Computer simulated phacoemulsification, improvements

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ABSTRACT

A simulator for phacoemulsification cataract extraction is developed. A three dimensional visual interface and foot pedals for phacoemulsification power, x-y positioning, zoom and focus were established. An algorithm that allows real time visual feedback of the surgical field was developed. Cataract surgery is the most common surgical procedure. The operation requires input from both feet and both hands and provides visual feedback through the operation microscope essentially without tactile feedback. Experience demonstrates that the number of complications for an experienced surgeon learning phacoemulsification, decreases exponentially, reaching close to the asymptote after the first 500 procedures despite initial wet lab training on animal eyes. Simulator training is anticipated to decrease training time, decrease complication rate for the beginner and reduce expensive supervision by a high volume surgeon.

Keywords: cataract surgery, phacoemulsification, simulator

1. INTRODUCTION

The present work aims at developing a simulator for phacoemulsification cataract surgery (PHACO) from proof of principle to tool for clinical testing.

Cataract surgery is today the most common surgical procedure in modern societies approaching 1/100 inhabitant/yr. Due to increasing population age in these societies, the prevalence for the procedure is expected to increase further.

PHACO is the state of the art technique for cataract surgery. This technique is based on an approximately 3 mm incision into the eye in the periphery of the cornea, opening of the crystalline lens by tearing an operculum in the anterior lens capsule, capsulorhexis, liquid dissection of the crystalline lens into cortical and nuclear components, ultrasound emulsification and simultaneous aspiration of the nucleus, aspiration of the cortical material and implantation of an artificial intraocular lens into the empty capsule. The success of the operation is related to the maintenance of an intact capsular bag.

PHACO is usually taught in two phases. During phase one, the student is watching the teacher, an experienced colleague, and excercising the procedure on enucleated animal eyes or human eye bank eyes. The duration of the first phase varies depending on surgical center, previous experience of ocular surgery and learning speed, up to 12 months. During phase two, the student operates and the teacher stands by. Since surgery is almost exclusively done in local anesthetics with the patient awake, the possibilities for the teacher to comment the student during surgery are very limited. Further due to space constrictions, the teacher has no immediate access to the operating field during surgery and can therefore not easily avoid erroneous manipulations by the student. The duration of the second phase again varies up to 12 months. Altogether, the teacher and the student on an average spend a year in the surgery room together before the student starts to operate independently.

PHACO requires relatively complex coordination of both hands and feet and the margins for erroneous manipulation is small. Despite careful training, residents have an overall incidence of 5-20 % ruptured capsule during their first 200 cases (Cruz, Wallace, Gay, Matoba and Koch, 1991; Tarbet, Mamalis, Theurer, Jones and Olson, 1995; Yang, Kirwan, Foster and Pereira, 1995; Robin, Smith, Natchiar, Ramakrishnan, Srinivasan, Raheem and Hecht, 1997). Similar figures have been published for experienced surgeons learning phacoemulsification (Seward, Dalton and Davis, 1993; Thomas, Braganza, Raju, MBBS and Spitzer, 1994). A study of 1000 consecutive cases operated by one surgeon demonstrated that the number of complications decreases exponentially and that the asymptote is reached after approximately 400 cases (Ng, Rowe, Francis, Kappagoda, Haylen, Schumacher, Alexander, Boytell and Lee, 1998). A similar study of another experienced surgeon demonstrated that the asymptote is reached after approximately 1000 cases (Martin and Burton, 2000).

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Considering the long learning period for PHACO, efforts should be made to reduce it so that the number of complications are minimized.

Further during the training of a new surgeon, two ophthalmologists spend on an average almost one year together in the surgery room. During phase one, the student is sitting by instead of seeing patients in the clinic. During phase two, the teacher is sitting by instead of being a high volume surgeon. If the training time can re reduced, there is a substantial potential economic gain.

It has been suggested to train and test the hand-eye coordination of prospective surgeons (McDonald, 1998).

The current research project intends to develop a computer simulator for training of a becoming surgeon before the student is starting to operate human eyes. In a first step, the phacoemulsification procedure was simulated using a nuclear manipulator and a phaco handle for input and a computer screen as a visual feedback interface to the student (Laurell, Nordh, Skarman, Andersson and Nordqvist, 2001).

