Robotic consolle for ocular surgery: a preliminary study

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ABSTRACT

Minimally invasive surgery has recently been improved by the use of robot-assisted procedures in several medical fields. Among the ocular surgeries there are a few examples of sophisticated vitreoretinal procedures, while robotic-assisted surgery of the anterior eye segment is still under study. In this paper we propose a new approach to the robotic assisted ocular surgery: a CO2 laser system is equipped with a micromanipulator and scanner, and it is proposed to induce photothermal effects for the removal of neoformations. A sensorized tool is connected to the patient eye and to the robotic arm. This tool is equipped with force and position sensors: by the use of the spatial information from the robotic console and from the patient it is possible to control the position of the target itself and to block it in the correct position for performing surgery. The system is provided by a feedback alarm that remove the block of the patient head in any moment. The optimized robotic consolle can be used in performing scleral cuts and in the treatment of pterigium or neoformations.

Keywords: laser assisted, minimally invasive surgery, robotic eye surgery

1. INTRODUCTION

Minimally invasive surgery is typically based on the remote-control manipulation of the surgical instruments. The use of a laser source to induce a surgical or therapeutical effect and its remote control via a robotic consolle are commonly used in the new surgical approach in different medical fields: laparoscopic surgery, orthopedics, gynecology etc., have been revolutionized. Robotic control of a surgical tool improves the surgical outcomes: tremor filtration can reduce or eliminate the defects of a manual procedure; scaling of motion allows precision that is not possible with unassisted human hands. Narrow and confined anatomic spaces can be investigated, without direct visualization.[1-3] Laser sources can offer unique minimally invasive treatments of biological tissue, such as laser welding or cutting with extremely high precision [4], [5] and can be proposed for the applications in microsurgery[6] and for the treatment of extremely thin tissue, otherwise impossible to treat with a manual technique[7].

Despite the exponentially increasing clinical use of a robotized control in different surgical fields, in Ophthalmology there are a few preclinical studies on robot-assisted surgery. The principal applications are in vitreoretinal studies and in trauma surgery, while the anterior segment surgery is still under study[8-10]. On the other hand laser sources are commonly used in corneal and cataract surgery, due to the particular optical characteristics of these structures[11,12].

The main reason of an underdeveloped robotic ophthalmic surgery is that the required precision is extremely higher than in other surgical fields. It has also to be considered that the view of the surgical scene is always mediated by the operating microscope and sometimes by a particular lens systems (as in vitreoretinical surgery). Moreover, the remote center of motion differs from typical laparoscopic surgery, making adaptation of commercial laparoscopic robots problematic[13].

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In this experimental work we propose a feasibility study of a robotic consolle for the laser assisted surgery of the anterior eye segment. In particular we studied the new applications in ocular surgery of a CO_2 laser, currently used in dermatology, gynecology and ORL. The CO_2 laser light is absorbed by the water content of the tissue, and the predominant induced effect is a thermal effect, resulting in tissue ablation, vaporization or carbonization depending on the laser settings, irradiation conditions and tissue parameters. In ocular surgery the CO_2 laser was studied for the welding of ocular tissues, but till now there is no clinical application of this light source. The proposed laser source is equipped with a micromanipulator and scanner and it is used in combination of a robotic consolle used to control the patient's eye position.

2. MATERIALS AND METHODS

2.1 The CO_2 laser system

The proposed laser system is based on a RF excited CO_2 laser, having high emission versatility and delivering laser pulses with variable structure, duration and peak powers. The laser spots (a hundred microns in size) are delivered to the target tissue through a scanner (HiScan Surgical, a dual galvanometer scanner patented by DEKA, M.E.L.A. srl, Calenzano-FI, Italy) and a micromanipulator (EasySpot Full Holo). The synergic combination of the HiScan Surgical scanner and the EasySpot Full Holo micromanipulator enables: precise ablations with reduced lateral thermal damage to tissues; control and selection of the indicative ablation depth of each single scan (depth mode); optimal scanning figures for incision and ablation of tissues.

2.2 ESPRESSO, the sensorized arm

The ESPRESSO (Eye Stabilization maniPulatoR for lasEr aSSisted Ophthalmic surgery) is a robotic platform for ophthalmic laser assisted surgery. The main aim of the system is the stabilization of the patient's eye during laser assisted surgical procedures. ESPRESSO is designed to be lightweight and have a small encumbrance in order to be mounted on the operative bed close to the patient's head. Furthermore, the system must not interfere with traditional surgical and visualization instrumentation, such as the surgical microscope. The overall design is low cost, simple and compact. An overview of the ESPRESSO platform is shown in Figure 1a.

The proposed system has a two linear stage actuation system for positioning a stabilizing tool on the patient's eye. The main component, a macro-positioning system, is used for coarse approaching to the patient's head. The other component is a micro-positioning system with stabilizing tool placed in contact to the patient's eye.

The ESPRESSO platform is also provided with a sensing unit that comprises an optical fiber based proximity sensor and a miniaturized pressure sensor. The proximity sensor monitors the distance between the stabilizing tool and the patient's eye. This feedback is used to control the macro-positioning phase. The pressure sensor monitors the pressure exerted on the eye by the stabilizing tool. This feedback is used to control the micro-positioning phase. The location of the platform components, i.e. macro and micro-positioning system, proximity and pressure sensors, is shown in Figure 1b.

The overall procedure can be controlled by the surgeon thanks to a graphical user interface (GUI) and a joystick. The GUI is provided with security and alarm systems in order to ensure the safety during surgery. ESPRESSO is also provided with an automatic release system that can move the overall system away from the patient's eye if any sudden urgency happens.

