REVIEW

Concept of Simulation Surgery

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Abstract. The concept of simulation surgery was first proposed by Fujino in 1989 and reinforced in 1991. It is divided in two sections; empirical simulation surgery, where the surgical procedure is designed first in the surgeon’s brain, and computer simulation surgery, where the disease condition and the possible surgical procedures can be viewed in three-dimensions (3D) either on a computer monitor, or by means of a solid 3D model, crafted from computer generated data, before proceeding to the actual surgery itself. Each of these sections is subdivided into three subsections; morphological, functional and psychological simulation surgery, respectively. Along those lines, the concept of simulation surgery is discussed, with special reference to plastic and reconstructive surgery. (Keio J Med 42 (3): 104–114, 1993)

Key words: computer surgery, virtual reality, 3D, 4D simulation surgery, 5D simulation surgery

Introduction

In plastic surgery, the tissue from the donor site into the recipient site is transferred to be as similar as possible to the original, but can almost never be exactly the same. The art of the reconstructive surgeon is therefore to craft the new tissue so as to resemble and simulate as much as possible the original and its surrounding tissue morphologically such as in the aspects of color and configuration, in addition to functional and psychological aspects. This is conventionally and empirically carried out in daily practice. So this is called empirical simulation surgery.

On the other hand, modern plastic surgery has developed computer technology as a simulative surgical tool, the creation of a model or replica constructed to allow practice, demonstration or analysis of a problem. This model is constructed in 3D on a computer screen, or some form of solid, tactile 3D model pre-, intra- and post-operatively. Utilizing a then-modern computer system in 1972, an experimental 3D study was first performed by us in medicine to examine the mechanism of blowout fracture of the orbit. Later in 1983, Marsh and Vannier reported first clinical application of computer graphics in craniofacial surgery. This is referred to as computer simulation surgery or computer aided simulation surgery (CASS).

Classification

Simulation surgery consists of empirical and computer simulation surgeries. They are divided into three sections, namely, morphological, functional and psychological simulation surgery, respectively. Empirical simulation surgery is subdivided into three sections, best simulation surgery, second best simulation surgery and preferred simulation surgery. In computer simulation surgery, subdivision is not mentioned herein due to the fact that it is not yet so advanced yet (Table 1).

Table 1 Classification of Simulation Surgery

<table>
<thead>
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<th>Empirical Simulation Surgery and Computer Simulation Surgery (CASS)</th>
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<td>I Morphological Simulation Surgery</td>
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Empirical simulation surgery
Morphological simulation surgery

Fig 1  Best simulation is obtained by local skin flap and intentionally created local skin flap by tissue expansion method. Local skin is expanded to the same width of the lesion. The lesion is excised and the local flaps are closed without tension (1-1, -2, -3, -4).

Fig 2  Second best simulation is obtained by thin myocutaneous flap. Skin color is not the best but contour is well gained (Nakajima's case) (2-1, -2, -3).
Empirical Simulation Surgery

The reconstructive plastic surgeon practices his art on any part of the human body, from top to toe, with tissue transplantation as the main technique being used. In some cases it is impossible to repair a defect with tissue of a similar type, and so a distant donor site must be identified with tissue as similar as possible to the recipient site, in order to provide a repair as similar as possible to the surrounding normal tissue. Typical clinical cases will be presented in each simulation surgery in order to make the concept easily understood.

Morphological Simulation Surgery

Best simulation surgery

The local skin flap shows the best simulation of the transplanted skin in color as well as its texture. Clinical suturing of laceration, scar revision and Z-plasty are such cases. Tissue expansion is a recently developed method to create the local skin flap and is an internationally well accepted method (Fig 1).7

Second best simulation surgery

The skin defect is covered by a distant pedicled or free flap. In this case, simulation is not the best, but the second best, as it is often difficult to match tissue types between distant body sites, especially in texture, configuration and color. Conventionally myocutaneous flaps do not follow the convex and/or concave shapes of the body curve satisfactorily due to their thickness. However, the newly developed thin or reduced myocutaneous flap does such a job, surgically satisfying the morphological simulation (Fig 2).8

Preferred simulation surgery

In adopting the prefabricated or secondarily vascularized flap, an otherwise impractical random pattern flap can be surgically transformed into a practical axial

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Fig 3  Preferred simulation is obtained by medically and intentionally created prefabricated or secondarily vascularized flap. The fascia flap carrying with an axial pattern vessels is moved under the skin. Later this thin skin axial pattern flap is transferred to the recipient site (Nakajima’s case) (3-1, -2).

