Virtual Hip Replacement Simulator for 3D Printed Implants

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1 Background

This research presents a virtual reality simulator for total hip replacement surgery. The simulator supports a library of 3D hip stem models for different sizes and manufacturers. The 3D hip stems can be adjusted in size and shape by parametric software and sent for 3D printing. Biocompatible materials such as titanium enable the 3D printed stems to be directly implanted on patients.

Currently surgical simulation for orthopaedic procedures is not as advanced as other surgical disciplines. As a result there are only limited training simulators available for orthopaedic surgery such as total hip replacement, hip resurfacing or knee replacement. This is demanding since 66,000 hip replacements are performed annually in the UK.

One area which is neglected in VR orthopaedic simulation is the digital library generation of implants. Currently orthopaedic surgeons have limited choice in terms of an exact identification of implant specific to patient requirements. We conducted a literature review of orthopaedic training simulators which found no simulators catering for this [9].

Orthopaedic surgeons generally have a positive opinion for the use of virtual reality (VR) training systems. A survey amongst all orthopaedic surgeons in New Zealand found that 77% of qualified surgeons believe simulation is effective for practicing and learning surgical procedures [1]. A separate review from the American Academy of Orthopaedic Surgeons (AAOS) showed that over 80% agreed that surgical skills simulations should become a required part of orthopaedic training, based on views from 185 program directors and 4549 residents. There was a strong agreement that simulation technology should be a required component of orthopaedic resident training [2].

The hip replacement procedure has been considered as the most successful and influential orthopaedic surgery of the twentieth century. Currently over 66,000 total hip replacements (THR) are performed each year in England and Wales by the National Health Service (NHS) and around 75,000 hip fractures are treated each year in the UK. Knee arthroscopy has increased 49% from 1996-2006 and now over 1 million are performed each year [3].

Each year there are an increasing number of orthopaedic procedures due to the aging population. Currently 247,000 hip fractures occur yearly in the United States, with the majority occurring in the population over 45 years old [4]. The incidence of hip fracture is also on the rise, partly due to the aging population, with over half a million hip fractures annually expected by 2040. The cost of these fractures is also expected to rise from $7 billion per year [4], to nearly $16 billion per year by 2040 [5]. Each hip fracture is estimated at costing between $39,555 and $40,600 in the first year after surgery [6]. Hip fractures have the highest cost of any orthopaedic procedure after surgery, and also incur $11,241 each year following surgery in extra health costs. Due to increased life expectancy, worldwide by 2050, it is projected that 6.26 million hip fractures will occur annually [7].

A paradigm shift is underway toward use of surgical training simulations [8]. The conventional master-apprentice learning model for surgical training of 'see one, do one, teach one' has recently been seen as inefficient. Due to orthopaedics being heavily dependent on technical skill, orthopaedic VR simulation holds potential to have great impact for improving surgical skill. The transition to VR simulation is relatively new compared to cadaver training which has been the gold standard for several centuries.

2 Methods

Virtual reality software was developed for simulating the hip replacement steps. A Geomagic Touch device was used to provide haptic feedback in the developed system (Fig. 1). The haptic device was configured to exert forces and haptic sensations including haptic drilling vibration, soft and hard tissue, striking bone surface, edges of bone, convex surfaces, and slippery wet surfaces, emulated at 1kHz.

Graphics models were developed to represent some of the tools commonly used in orthopaedic surgery. In the actual procedure, tools vary between different surgeons and different manufacturers. The software allows the user to select various tools which could have different properties associated with them such as saws with variable cutting tooth size.

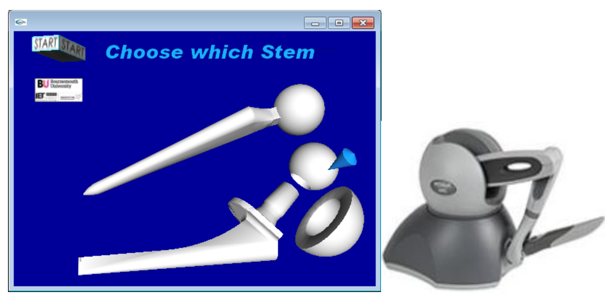

Fig. 1. Haptic software simulator for 3D stem implants.