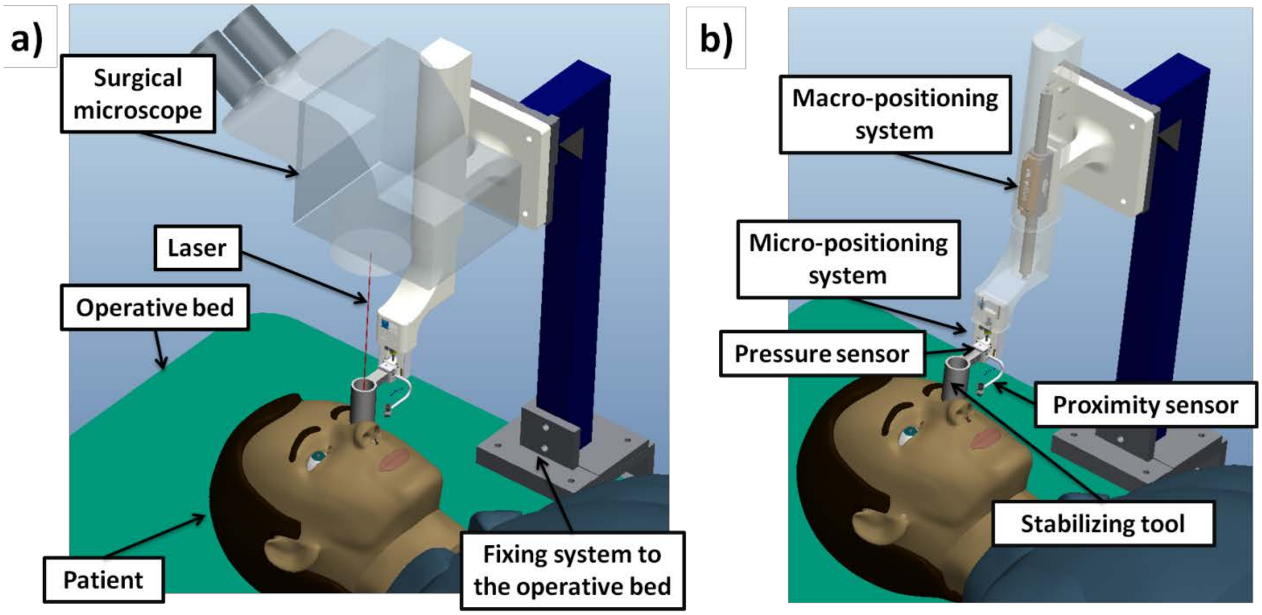

Figure 1. The ESPRESSO robotic platform for laser assisted ophthalmic surgery: a) system overview, b) location of system components.

3. RESULTS

The CO_2 laser robotic consolle has been tested in pig eyes ex vivo. It can be easily adapted to the standard surgical microscopes, thus enabling laser-assisted surgeries for the removal of anterior ocular neoformations and for glaucoma surgery. CO_2 laser effects in cornea, sclera and ocular annexes were studied ex vivo in 10 pig eyes. These results were used as a feedback to design an optimized CO_2 laser source, that can be used for performing extremely precise incision in scleral tissue and to remove pterigium or anterior ocular neoformations.

Figure 2 The experimental tests in pig eyes

Figure 3. Possible applications in ocular surgery: precise removal of superficial tissues (left); creation of flaps/holes with known thickness and dimensions in the scleral tissues (right).

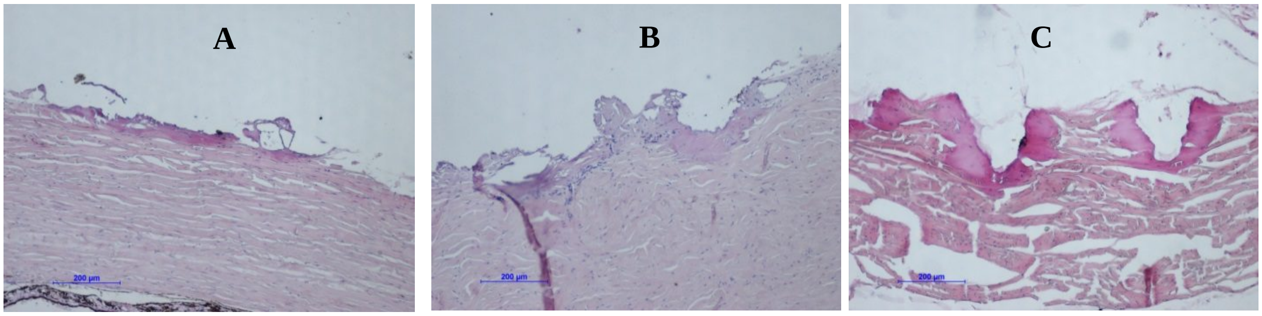

Figure 4: H&E hystology of the CO2 laser treated (sclera) with three different laser settings: 1W UP 3ms (A); 2,5W UP 3ms (B); 2W SP 3ms (C).

4. CONCLUSIONS

The optimized CO_2 laser system, equipped with a scanner and micromanipulator, can be satisfactory used in anterior eye surgery, and in particular to perform controlled scleral cuts and for the treatment of pterigium and neoformations. The setup of a robotic arm to stabilize and control the patient's eye improves the outcomes of this robot-assisted surgery. An upgrade of this configuration is currently under study and will be proposed for the preoperative design of the surgery, for the real time control in the surgery room and to move specialized end effectors for ocular surgery, such as a fiber optic delivering a laser light (e.g. in the laser welding of the tissues). Further development of the system design are needed in order to set up a marketable CO2 laser for Ophthalmic surgery.

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