The aim of the current work was to develop a stereo operation microscope visual interface feed back system, a foot pedal control of phaco power for the simulator phaco handpiece ultrasound power, software for zooming and X-Y positioning with commercial foot pedals, a computer algorithm for foot pedal real time focusing-defocusing the simulated image with a regular personal computer.

1 METHODS

1.1 Hardware

The system consists of a nucleus manipulator, a phaco emulsification handpiece, a visual interface, a personal computer, a commercial foot pedal for microscope focusing, zooming and X-Y positioning and a commercial foot pedal for control of the phacoemulsification procedure (Figure 1).

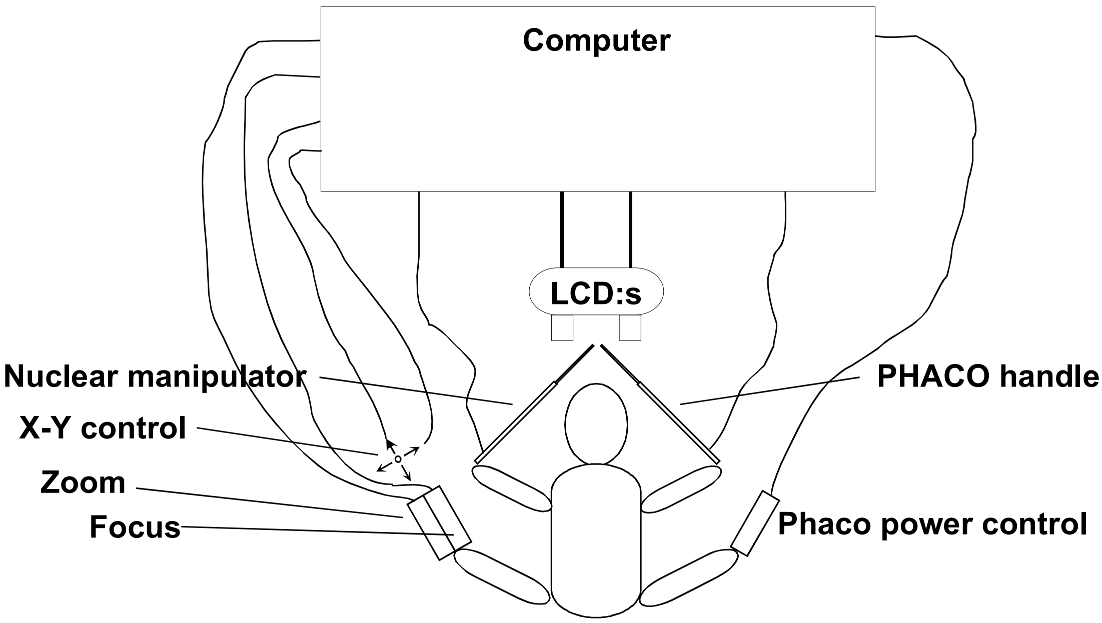

Figure 1 Simulator for phacoemulsification cataract surgery

The nucleus manipulator and the phacoemulsification handpiece are mounted with four degrees of freedom (three space dimensions and rotation) with an electronic transducer for each degree of freedom. Similarly, the positions of the foot pedals are sensed with analogue electronic transducers. All signals are analogue/digital converted in a PC-card. The digital signals are used as imput in the simulation software.

1.2 Software

The simulation is base on a generalized simulation software (M-base®, Melerit AB, Sweden) working on top of Cosmo 3D/Optimizer (Silicon Graphics Inc., USA). On top of M-base, a module has been written for the phacoemulsification procedure.

1.3 Mode of action for phacoemulsification

A three dimensional model of the field of surgery is generated. The surgeon may push or rotate on the lens nucleus with either of the instruments and dig into the nucleus with the phacoemulsification handpiece. The action of the two instruments is immediately fed back as image information with an update frequency of 25 Hz, thus directing the next move of the surgeon.

2 RESULTS

2.1 Visual interface for three dimensional view

Two small liquid crystal monitors (Figure 2) from a virtual reality helmet (AddVisor™100, Saab Avionics, Sweden) are mounted above the nucleus manipulator and the phacoemulsification handpiece.