Fig 4  Best simulation is obtained by local compound flap, for example, in cleft lip repair (Fujino’s method) (4-1, -2).
pattern flap. Therefore, this can be classed as a member of the axially simulated flap group, but as far as color and texture are concerned, the same problems and disadvantages with mismatch in the recipient site can be found as with distant or free flap transfer (Fig 3).

**Functional Simulation Surgery**

*Best simulation surgery*

Local compound flap such as mucomyocutaneous flap in cleft lip repair and myomucosal flap in cleft palate

**Fig 5** Second best simulation is obtained by utilizing the similar tissue such as toe-to-thumb transfer. This particular case of floating thumb had an extratoe, which was transferred microsurgically to the thumb and shows a satisfactory functional thumb (5-1, -2, -3, -4, -5, -6).
Functional simulation surgery

Fig 6 Preferred simulation is obtained by an autogenous myocutaneous flap transfer. Microsurgically transferred skeletal muscle is quite different from the facial expression muscles, but gives an acceptable function (6-1, -2, -3).

Psychological simulation surgery

Fig 7 Best simulation is obtained by morphological and functional recovery by an autogenous tissue repair, for example, microsurgical anastomosis of severed temporal branch of the facial nerve (7-1, -2, -3).
repair does such a job, because the flap contains its original functional muscle fibers (Fig 4).

**Second best simulation surgery**

In the case of a patient with a congenital floating thumb or traumatic loss of the thumb, a free toe to thumb transfer offers one of the second best (sometimes the best) functional simulation (Fig 5). This, however, requires a highly trained surgeon with good microsurgical technique.

**Preferred simulation surgery**

Sacrifice or loss of the facial expression muscles can be psychologically disastrous to the patient. Therefore, a simulative surgical procedure which by any means can restore even a degree of facial expressive mobility is most appreciated by the patient. This procedure can only be successfully carried out by using an autogenous myocutaneous tissue transfer, rather than an artificial prosthetic device for defect replacement and repair (Fig 6).

**Psychological Simulation Surgery**

**Best simulation surgery**

Morphological and functional recovery by means of an autogenous tissue repair offers the best simulation surgery. Surgical repair of severed temporal and marginal branch of the facial nerve is often unsuccessful due to characteristics of the nerve, a single but not multiple anastomosed one. Microsurgical attempts to anastomose the severed nerve are often successful and give the best satisfaction to the patient (Fig 7).

**Second best simulation surgery**

Though accepted by the patient, a large facial defect reconstructed by free and distant myocutaneous flap does not demonstrate the best, but the second best color match (Fig 8).

**Preferred simulation surgery**

Even though the best simulation surgery is carried out by the surgeon, the patient himself or herself is not satisfied with its result and falls in psychological distress. Such a case will be in this category.

**Computer Simulation Surgery (CASS)**

The historical development of the use of the computer to provide first 2 dimensional and later 3D imaging of the bony structures has already been mentioned above. With later state-of-the-art computer enhanced 3DCT data, computer assisted design (CAD) and computer assisted

![Psychological simulation surgery](Fig 8) Second best simulation is obtained by an autogenous distant flap transfer, not with prosthetic device (8-1, -2, -3).
manufacturing (CAM) techniques, originally purely commercial in nature, it became possible to design and manufacture very accurate prosthetic implants; to introduce animation to the on-screen simulation; to cut sections of the bony and other tissue out and move them on the screen as in the actual operation itself; and then to view the results of completed procedure, computer simulation surgery became in reality (Table 2).

Computer simulation surgery has found applications, not only in plastic surgery but also in many other surgical specialties, using techniques of computer graphics, virtual reality, robotics and others. Up to present, the plastic surgery field appears to have the majority of reported works in both research into and clinical applications of computer simulation surgery, simply because the primary aim of computer graphics and plastic surgery is the same, both being based on morphological changes, and easily accomplished in computer simulation.

Computer simulation surgery is now practiced in the form of screen simulation surgery and tactile replica simulation surgery.

