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Simulation in Plastic Surgery Training: Past, Present and Future

Phoebe Arbogast and Joseph Rosen

*Dartmouth-Hitchcock Medical Center, Dept. of Surgery,
Division of Plastic Surgery and Thayer School of Engineering
USA*

1. Introduction

The face of medicine is characterized by rapid and constant evolution. New procedures, new technology, and new solutions to clinical challenges are forever changing the field. However, medical education has been historically stagnant. From the advent of medicine until Abraham Flexner's landmark report on the state of medical education in 1910, the apprenticeship model reigned. Training was highly variable and largely dependent on one's supervisor. As a result, by the turn of the 20th century the quality of health care in the United States (US) was cause for concern. Flexner's report proposed several radical changes to medical education and in doing so, redefined the fundamental contract between physicians and society (Flexner, 1910).

Today, new challenges in medical education demand a revolution similar to that which Flexner enacted a century ago. Present undergraduate medical education is rooted in lectures, laboratories, standardized patients, and (in some cases) simulators. Problems with this system include limited integration of basic and clinical sciences; a biology-centric rather than patient-centric focus; and an emphasis on knowledge and discrete skill over critical thinking, decision-making, and teamwork. This last issue is especially problematic, as physicians are routinely faced with the complex tasks of diagnosis and treatment in chaotic environments, in which information is often inadequate, inaccurate, or not readily available. Success in this setting requires the integration and synthesis of information from many sources – a skill set not adequately addressed in current medical education.

In response to these observed shortcomings, two seemingly contradictory goals in education have been put forth as priorities. On the one hand, there is a push for further standardization of education. To this end, the Accreditation Council for Graduate Medical Education (ACGME) and the American Board of Medical Specialties have defined six core competencies required of all residents. Standardization aims to increase patient safety by reducing surgical errors and improving the quality of care, while at the same time maximizing hospital resources. On the other hand, the medical education model ought to allow for individualization to reflect the fact that people learn differently from one another. In this line of reasoning, there should be room for one student's path to differ from another's to best accommodate the student's learning style. Richard Satava, MD, (a professor of

surgery at the University of Washington and member of the American College of Surgeons (ACS) committees on Emerging Technologies and Resident Education, and Informatics; <http://depts.washington.edu/biointel/biograph.html>) cites three concepts that will be key in revolutionizing medical education, which exemplify these dual priorities: 1) an increased efficiency of education by standardizing curriculum; 2) an individualization of education; and 3) a shift from time-based training to competency-based training (Satava, 2010). In competency-based training, students practice a skill until they can demonstrate proficiency, at which point they proceed to the next skill. In contrast, time-based training requires only a set amount of time practicing the skill before it is checked off as complete, regardless of the student's competence at the end of that time period. Satava's first two concepts echo the previously mentioned goals of standardization and individualization, and his third concept demonstrates how such goals can coexist. Standardization here refers to the material presented, while individualization refers to the delivery of that material. By shifting to competency-based rather than time-based requirements, the end point of training can be standardized, while the path to reach it remains flexible from individual to individual.

Simulation can fulfill all three of Satava's educational goals, allowing for standardization of curriculum, individualization of delivery, and a shift to competency-based training. Wide adoption of simulation technology will facilitate a needed shift in education and will fundamentally change how we deliver medicine, just as Flexner's report did in 1910. Simulation offers residents the chance to advance along a learning curve, without subjecting patients to a novice's initial practicing of a skill or procedure. Furthermore, practicing skills outside of the operating room may decrease the operating room (OR) time for a procedure, and thus its cost. In recognition of simulation's power as a training tool, the American College of Surgeons is pursuing a strategy to incorporate simulation into general surgery residency programs. Their plan comprises three phases: skills training, procedure training, and team training.

This paper discusses how plastic surgery might follow the example set by the ACS and adapt the ACS's simulation training strategy to the needs and challenges specific to plastic surgery. Since many of the skills required in plastic surgery are taught during general surgery residency, Phase 1 (skills training) would require few modifications. Phase 2 (procedure training), however, necessitates the development of procedure simulations particular to plastic surgery. The team training of Phase 3 will overlap considerably with general surgery requirements, as competencies in teamwork are similar across specialties. Simulators in Phase 3 (team training) would facilitate cooperation and communication within a diverse team in a variety of environments, from the operating room to the clinic to the emergency department. Incorporating simulation in plastic surgery training is only the beginning of the needed changes in medical education; we will conclude this paper by anticipating the future roles of simulation in settings ranging from medical school to point of care.

