Image Rotation and Reversal - Major Obstacles in Learning Intracorporeal Suturing and Knot-Tying

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ABSTRACT

Background and Objectives: A major stumbling block to teaching and learning the finer skills of laparoscopy is related to the "optical illusions" the video camera plays on the surgeon's eyes. Until now, the belief was that lack of coordination was the result of depth perception deficiencies resulting from the two dimensional plane of the video monitor. In reality, this is a minor problem that is easily surmounted with practice. A closer analysis of how organ orientation at the operative site compares to the video camera's fields of focus reveals the real problem: the major optical difference between laparotomy and laparoscopy involves rotation of the images received by the brain.

Conclusions: There are four major operating positions in laparoscopy: camera position, right camera position, left camera position and opposite camera position. The object in front of the camera has two components; the first, a reality image, which results from light reflected off the object as it exists in time and space. The second, a visual image, which represents the actual light entering our eyes. At right camera position the visual image is a 90 degree counterclockwise rotation of the reality image. At the left camera position the visual image is a 90 degree clockwise rotation of the reality image. At opposite camera position, a 180 degree rotation and complete reversal of the reality image occurs. It is only at camera position that the visual image is equal to the reality image, and we approach a scenario similar to that found in laparotomy. Every other position will be unlike what we were accustomed to in open surgery.

Key Words: Image rotation, Intracorporeal suturing, Intracorporeal knot-tying.

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INTRODUCTION

A major stumbling block to teaching and learning the finer skills of laparoscopy is related to the "optical illusions" which the video camera plays on surgeons' eyes. Until now, the belief was that lack of coordination was the result of depth perception deficiencies resulting from the two-dimensional plane of the video monitor. In reality, this is a minor problem that is easily surmounted with practice. A closer analysis of how organ orientation at the operative site compares to the video camera's field of focus reveals the real problem: the major optical difference between laparotomy and laparoscopy involves rotation of the images received by the brain.

Before proceeding, it is essential to define two important concepts involved in processing information to our brains. When an object is before us, such as an apple on a table, light is reflected off its surface in all directions creating its own intrinsic reality image and is interpreted as an essence of the solidness of the apple and evidence of it existing in time and space. Next, there is a visual image present, which involves the actual light entering our eyes. This light serves as a source of neuronal activity to be processed by the brain. It provides information about what "appears" to be out there in the world. If we have eye disorders of the lens or retina, the visual image our brain receives will be different from the reality image the apple is giving off.

Magicians make their living by capitalizing on the natural tendency of the brain to equate visual images with reality images. "Seeing is believing" is deeply ingrained in our psyche. Holographic images are other examples of visual images that fool the eye. We may see an apple on a table before us, and even try to grasp it - with no success. The reason for this is that there is no actual solid apple on the table sending our eyes a reality image to coincide with the visual image we are receiving.

In laparoscopy, what we have done is separate the reality image from the visual image. To understand the fine concepts here, imagine four individuals surrounding an elephant on all four sides. Each person sees a different perspective of the animal. To move the elephant, the four people can work in a coordinated fashion. Each gently touching and grasping that portion of the elephant immediately in his or her sight and directing it along the proper road.

The person in the front would receive a reality image (RI) of an elephant trunk that would coincide with the visual image (VI) his brain was receiving. The other individuals would see either the sides of the elephant or its tail. If we name the four individuals A, B, C and D, then the images involved can be labeled and categorized as follows: person A receives reality image RI-A, which equals visual image VI-A; person B receives reality image RI-B, which equals visual image VI-B; person C receives reality image RI-C, which equals visual image VI-C; and finally person D receives reality image RI-D, which equals visual image VI-D.

Now imagine we bring technology into the arena. We ask the four individuals around the elephant to close their eyes and then place on three of them - B, C and D - special eye visors which present an image to their eyes instead of allowing them to see directly in front of them. Individual A, who is standing immediately in front of the elephant, is given the same visors - but with a small video camera in the middle, positioned on his forehead. The picture that all four individuals will see displayed on their visors is that of the camera recording from individual A. If we analyze the images the brain receives in this scenario, we find the following: person A receives reality image RI-A, which equals visual image VI-A; person B receives reality image RI-B, which does not equal visual image VI-A; person C receives reality image RI-C, which does not equal visual image VI-A; person D receives reality image RI-D, which does not equal visual image VI-A.