**Morphological Simulation Surgery**

*SurgiPlan system in craniofacial surgery*

As one of 3D screen simulation surgeries, we have developed the *SurgiPlan* system. The object of the *SurgiPlan* system is to perform surgical simulation of complicated craniofacial surgery and to help the surgeon to assess the feasibility of the planned operation.

Four main functions; cut, movement, measurement and attribution, are the characteristic features of the system. 3D images are reconstructed from original CT data. The display consists of a menu area, a front view, a side view and a top view. The viewpoint may be changed at any time. When the user selects a bone, that bone turns blue. Functions such as cut, move and rotate, are now available for the selected bone. Using these three views, the user can identify a specific point in 3D. First, the user will input a point in the front view, and then determine the depth using the side and top view. This provides a complete understanding of the bone structure throughout the simulation.

**Tactile 3D life sized solid model in craniofacial surgery**

On screen 3D images are only visualized on 2D display and the advantages are somewhat limited, for example, to determine the depth of the lesion. In order to overcome this fact, as one of the aspects of visual and tactile 3D simulation surgery, we have developed life-sized solid modelling, using laser curable resin in craniofacial surgery. The same hardness as actual bone is feasible with resin. So manufactured model are used for surgical training with actual surgical instruments. By model training, surgical time is shortened and surgical skill of surgeon is promoted.

**Tactile 3D life sized mirror imaged wax model in microtia surgery**

Tactile 3D life sized solid model is made of the real image, but not a mirror image. In microtia surgery, the standard practice is to trace out the 2D design on some sterilized material such as X-ray film from the ear on the normal side. By empirical consideration of this reversed 2D film, a new 3D cartilage frame is made with an autogenous costal cartilage. This standard procedure does not always offer the best reconstructed ear frame due to unsolved problems such as contour of ear frame, thickness of the ear skin and height of the concha.

The problems mentioned are well managed by introducing a combination of a tactile 3D life sized mirror imaged wax model by non-contact 3D shape measurement system and tissue expansion methods. The data from normal side is mirror-imaged electronically and transferred to the computer controlled milling machine to create the life sized mirror imaged wax model. These models are sterilized and used as template or an aid during assembling procedure of the autogenous cartilage frame work in order to reproduce the 3D configuration of the wax model. Details of the tissue expander are described elsewhere.

**Functional Simulation Surgery**

Functional changes should be investigated, but to achieve the same degree of accuracy and reality as can now be achieved in the morphologic simulations, the memory, function and overall capacity of computers will have to be dramatically increased from the present systems, in order successfully to handle simulations involving all the factors connected with soft tissues.

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**Table 2** Classification of Computer Simulation Surgery (CASS)

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<tr>
<th>I</th>
<th>Morphological Simulation Surgery</th>
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<tbody>
<tr>
<td>1</td>
<td>3D CT</td>
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<td>2</td>
<td>3D replica</td>
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<tr>
<td>II</td>
<td>Functional Simulation Surgery</td>
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<tr>
<td>1</td>
<td>4D simulation surgery</td>
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<td>III</td>
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<td>1</td>
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<td>2</td>
<td>Medical education and postgraduate training</td>
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</table>
Computer simulation surgery
Morphological simulation surgery

Fig 9 SurgiPlan system displays 3D morphological simulation surgery on 2D visual screen (9-1, 2-3, -4). (Nakajima's case).

Fig 10-1 A 3D accurate and life-sized solid model with laser curable resin is tactile and makes it possible to practice the surgery preoperatively, followed by actual surgery with the best result (10-1, 2-3).
Morphological simulation surgery

Fig 10-2 Preoperative accurate and morphological planning of prosthesis for bone defect is feasible (10-4, -5).

Fig 11 Tactile 3D life sized mirror imaged wax model in microtia surgery (11-1, -2, -3, -4) offers the best reconstructed ear frame, contrary to the conventional reversed 2D film (11-5).
Therefore, the investigations for functional simulation surgery are far less than those of morphological simulation surgery.

**Fourth dimensional simulation surgery**

In craniofacial surgery, it is important to obtain the satisfactory intracranial volume to accept favorable 4D postoperative growth. Recent progress of 3DCT makes it possible to observe the intracranial cavity without surgical intervention. Kurihara has developed a technique to determine the intracranial volume using a console attached to the CT.