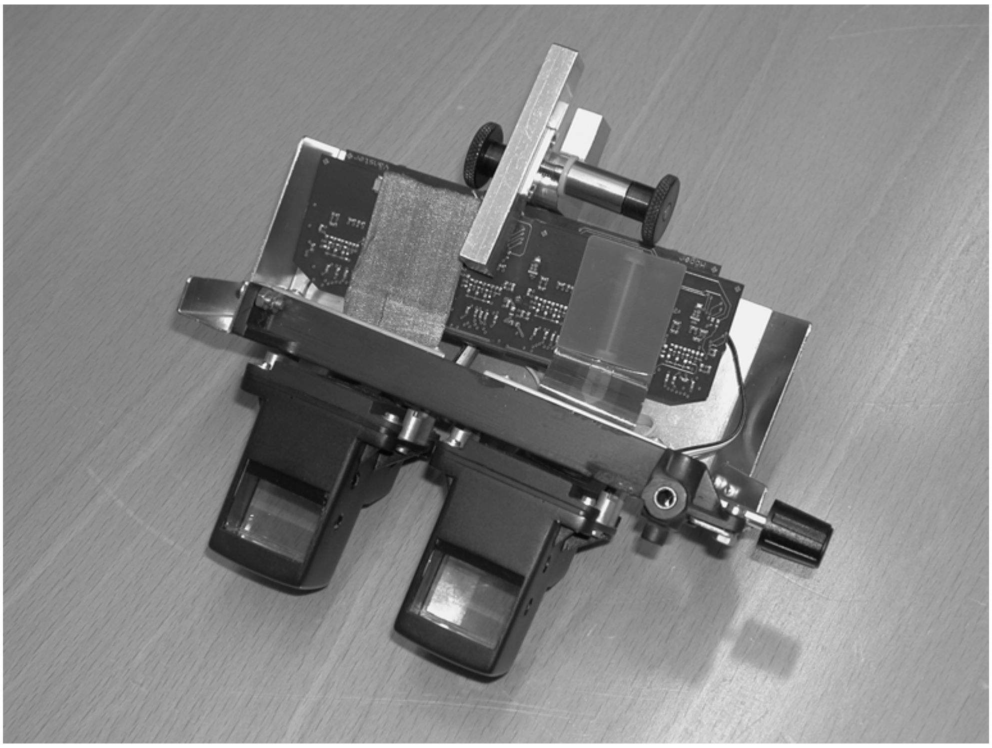

Figure. 2 Liquid crystal displays from AddVisor™100 (Saab Avionics, Sweden) head mounted display.

Each liquid crystal display has a resolution of 1280x1024 pixels and is fed with image information from the computer.

The phacoemulsification module is made to generate two virtual cameras recording the model of the virtual field of surgery as seen through each of a microscope ocular, including the image of the nucleus manipulator and the phacoemulsification handpiece. This provides a three dimensional view of the field of surgery.

2.2 Foot pedal control of phaco power

The position of the transducer for foot pedal control of phaco power is fed into the algorithm and determines the efficacy of the virtual phacoemulsification process.

2.3 Zoom and X-Y positioning

For zooming, the magnification of the virtual image presented on the liquid crystals is altered. For positioning, the position of X-Y and zoom is fed from the foot pedal transducer into the software. The virtual image on the liquid crystals is moved according to the position of the foot pedals.

2.4 Focusing

The input of data is a three dimensional model of the surgical field with a defined focal plane. A sharp image of the focal plane is generated and a very blurry image is generated. The blurry image is generated by averaging over several pixels. For each pixel the distance between the focal plane and the image is measured. The final image is generated as a mixture of the sharp and the blurred image, using the distance to the focal plane as a the weight for luminous intensity of sharp and blurred image, respectively. The focusing algorithm provides an image update frequency of 80 Hz and exert no load on the other part of the simulation.

3 DISCUSSION

The current project aims at developing a simulator for training of cataract surgery.

With the current improvements, it is felt that the system is ready for initial clinical testing. As a first step, it is intended to compare simulator phaco surgery among experienced cataract surgeons, residents of ophthalmology, and medical students before they studied ophthalmology. If the experienced surgeons perform better than the medical students, this is an indication that the simulator is simulating the real surgical procedure.

The first development of the simulator has focused on development of a module for the phacoemulsification procedure. In future, additional modules for other parts of the PHACO surgery will be developed.

The current simulator is primarily developed for pre-clinical training of prospective cataract surgeons. With a more developed system, it is anticipated to provide possibilities for experienced cataract surgeons to train on very unusual events without risk for the patient. There is a possibility that in the future, surgeons will be required to undergo a regulated amount of simulator training to be the licensed for surgery (Kilby, 1998).

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