With the visors on, the chore of moving the elephant has now become almost impossible. The only person who can possibly accomplish anything is person A, who can grasp the elephant by the trunk and encourage it to move. Persons B, C and D will be of no help because when they try to grasp a trunk before them what they encounter is a physical reality they can not see. Something solid is in front of B and C and something rope-like in front of D. These coincide with the sides of the elephant and its tail. What they see and what they feel are not the same. For them, the reality images do not coincide with the visual images their brains receive. The result is uncoordinated movements.

When performing a laparotomy, we receive a visual image directly from the organ we are working on. Our hand and body movements are then subconsciously directed by this information. In the operating room, if the primary surgeon is on the right side of the table and the first and second assistants on the left and foot of the table, each individual receives a different visual image of the operative site. While different, it is an exact representation of the reality image in front of him or her. As a result, each surgeon's brain receives non-conflicting information and actions are smooth, effortless and coordinated among all members of the operating team. Although they are not all seeing exactly the same things, but different perspectives of the operating scene, they are able to coordinate their movements and operate smoothly.

In contrast, what laparoscopy has done is separate the reality image from the visual image. Instead of each person receiving his own different, individual image, in laparoscopy each individual in the team receives the same impersonal image. We no longer look directly at our organ of interest, but see an electronically processed interpretation of it. The visual image we receive is not always a true indication of the reality image that exists, immediately in front of us - concealed behind the abdominal wall. Because of these distortions, the brain receives conflicting information and uncoordinated movements occur. This is why we are unable to perform advanced laparoscopic maneuvers.

MATERIALS AND METHODS

The presence of rotation and reversal were discovered by the author while practicing advanced skills using a laparoscopic simulation setup. The author was the sole investigator and experimental subject in this simulation experiment. The device used was the Borinquen Ring laparoscopic training device.[1] This consists of movable laparoscopic instrument ports, which can be placed around any practice specimen while at the same time allowing use of a camcorder and television monitor. The advantage of this open arrangement is the ability to go back and forth between the monitor image and the "operative site" to compare different maneuvers and angle relationships between laparoscopic instruments and the task being performed.

The major skills practiced were suturing in a continuous fashion and two-handed "intracorporeal" knot-tying. While mastery of suturing and knot-tying was easy in the camera position, the eye and hand coordination acquired in this position were useless when the same task was attempted in any other position. Countless attempts to practice in different positions were made to become proficient in these apparently simple skills. After stepping back and analyzing the physics involved, the intrinsic characteristics of each optical position became apparent. It became obvious that what the eyes saw could not be directly translated into coordinated hand movements - as had been the case in open surgery.

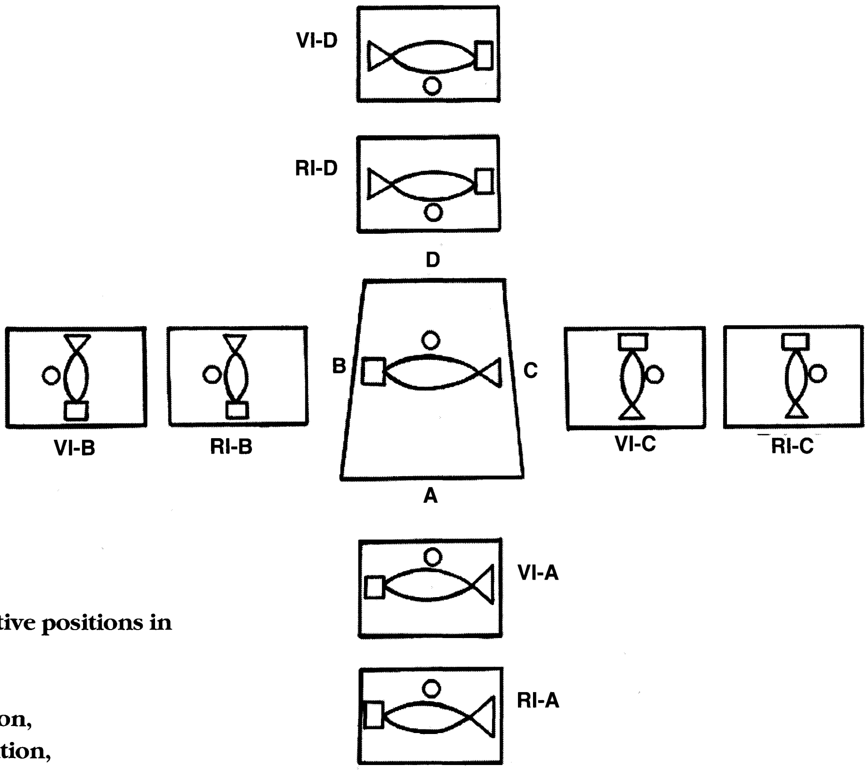


Figure 1. Four operative positions in open surgery.
A: camera position,
B: left camera position,
C: right camera position,
D: opposite camera position.
VI: visual image, RI: reality image.