**Fifth dimensional simulation surgery**

Virtual reality is a combination of visual, audible, tactile and other sensory stimuli, computer controlled and generated, which can give the impression to the participant of actually taking part in what ever activity is being created.

Virtual reality requires the use of head-enclosing helmet, eyephones and gloves, which are all connected to the computer to enhance the feeling of virtual reality. As the participant’s limbs move, or as the head turns, the signals are sent to the computer which in turn generates the necessary reactive stimuli. Virtual reality demonstrations involve many simulations, but a complex surgical procedure is a very difficult one, though soon or later it will become in reality.

**Fuzzy logic simulation surgery**

According to Anbe, the cardiac surgery has become relatively safe procedure under extracorporeal circulation (ECC), provided a well trained perfusionist is present in order to perform ECC safely. His group introduced a new approach, fuzzy logic inference to simplify these complex processes of perfusion, using computer control. Hemodynamic control by a computer system will be also useful for flap circulation in the plastic surgical field.

**Computer animation surgery**

Marsh reported on an animation program to study lower jaw articulation, but the computer memory and manipulative requirement even for their initial program were huge.

**Psychological Simulation Surgery**

**Informed consent of the patient and family**

The medical application of computer simulation surgery is especially well-adapted to patient education, and in particular to maintaining patient confidentiality when explaining a disease or condition, its surgical procedures and its possible prognosis as part of the mandatory preoperative informed consent procedure.

**Medical educational tool**

It is possible to foresee the widespread use of computer simulation surgery in the education of undergraduate medical student and inexperienced residents without actually letting them loose on real patients. Because the simulations are stored on magnetic media, they can be duplicated and replayed as often as is necessary, with guaranteed repeatability. They can be also be periodically updated as any new parameters become known. This will provide a very effective educational tool in medical faculties of universities and teaching hospitals.

Training of computer simulation surgery is practiced in our Institute. Based on data generated from a preoperative CT scan, a 3D tactile and accurate skull replica is made of laser curable resin. This replica is used for practice of cutting with the actual use of an Aesculap drilling machine in order to make an ideal form of the anticipated skull shape by computer analyzed postoperative determination.

**Discussion**

Historically, Susrhuta’s rhinoplasty in 6BC, the use of an upper arm flap by Tagliacozzi or the “Italian method” in 1597, and the cheek or forehead flap by the “Indian method” in 1794 are well known examples of simulation surgery.

In painting with a 3D component, the “Las Meninas” by Diego Velazques in 1656 is the first time 3D ever appeared in a oil painting in history (Fig 9). A typical example of a modern but deformed 3D picture is the “Daughters in Avignon” by Pablo Piccaso in 1907, the origin of the concept of cubism and 20th century’s style of painting (Fig 10).

Now, such media are promoted from empirism to the computer system. It might be true to say that simulation surgery has had a comparatively rapid evolution; from 2 dimensional models drawn on tracing paper; early 2 and 3 dimensional computer programs; and the first 3D simulation requiring supercomputer to run them. We have now progressed through 3D full color video simulations of a patient’s condition and disease, and finally reached the stage where a complete operative procedure may be simulated on screen, or with tactile solid models. The on-screen simulations may be rotated in any plane, and tissue may be selected and excised just as in the actual operation. Thus, visual and tactile replicas of actual cases are created for exploration of the particular problems of each case, and their solution.
Historical and empirical 3D simulation

Fig 12 The first 3D oil painting by Velazques in 1656 is “Las meninas”. King Phillipe IV and his Queen are captured watching her royal highness Princess Margarita in a mirror.

Fig 13 The first deformed 3D painting (cubism) by Piccasso in 1907 is “Daughters in Avignon”.

Though not uniform in progress, computer simulation surgery has been accepted in major surgical fields such as neurosurgery, craniomaxillofacial surgery, cardiovascular surgery, general and intraabdominal surgery, and orthopedic surgery, reinforced by valuable input from the fields of engineering and radiology.

These are the true state-of-the-art in computer simulation surgery, giving a broad band and fascinating glimpse into tomorrow’s world, but a world which is already with us today.

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References

19. Tagliacozzi G: Curtorum Chirurgia per Insectionem, Venetis, apud G Bindonum, 1597