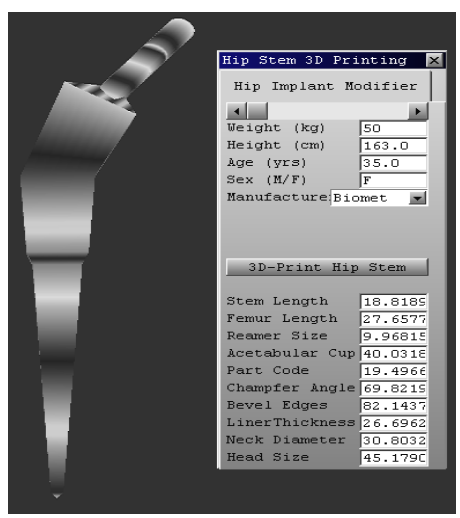

Fig. 2. Software for generating 3D printable stem models.

The software is able to generate digital 3D models of hip stems in adjustable 3D geometrical sizes and shapes. This software estimates the size of the femur based on the relationship between the patient's measured parameters such as weight and height and the size of femur. The size of femur can then be used to identify the optimum size of a hip stem, which is generated as a 3D model (Fig. 2). These can be saved as STL files and directly sent for 3D printing in biocompatible material for directly implanting on patients.

3 Results

The geometric design of the hip stem can be adjusted in the software including acetabular liner thickness, chamfer and bevel angles, lip breadth, head center inset and changes in the head size and head to neck diameter ratio (Fig. 3).

Patient-specific stems can ensure optimum fitting for individual patients and minimum impingement. Impingement between the neck of the femoral implant and the rim of the acetabular component causes advanced wear of the acetabular rim. The primary cause for impingement problems is incorrect acetabular positioning during surgery, and a training simulator could enable practice of this technique.

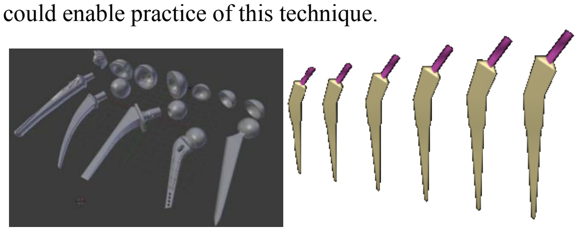

Fig. 3. Adjustable 3D models of hip stems for 3D printing.

There is growing evidence showing that simulators can distinguish between trainees of differing skill levels and could objectively assess trainees. Also experienced surgeons can often complete VR simulated surgery faster than students, demonstrated by various simulator validation studies.

Scoring by virtual reality could potentially be fairer to all trainees than current scoring methods with live sessions. In live training sessions, trainees are evaluated by external reviewers on several aspects of technique. Evaluations are based on several individuals from their own vantage point so the system is subjective and also difficult to consistently repeat between students.

4 Interpretation

Evidence for the educational value of VR surgical simulators is accumulating rapidly. Several studies have provided verification of simulator validity and have shown the transfer of simulator-acquired skill to the operating room. Several validation studies on existing arthroscopy training simulators have shown improvement after simulator training. Studies recommend that international standards should be developed for the effectiveness of orthopaedic simulators.

This research aimed to develop a digital library of implants and generate customized sizes of patient-specific implants. Patient specific approach can allow simulation of procedure for patients of various size, height, weight or pre-operative planning based upon actual patient measurements. Surgeons could practice beforehand on a virtual model of the patient thereby reducing the learning curve.

Assessment of trainee skill level and performance feedback could be a real advantage in a surgical simulator. There is strong evidence in literature that simulators can differentiate between expert and novice surgeons.

There is increasing accountability in the medical profession and an increased emphasis on patient safety.

Simulators may be a useful learning aid helping to improve surgical training, reduce health service costs from injury litigation and reduce the rate of patient injury. Skills learned during this simulation can then be transferred to the actual clinical environment.

The ability to modify the 3D geometric design of hip stems and a digital stem library increases the chance of the stem fitting accurately for individual patients.

Acknowledgements

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