2. Surgical simulation: Definitions and history to present

2.1 Definitions

To proceed with a discussion of simulation, it is first necessary to establish definitions of key terms. Here, a *model* refers to "a physical, mathematical, or logical representation of a

system, entity, phenomenon, or process" (Rosen *et al.*, 2009). Examples of models in medical simulation include mathematical representations of tissue deformation under pressure from surgical instruments or a three-dimensional visualization of a lung. A *simulation* is "a model implemented over time, from nanoseconds to centuries, displayed either in 'real time' or faster or slower than real time" (Rosen *et al.*, 2009). Such simulations can be used to condense 100 years' worth of glacial change to a few minutes, or, alternatively, to teach cellular metabolism with a significantly decelerated animation. Building on these definitions, a *simulator* is "a device that uses simulation to replace a real-world system or apparatus, allowing users to gain experience and to observe and interact with the simulation via realistic, visual, auditory, or tactile cues" (Rosen *et al.*, 2009).

2.2 History to present

Medical simulators, in one form or another, have been used for centuries to develop and practice surgical procedures without breaching the Hippocratic promise to do no harm to the patient. Around 600 BC in India, leaf and clay models were used in the first recorded surgical operation, a forehead flap nasal reconstruction (Limberg, 1984). More recently, simulators have taken the form of animals, cadavers, and bench models to allow trainees to practice various skills. Live animals have the advantage of providing a living anatomy; however, their downsides include availability, anatomical differences from humans, and ethical concerns. Human cadavers supply a high level of anatomical relevance, but availability and infection risks limit their practical use. Bench models are inanimate interactive tools that are readily available, reusable, and free of ethical drawbacks. There exists a wide range of bench models, from foam bricks for practicing injection to laparoscopic box trainers. Sawbones Worldwide offers over 2,000 bench models of different orthopedic pathologies, which are designed to be cut, drilled, or tapped with actual surgical tools (Sawbones Worldwide, December 15, 2011, <http://www.sawbones.com/default.aspx>). Best used to teach discrete, mechanical skills, bench models have been shown to possess training capabilities similar to cadavers (Anastakis *et al.*, 1999). Table 1 (adapted from Rosen *et al.*, 2009) compares the strengths and weaknesses of these simulators.

Modern computer simulators offer a solution to many of the limitations of these preliminary simulators. They are reusable, they display relevant patient-specific anatomy, they can accurately reflect the consequences of various surgical choices, they can provide feedback to the user, and they raise no ethical issues. Computer-based simulators used in medicine have built upon the example set by the aviation industry, which has been using flight simulators to train pilots and increase safety for over 50 years (Satava, 2007).

Today, a main focus of computer simulation development is to augment the authenticity of the simulated experience. Haptic feedback, for example, is being pursued to add a realistic sense of touch to simulators, so that a surgeon-in-training can feel (and not just see) when her simulated tool has entered an organ, cut into a blood vessel or crossed any anatomical boundary. Developers are also working to model specific environments, such as the battlefield or a disaster site, that have particular challenges and considerations. The development of surgical simulators for plastic surgery residents must take into account the needs of the trainee, which include patient specificity, anatomical variations, a range of pathologies, and both ideal conditions and unexpected complications.

Simulator Types: Comparison	Bench Models	Animal	Cadaver	Mannequin	Computer Simulation
Description/ Use:	Foam, basic skills (i.e., injections, suturing)	Microsurgery MIS-gallbladder	Entire anatomy	Anesthesia, resuscitation	Virtual, software visual-haptics-computer
Examples:	"Brick," IV insertion, catheterization, anastomosis, endoscopy/ laparoscopy, stent placement	Primate, sheep, pig, dog, cat, rat, many others	N/ A	ePelvis, Virgil	Lap Mentor, GI Mentor, ES3, Virtual Environment
Advantages:	Inexpensive, portable, multiple use, safe	Closer to human anatomy than blocks, "living" physiology	Accurate anatomy	Multiple use	Multiple use, patient-specific, no ethical concerns, performance feedback
Dis-advantages:	Limited realism, finite use	Anatomical differences, ethical concerns, availability, cost, no multiple use	Ethical concerns, availability, cost, no multiple use, tissue compliance, infection risk	Limited realism, no "living" physiology	Realism varies, cost often increases with fidelity
Costs:	Low to medium	High	High	Varies	Varies
Sources:	Immersion Medical, SimQuest, Simulation, Mentice, Energid, Touch of Life	Various animal-sales laboratories	Donations to medical schools	METI, Laerdal, CIMIT	Simbionix, METI, Lockheed Martin

Table 1. **Comparison of simulators used in medical education.** Table adapted from Rosen, J. M., Long, S. A., McGrath, D. M., & Greer, S. E. (2009). Simulation in plastic surgery training and education: the path forward. *Plastic and Reconstructive Surgery*, Vol. 123, No. 2, (Feb 2009), pp. 729-740, 1529-4242. Used with permission.