RESULTS

On analysis it became apparent that in laparoscopy there are four major operating positions, each having its own unique optical characteristics. These are: camera position, right camera position, left camera position and opposite camera position. At the right camera position the visual image is a 90 degree counter-clockwise rotation of the reality image. At the left camera position the visual image is a 90 degree clockwise rotation of the reality image. At opposite camera position, a complete 180-degree rotation and complete reversal of the reality image has occurred. It is only in the camera position that the visual image is equal to the reality image, and we approach a scenario similar to that found in laparotomy. Every other position will be unlike what we were accustomed to in open surgery.

To illustrate this further, **Figure 1** represents a schematic of the four operative positions in open surgery and laparotomy. In this theoretical experiment, the operative subject here is an oval with a square on its left, a triangle on its right and a small circle on its top - or a fish, with a halo on top, eating a cracker. This scene is comparable to the four persons surrounding the previously mentioned elephant. Because each surgeon is viewing his own operative field with his own eyes, we have the following findings at the various locations around the operating table. Position A, RI-A equals VI-A; position B, RI-B equals VI-B; position C, RI-C equals VI-C; position D, RI-D equals VI-D.

Now compare this to **Figure 2**, a simulation of the laparoscopic scenario. In this second theoretical experiment, the camera is at position A, recording the fish eating a cracker and projecting its image to a video monitor M - which all participants look at. The only optical image available at any of the positions is that of the monitor, which represents VI-A. Only at camera position is RI-A equal to VI-A. At the other positions we encounter the dilemma of the elephant caretakers with visors on their heads. At camera position A, the reality image RI-A shows a fish with a cracker to the left at the 9 o'clock position. This coincides exactly with the monitor picture image VI-A. Now if you were standing in left camera position B and were able to look down to your immediate operative field, you would discover that the fish was actually holding the cracker at the 6 o'clock position and the halo was to the left. If you have only the monitor to look at in this position, then the monitor will have transposed the reality image RI-B 90 degrees in a clockwise rotation. Standing in right camera position C, the reality image RI-C consists of a fish holding a cracker at the 12 o'clock position with the halo to the right. In this position RI-C is transposed by the monitor 90 degrees in a counter-clockwise rotation. In position D, the reality image RI-D has the fish eating a cracker that is at the 3 o'clock

