Medical Engineering and Physics 38 (2016) 59–71

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Review

A review of virtual reality based training simulators for orthopaedic surgery

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ARTICLE INFO

Article history:
Received 13 April 2015
Revised 14 August 2015
Accepted 13 November 2015

Keywords:
Orthopaedic
Hip replacement
Resurfacing
Simulator
Haptics
Modelling

ABSTRACT

This review presents current virtual reality based training simulators for hip, knee and other orthopaedic surgery, including elective and trauma surgical procedures. There have not been any reviews focussing on hip and knee orthopaedic simulators. A comparison of existing simulator features is provided to identify what is missing and what is required to improve upon current simulators. In total 11 hip replacements pre-operative planning tools were analysed, plus 9 hip trauma fracture training simulators. Additionally 9 knee arthroscopy simulators and 8 other orthopaedic simulators were included for comparison. The findings are that for orthopaedic surgery simulators in general, there is increasing use of patient-specific virtual models which reduce the learning curve. Modelling is also being used for patient-specific implant design and manufacture. Simulators are being increasingly validated for assessment as well as training. There are very few training simulators available for hip replacement, yet more advanced virtual reality is being used for other procedures such as hip trauma and drilling. Training simulators for hip replacement and orthopaedic surgery in general lag behind other surgical procedures for which virtual reality has become more common. Further developments are required to bring hip replacement training simulation up to date with other procedures. This suggests there is a gap in the market for a new high fidelity hip replacement and resurfacing training simulator.

1. Introduction

This article reviews current virtual reality (VR) based training simulators for hip replacement and resurfacing, with comparison to other areas of orthopaedic surgery simulation. A comparison of the simulator features is provided to identify what is missing and what is required to improve upon current simulators.

There have not been any reviews focusing on hip surgery training simulators. It is likely that in the near future hip surgery simulation could become a focus area for new development to catch up with other surgical training procedures.

Simulators for orthopaedic surgery lag behind other surgical disciplines [1]. In the past two decades there has been very little research attempting to create an orthopaedic surgery simulator, and even fewer studies attempting to validate orthopaedic simulators. More simulation needs to be done in orthopaedics, as trainees are getting more exposed to computers and laboratory training [2]. Spinal simulation training is still in its infancy. Simulators for orthopaedic surgery provide an important training tool. Currently training simulators are only available to a select a few trainees who have to register for courses and workshops to do simulation for specific procedures.

There is a lack of training simulators for total hip replacement, which may be due to the relatively long length of the procedure taking around 60–90 min to complete. The keys steps in the hip replacement procedure are acetabular reaming, fixation of acetabulum cup, broaching the femoral canal and placement of the stem. Reviews recommend that simulation is also an excellent way to teach arthroscopy skills, which are a different skill set than open orthopaedic surgery [3]. A review [4] identified 19 existing arthroscopy simulators (9 shoulder, 9 knee, and 1 hip) showing arthroscopy is a popular field for simulator training.

Hip joint replacement has been considered to be the most successful and influential orthopaedic surgery of the 20th 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 [5]. Knee arthroscopy has increased 49% between 1996–2006 and now over 1 million are performed each year.

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http://dx.doi.org/10.1016/j.medengphy.2015.11.021

An increasing number of orthopaedic procedures are required annually, due to the aging population. It is estimated that 247,000 hip fractures occur yearly in the United States, with a majority occurring in the population over 45 years old [6]. The incidence of hip fracture is on the rise, partly due to the aging population. The cost of these fractures is also expected to rise from $7 billion per year [6], to nearly $16 billion per year by 2040 [7]. Each hip fracture is estimated to cost between $39,555 and $40,600 in the first year after surgery [8]. Hip fractures have the highest cost of any orthopaedic procedure after surgery, amounting to an extra $11,241 per year in health costs. Due to increased life expectancy, worldwide by 2050, it is projected that 6.26 million hip fractures will occur each year [9]. Hip fracture surgery is one of the most common orthopaedic surgeries, behind only knee arthroscopy, shoulder arthroscopy, removal of a support implant, and total knee replacement. Approximately half of the population 85 years old or older has a hip fracture. Hip fractures have a mortality rate of 21.9% within 1 year of surgery.

