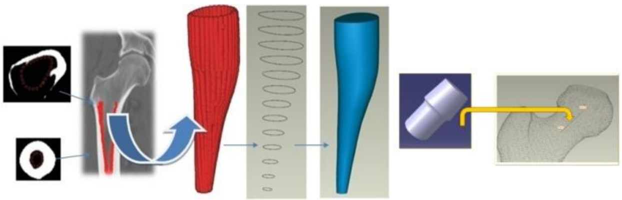

Fig. 3.3D reconstruction of femoral canal and stem design (left) and neck reconstruction by CAD techniques (right)

In this case study, standard prosthesis has CCD of 135 degree and anteversion of zero degree. For the custom-made designed prosthesis, the above values are 131.27 and 12.57 degree, respectively. Differences between these two will affect prosthesis performance and durability. Eventually, the custom-made prosthesis is fabricated via RP technology and will be implanted in the patient body (Fig6). The reason for using additive manufacturing technology versus subtractive manufacturing technology is overcoming complexity of prostheses fabrication and saving material loss (Abbaszadeh et al., 2009).

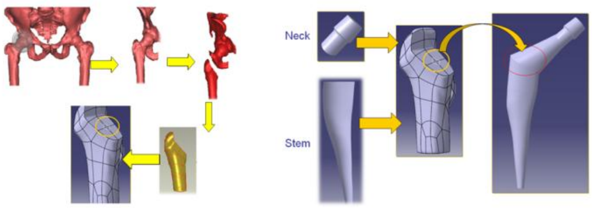

Fig. 4. Simulation of THR surgery (left) and final design of custom – made prosthesis using interface (right).

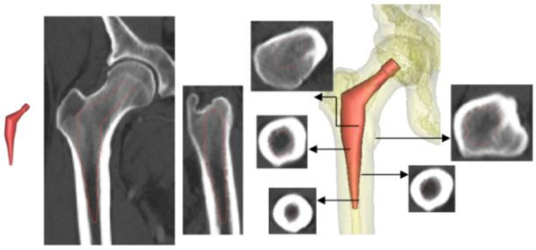

Fig. 5. Investigation on fill and fit criteria and other important parameters in designed custom – made prosthesis.

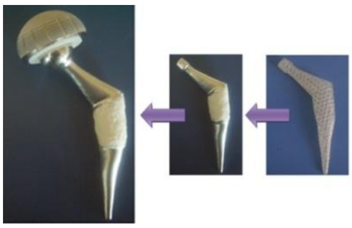

Fig. 6. Fabrication steps of custom – made hip prosthesis using SLA, investment casting and finally assembly with **acetabulum** and femoral head for implanting in patient body.

3. DISCUSSION

Due to the variability of the femoral canal and femur bone shape of people, success of THR operation depends on the right selection of prosthesis. Whether to use standard prosthesis or custom-made prosthesis is a question which is hard to answer using conventional planning methods. Due to the fact that the measurements in conventional planning methods are done two dimensionally, such as radiographic films, lack sufficient accuracy and are bound to error. Application of advanced computer simulation and 3D VR techniques facilities answering to the questions (Kosashvili et al., 2009; Wong et al., 2009). In this study, THR surgery aided planning using based on VR techniques is presented. In this methodology, it is shown that how proper prosthesis (standard / custom-made) with maximum advantages and minimum disadvantages for implantation is selected. In addition to introducing surgery planning and prosthesis selection, as well as novelty in design of custom-made prosthesis, a new technique of fabrication of custom-made prosthesis is also described. Nowadays, custom-made prostheses are fabricated using Quickcast or any laser melting technologies (LMT) such as Electron Beam Melting (EBM) in diverse biocompatible materials (Abbaszadeh et al., 2009; He et al., 2006). In this study, due to the lack of access to LMT machines, SLA is utilized to fabricate and subsequently investment casting is applied to produce the implant. However, the prosthesis is finally completed by other components such as **acetabulum** and femoral head.

4. CONCLUSION

This methodology is aimed to help designers and surgeons to improve THR surgery. In contrast to the method of surgery planning based on 2D views such as radiographic films and prosthesis utilization, the present 3D simulation and surgery preplanning has the following advantages: (Facilitating communication between surgeon and designer), (Possibility of calculating important parameters such as femoral offset or arm length, anteversion and CCD angles, and fill and fit, in 3D), (Safe and precise implantation of prosthesis), (providing favourable conditions for bone remodelling), (Stress distribution improvement), (Improvement of initial and secondary stability). In addition to the above, using RP technology in fabrication of prosthesis is other advantages that can improve time and cost of fabrication versus conventional methods.

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