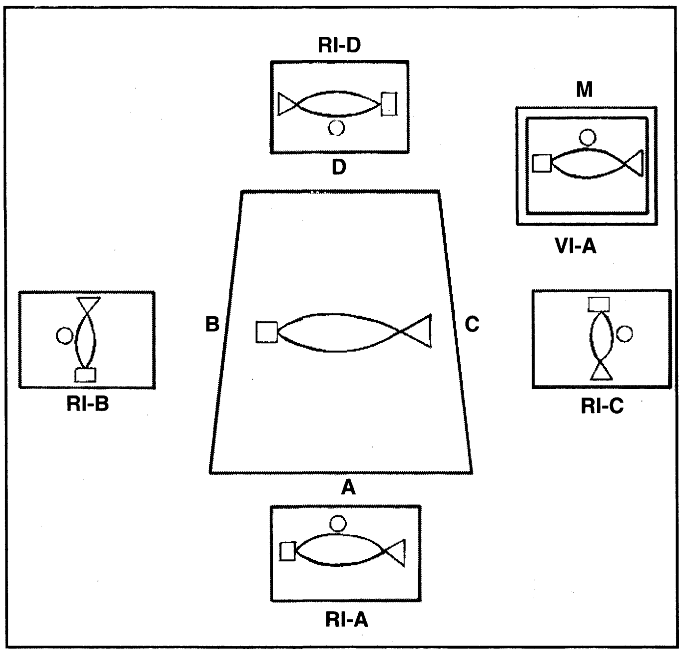


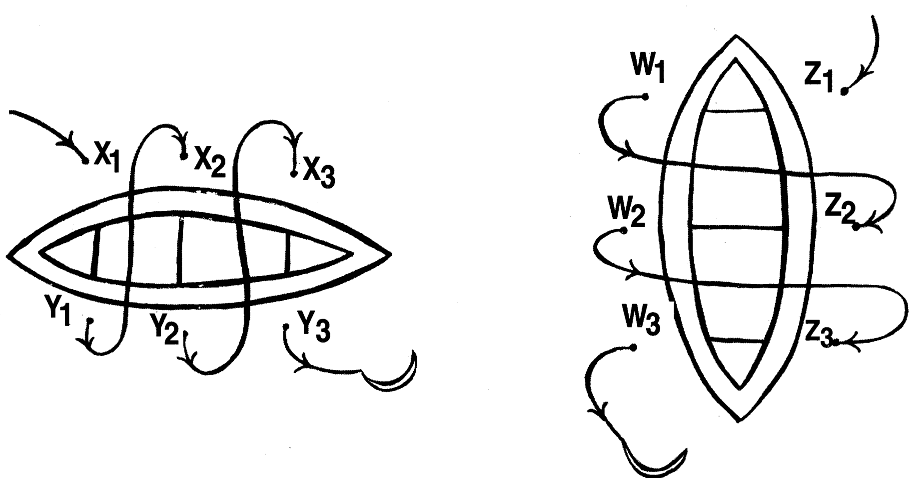
Figure 2. Four laparoscopic positions. A: camera position, B: left camera position, C: right camera position, D: opposite camera position, M: video monitor, VI: visual image, RI: reality image.

position and its halo lying under it. The surgeon standing in this position sees a monitor image VI-A, which represents a full 180 degree rotation of the actual RI-D immediately before him as well as a complete reversal between right and left and top and bottom.

The motions necessary for a surgeon to perform the closure of an incision were studied. **Figures 3A** and **3B** show the outline of two incisions, the first oriented in a horizontal position and the second in a vertical. When closing the first incision, most surgeons would place the needle at point X1 and then exit at point Y1. In the same fashion they would continue through point X2 to Y2 and then X3 to Y3. The motions would be smooth and proceed from top to bottom, in as many repeated sequences as necessary, to get to the end. In the vertical incision in **Figure 3B**, the motions would proceed from right to left, from point Z1 to W1 and so on.

The above motions are done automatically when we operate in an open field - without the interposition of a camera. In this setting, when we see a horizontal incision, our brains direct our hand motions to proceed in a top to bottom fashion. The same can be said for a vertical incision. Our brains immediately program our hands to move from right to left. Motions are efficient because the reality image in front of us coincides with the visual image our brains are getting from the open field.

In laparoscopy, unless you are standing immediately in front of the camera, you will encounter difficulty suturing in all the other positions. When attempting to suture from positions B or C, the 90 degree rotation that results - whether clockwise or counter-clockwise - means that when you suture a wound that appears horizontal on the monitor, in actuality the wound is lying vertically in front of you behind the abdominal wall. Looking at the video image, your brain will direct your hands to close the wound in a top to bottom fashion - when in actuality what you really need to do is work from right to left. In opposite camera position D, there is a complete 180 degree turn between the RI-D and VI-A. A horizontal incision will remain horizontal and a vertical incision vertical. Unfortunately, now there is a complete reversal of landmarks. The change between right and left and top and bottom makes it extremely difficult to control placement of the needle and advance the suture. It must be remembered that the refer-



A. **B.**

Figure 3. Suturing maneuvers.
A: Horizontal incision, X: entry points, Y: exit points.
B. Vertical incision, Z: entry points, W: exit points.

ences made here to the different position changes (right and left, top and bottom), all refer to a two-dimensional plane. If surgeon D is working directly opposite from surgeon A and trying to assist him, the task will be almost impossible beyond the most rudimentary movements.

The most difficult skill to master, in this self imposed experiment, was two-handed, intracorporeal knot-tying. Here the loose ends of the suture are extremely difficult to grasp, unless the surgeon is in the camera position. Out of frustration, the author created a double-looped suture to facilitate this task.[2] It has a loop at each end that permits easier grasping and passing of the suture under tubular structures.