Revision surgery can be necessary following primary total hip replacement surgery, if complications occur. Also after a successful operation a new hip is generally required after 20 years. The reason for revision surgery being required can be due to incorrect stem placement in the primary surgery, which may in some cases result from lack of surgeon experience, which simulators may help to improve. The incidence of dislocation is between 2%–6% and even higher following revisions [10]. Other studies report up to 8% dislocation [11]. There have been an increased number of hip revision surgeries recently associated with metal–metal prosthesis acetabular cups in hip prostheses which produce billions of sub-micrometer wear particles annually that can cause osteolysis and loosening of the components [12]. Another complication is impingement between the neck of the femoral implant and the rim of the acetabular component. Impingement can lead to advanced wear of the acetabulum rim resulting in polyethylene wear debris shown to accelerate loosening of implant bone interfaces. The most common cause of both impingement and dislocation is malposition of the acetabular component, which may be caused by lack of surgeon experience. Training simulators could specifically allow practice of this key skill. Simulating these key procedures could improve the skill of novice hip surgeons and reduce the risk of injury to patients.

1.1. Advantages of virtual reality over conventional training

A paradigm shift toward use of surgical training simulations is underway [13,14]. The conventional master-apprentice learning model for surgical training of ‘see one, do one, teach one’ is inefficient with no guarantee of case mix. Due to orthopaedics being heavily dependent on technical skill, orthopaedic VR simulation holds great potential creating a heavy impact on improving surgical skill. The transition to VR simulation has only begun in the past twenty years, whereas cadaver training has been the gold standard for over 500 years.

Training with VR could be particularly useful for medical residents. Residency refers to a stage of graduate medical training, for a trainee who has received the title of ‘physician,’ usually a M.D., D.O., or MBBS, MBChB, BMed.

Residents trained with virtual reality perform surgery substantially faster, whereas residents with conventional training are slower, much more likely to cause injury, damage tissue or fail to progress the surgery, as demonstrated by a prospective, randomized, blinded study on the MIST-VR laparoscopic simulator [15]. Similar benefits of VR training were demonstrated in laparoscopic [16] and shoulder arthroscopy simulators [14].

An article dating back to 1986 on computer-aided orthopaedic surgery concluded that “real time operative rehearsal, precision surgical planning and execution, and interactive teaching programs will be widely used once the costs associated with this technology come within the reach of clinical and teaching budgets” [17].

Table 1
Lists of the keyword sets used during literature and worldwide patent searching.

LIST A	LIST B
Hip replacement	Simulator
Hip surgery	Simulation
Hip arthroplasty	Training
Hip arthroscopy	Preoperative model system
Hip resurfacing	Preoperative planning
Orthopaedic	Virtual
Orthopedic	Virtual reality
Total hip	Commercial simulator
Prosthesis	Computer simulator
Prostheses	VR

Simulation is particularly attractive in the field of surgery because it avoids the use of patients for skills practice and ensures that trainees have had some practice before treating humans. Also simulation avoids need for cadavers or animals, which are currently the most realistic method of training. Surgical simulations break down the procedure into tasks, concentrating on chains of behaviour. The aim of surgical simulation is to improve the training of the surgeons of the future by providing a controlled, risk free environment where they can develop their operative and decision-making skills without any potential harm to patients. The idea is that they reach a certain level of skill before progressing to ’real life’ operating theatre scenarios.

Virtual reality provides enhanced understanding of complex 3D bony structures and handling of instruments [18]. Haptic technology can provide tactile experience of the surgical procedure and can be further advanced when combined with patient specific MRI or CT data for automatic segmentation for use in a visual and haptic virtual environment [19].

Scoring and assessment can be incorporated into VR simulators with the ability to replay or review. This can provide an objective unbiased score. An orthopaedic curriculum was recently developed containing 4 bone training modules to assess and track progress in orthopaedic manual skills [20]. Modules include (1) cortical drilling, (2) drill trajectory, (3) oscillating saw, and (4) pedicle probing. These modules were tested on 15 orthopaedic surgery residents and results were promising [20].

Surgical procedures require the operator to understand the anatomy and develop their sense of touch for procedures. VR training simulators assist the development of visuospatial awareness of anatomy and ‘feel’ of the procedure by allowing practice prior to in-vivo procedures. This will enhance patient safety in addition to creating a safe and controlled environment in which to practice the procedure. The ability for simulators to assess skill level or analyse performance of practical skills has been demonstrated by several studies including [21]. Simulation is gaining popularity not only for the purpose of creating mock scenarios but also in learning psychomotor skills [22].

1.2. Literature search methods

A literature search was performed to find existing orthopaedic training simulators. The Medline (Pubmed) database was used for searches of medical subject headings (MeSH) terms. Keyword searches were carried out additionally using alternative databases including searches from ACM Digital Library, IEEE Xplore, ASME Digital Collection, IEEE/IET Google Scholar and Electronic Library (IEL) which produced further relevant titles. Patent searches were conducted to identify existing intellectual property protection via the worldwide patent database using the European patent office (EPO). Searches for related hip surgery simulators used systematic keywords combining one word from List A with one word from List B, as shown in Table 1.