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Computer simulation for ergonomic improvements in laparoscopic surgery

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Abstract

It is the aim of this study to reduce the stress and strain of the medical staff during laparoscopic operations, and, simultaneously, to increase the safety and efficiency of an integrated operation room (OR) by an ergonomic redesign. This was attempted by a computer simulation approach using free modelling of the OR and 3D human models (manikins). After defining ergonomically ‘‘ideal’’ postures, optimal solutions for key elements of an ergonomic design of the OR (position and height of the image displays, height of the OR table and the Mayo stand) could be evaluated with special regard to the different individual body size of each member of the team. These data should be useful for the development of team adapted, user friendly integrated OR suites of the future.

Keywords: Laparoscopic surgery; Ergonomics; Image display OR table; 3D model; OR table height

1. Introduction

In laparoscopic or minor access surgery, large incisions through the abdominal wall for intraabdominal operations are avoided. This is achieved by inserting three or more trocars (ports) into the abdominal cavity. Via these ports, a videotelescope and specially designed instruments are brought into the abdomen, enabling the surgeon to perform the operation in a similar manner as in open surgery but in a by far less invasive way. In comparison to open surgery, however, this new approach requires an additional spectrum of sophisticated devices and comprehensive technical support (light sources, camera control units, videoscreens etc.).

Usually, the operative team comprehends three or four person: the surgeon, the scrub nurse and one or two assistants. The assistant has to align the videotelescope to visualize the site of the operation, while the surgeon performs the operation. The scrub nurse has the task to deliver the instruments required at the different steps of the operation and to support the surgeon's activities in all regards.

As compared to conventional, open interventions, the working conditions in minimally invasive surgery are by far worse due to specific constraints of the technical environment (Berguer et al., 1999; Nguyen et al., 2001; Vereczkei et al., 2003). The positioning of the monitors is one of the essential items (Hanna et al., 1998).

Real time video transmission of the intraabdominal view is a decisive precondition for a safe and efficient performance of the entire operation room (OR) team. Accordingly, each member of the team must have continuous and reliable visual access to the videoscreen.

In most standard ORs, however, the screen(s) are positioned atop of the so-called laparoscopy trolleys containing the dedicated laparoscopic equipment as needed for the operation. These trolleys are bulky, and more often than not it is impossible to find an optimal position because no appropriate space is left at the table. A compromise between the ‘‘ideal’’ position and the available space is inevitable (Herron et al., 2001). Since continuous observation of the screens is mandatory for each member of the team, they have to accept unergonomic working

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postures for long-lasting periods of time. Together with static holding and a variety of additional physical and mental stress factors this augments considerably the strain of the OR team and can, potentially, even lead to a reduction of the safety level (Berguer et al., 2001). Accordingly, it has to be assumed that, if the problem of an optimal monitor positioning could be solved, this would not only improve the working conditions of the team but also increase the efficiency and safety of an operation.

Leading manufacturers of OR suites are now offering new concepts of boom-mounted monitors which can be moved independent of bulky trolleys, allowing for a free spatial positioning of the screen(s) at the table. This offers the chance to realize an optimal observation of the operation to all members of the OR team. However, little is known about where, at which height and at which distance a screen should be ideally placed for the individual observer. In order to obtain valid data we attempted to identify the optimal positioning of the screen(s) using a computer simulation system.

Another very important issue influencing the ergonomic situation at the OR table is an appropriate adjustment of the elevation of the screen(s) and of the OR table with the Mayo stand (Berguer et al., 2002). The differences in the individual body height of each member of the team make it difficult to find a position which is acceptable for each of them. Scientific data to solve this problem are scarce. Therefore, the computer simulation of the intraoperative setting was also used to identify an ergonomically reasonable compromise for the height of these objects.

2. Material and methods

The working conditions at the OR table may vary considerably according to the type of operation and the OR team. Since it is impossible to simulate the whole spectrum of variations, this study was confined to laparoscopic surgery of the upper abdomen, with an OR team consisting of a surgeon (male), the scrub nurse and an assistant (male).

The simulator was composed of the two systems CATIA (www.catia.com) and RAMSIS (Bubb, 1997). CATIA is a CAD/CAM tool which was used to design the operating room.

RAMSIS is a simulation program for creating 3D human models. The human model of RAMSIS consists of an external skin model which renders a realistic outer appearance, and an internal skeleton model. The internal model represents the function of a framework, and is simultaneously the carrier of the kinematic model.

A team of three persons was simulated performing a laparoscopic operation. The human models (manikins) of the surgeon, the scrub nurse and the assistant were placed around the OR table within the OR as created by CATIA.

Thus, the optimal ergonomic position could be evaluated at each stage of the operation. Prior to the evaluation, the RAMSIS tool had to be adapted to the specific working conditions of an OR. This was achieved by a video measurement system which extracts 3D human frame models from two synchronized video spots of different viewpoints.

The method of the video measurement system was based upon combining two simultaneous and synchronized video recordings of laparoscopic operations using two digital camcorders in an orthogonal position. Thus, pairs of pictures were produced simultaneously from the two different viewpoints. For the extraction of the 3D human models that were used for the supervision of the RAMSIS manikins we used the PCMAN software.

By using the similar recordings of the calibrating body as a referral point, the digitalized pictures were analyzed with the software PCMAN, proven to accurately measure the rotation, lateral and anteroposterior movements of joints and parts of the body (Fig. 1).

The pairs of pictures were imported, and 17 orientation points of the body as required by the program were marked on both. A rough tracking of the posture was prepared automatically. This had to be refined step by step manually, until the closest similarity was achieved, as reported in detail elsewhere (Vereczkei et al., 2004) (Fig. 2).

Prior to the simulation of the various "realistic" constellations within an OR, an "ideal" working posture of a surgeon had to be defined. Two well-experienced surgeons were asked to demonstrate a posture they considered most comfortable to perform an operation. This "ideal" posture, which was identical in both cases, served as a reference position.

After this learning phase it was possible to evaluate the ergonomic positions of the RAMSIS mannikins according to the stored comfort positions, including the different subtasks for the surgeon, the assistant and the nurse. During the ergonomic evaluation of a RAMSIS manikin, the deviation from the stored comfort positions was computed. From this distance set, the smallest value represented the most ergonomic value (closest distance to comfort position). Thus, it seemed to be possible to identify the most ergonomic position among several different options.

Three different positions of the screen were suggested by an experienced surgeon and simulated with RAMSIS:

Design 1: The monitors were placed at the upper end of the OR table close to the patient's head (Fig. 3).

Design 2: The monitors were positioned exactly opposite to the surgeon (Fig. 4).

Design 3: The monitors were located diagonally close to the patients head (Fig. 5).

Each of these designs can be easily realized in a modern operating room with boom-mounted screens.

In addition to the position of the screen, the working posture results from a number of additional parameters, such as:

- the height of the individual member of the team;
- the height of the operating table;
- the position and height of the Mayo stand.