DISCUSSION

The ability to perform surgical tasks more easily in the camera position was discussed by A.K.C. Li and associates in their article, "Position of ports in laparoscopic surgery."[3] This study described the difficulties encountered by experienced surgeons tying a square knot at different camera angles. They used a piece of 000 polyglactin (Vicryl, L.T.D., UK), 20 cm long placed on a fixed point on the practice table. They varied their working angle by increments of 30 degrees, covering a full 360 degree range. Comparison of their data to the above described camera positions results in: camera position equals D0, right camera position equals R90, left camera position equals L90, opposite camera position equals D180. Surgeons of varied degrees of laparoscopic experience participated. The study concluded that the maximum range of surgical efficiency in performing the knot-tying ranged from DO (0 degree) to R60 and L60 (60 degrees to the right and left). Beyond these angles, there was a drastic rise in the time necessary to perform simple square knot-tying. The worst position was D180.

Li's data confirms there is a 120 degree range for working at the camera position - beyond which rotation and reversal start distorting the surgeon's perception of reality. The best results were obtained at 0 degrees, with surgeons tying the knot within two minutes. The worst position was opposite camera position, 180 degrees across from the camera. Here, half of the surgeons took between 14 to 25 minutes to perform knot-tying. Unfortunately, the authors made an incomplete conclusion as to the cause of this lack of skill by stating they "were operating with a mirror image, which was technically extremely difficult." In actuality, the reason is worse than that. In a mirror image only right and left orientations are changed. In the opposite camera position, D180, not only is there a reversal of right and left, but top and bottom are also reversed - making the optical situation even more complicated to work in than if it were a mere mirror image.

CONCLUSIONS

The experiment described here, and its results, are based on the sole experiences of one surgeon. They represent the result of the author attempting to acquire advanced laparoscopic skills in a self-taught environment. Further work in this area is encouraged to substantiate the reported findings as well as to uphold or refute the conclusions the author is now taking the liberty of stating.

If one accepts the above stated optical properties, then three important issues come up regarding future performance of advanced skills. First, it is not enough to practice skills, such as suturing and knot-tying, in the camera position alone but also in the right camera position, the left camera position and the opposite camera position. This is essential, because the movements necessary to tie a knot in one position are entirely different from those needed to tie the same knot at another. To practice advanced skills only in the camera position, and forget the other positions, is impractical.

All positions are important, because our laparoscopic camera is often fixed into one position, with multiple ports surrounding it. Since we are not always the primary surgeon in laparoscopic operations, but occasionally serve each other as assistants, it is necessary for all laparoscopists to be able to perform essential tasks in all port positions. Future training courses for advanced laparoscopic surgical skills will need to develop curriculum with laboratory exercises performed at the four major positions. This will require both in vivo practice in the animal laboratory and laparoscopic simulation devices.

The second issue arises from the fact that the theoretical experiments described above were based on the assumption that the operative subject (the fish) was on a two-dimensional plane. In reality, we work in three-dimensional space while performing laparoscopy. If we consider the two-dimensional plane to consist of the algebraic x and y coordinates, then the third dimension would be the z coordinate. In laparoscopy, the "z" coordinate remains unchanged - which means, that regardless of where the surgeon stands in relationship to the camera, the abdominal wall will always be in an "up" position and the abdominal organs in the "down" position.

The effects of depth perception were not addressed by this experiment. The issue arises because the reality image is always in three dimensions - while the video visual image is in two dimensions. The issue was addressed by A.K.C. Li and associates in their article entitled, "Comparison of two-dimensional vs three-dimensional camera systems in laparoscopic surgery."[4]

Li and associates studied surgeons performing a task consisting of stringing up 10 beads onto a suture with a straight needle using two- and three-dimensional cameras.[2] The results indicate that prior laparoscopic surgical experience was the only factor affecting performance - not the type of video camera used. It would appear then, that new curriculum need not incorporate three-dimensional cameras into skills training laboratories. Lack of depth perception does not appear to hamper acquisition of skills. Other researchers have come to the same conclusion.[5,6]

In view of the obstacles that image rotation and reversal cause, perhaps the solution is to provide an individual camera and video monitor for each surgeon. This would allow each surgeon to have projected a visual image that reflects his or her own unique reality image. In view of the many hours it would require to retrain surgeons to perform simple skills in the four laparoscopic camera positions, this is perhaps a more practical alternative. If we are ever to advance, on a grand scale, to complicated laparoscopic operations, it would appear that we need to place more eyes in the operative field. Now that surgeons such as Demco and Love are performing micro-laparoscopy with tiny cameras and dissection instruments,[7,8] the ability to incorporate two small laparoscopic cameras into the abdomen is a reality. This can now be done, and still maintain good cosmetic results for the patient.

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