3. Use of simulation in medical education

The efficacy of simulation as a training tool in the medical field has been validated in numerous studies. Okuda *et al.* conducted a thorough search of original papers relating to simulation in medical education, from undergraduate training to continuing medical education. They found numerous studies demonstrating that simulation is an effective tool to teach basic science, clinical knowledge, procedural skills, teamwork, and communication. Measurable clinical improvements were demonstrated in a number of studies that focused on simulation-based training in two particular areas of medicine. In the field of laparoscopy, residents who trained on a simulator performed better in the operating room than those who did not train on the simulator (Duncan *et al.*, 2007, as cited in Okuda *et al.*, 2009). Another study demonstrated that simulation training increased residents' adherence to advanced cardiac life support protocol, compared to residents who received traditional instruction (DeVita *et al.*, 2005, as cited in Okuda *et al.*, 2009). Though these results are encouraging, additional studies are needed to establish that ultimately patient outcomes also improve as a result of simulation.

In recognition of the benefits of simulation, several mandates have been put in place for the incorporation of simulation into general surgery residency training. In 2008, the Residency Review Committee (RCC) of the Accreditation Council for Graduate Medical Education required that all surgical residents have access to a simulation center with certain specifications (ACGME Program Requirements for Graduate Medical Education in Surgery, December 15 2011, http://www.acgme.org/acwebsite/rrc_440/440_prindex.asp). In 2009, the American Board of Surgery (ABS) added the requirement of successful completion of the Fundamentals of Laparoscopic Surgery simulation course in order to sit for the General Surgery Qualifying Examination (ABS Booklet of Information for Certifying Exam, December 15 2011, <http://home.absurgery.org/xfer/BookletofInfo-Surgery.pdf>). The American College of Surgeons (ACS), in response to these mandates, initiated the development of a simulation center certification process. The ACS Program for Accreditation of Education Institutes aims to create a network of training centers that incorporate bench models, virtual reality, simulators and simulation, with the ultimate goal of improving patient safety. A consortium of the accredited centers meets annually to develop a more uniform approach to simulation center training. A second objective of the program has been to develop a standardized residency curriculum that meets the requirements of the RCC and ABS and maximizes the utility of the simulation centers. It was from this objective that the three-phase strategy described earlier arose. The curricula developed under this initiative can serve as a starting platform for training programs developed by the ACS-Accredited Education Institutes (AEI) consortium (Satava, 2010).

In addition to a network of like-minded centers and a standard curriculum, measures of assessment are needed in order for simulation to be truly effective as a training tool. Current methods in use can be divided into qualitative and quantitative systems of evaluation. Qualitative measures are based on assessor observations and checklists. One such system is the Objective Structured Assessment of Technical Skills (OSATS), in which a variety of skills are performed on benchtop models during timed rotations. Educators grade residents' performances using checklists of global measurement standards (Martin *et al.*, 1997). The main drawback to OSATS, as with other qualitative tools, is the time requirement of the assessors, who must be physically present during training sessions in order to evaluate

trainees. Jensen *et al.* found that OSATS could also be used as a valid tool to evaluate video-recorded surgical performance. While using OSATS following a procedure may ease scheduling conflicts and difficulty ensuring assessor blindness, the system does not minimize the assessor's time requirement (Jensen *et al.*, 2009). Quantitative evaluations avoid the need for an assessor by incorporating performance measurements into the training tools themselves. Such systems evaluate movement velocity and magnitude of forces imposed, among other metrics. Haptica's ProMIS is an example of a laparoscopic simulator with built-in motion tracking technology, which assesses and provides quantitative feedback in real time. It has been validated in a number of studies, though confirming improvements in real-life surgical skills remains a gap in the literature (Pellen *et al.*, 2008). The Electronic Data Generation for Evaluation (EDGE) is a laparoscopic simulator currently in development by Simlab Corporation, as a successor to their BlueDRAGON system. EDGE measures time, path, and force exerted for haptics-enabled laparoscopic instruments and allows trainees to see the collected metrics as they proceed through an exercise (Products in Development, December 15 2011, <http://www.simulab.com/products-development>).

4. Implementing simulation in plastic surgery training

This section of the paper focuses on adapting the ACS simulation initiative to plastic surgery training. ACAPS, together with the American Society of Plastic Surgeons (ASPS), recently launched the online Plastic Surgery Education Network (PSEN). Modules corresponding to divisions of plastic surgery (such as upper extremity, breast, and trunk) present a variety of learning tools, including case reports, clinical courses, procedural videos, and self-assessments (Plastic Surgery Education Network, December 15 2011, <http://www.psenetwork.org/REC/Default.aspx>). The wide range of educational materials offered by PSEN may be augmented in the future by the inclusion of simulated procedures, interactive animations, or virtual patients. PSEN is but one platform upon which simulation can be used to supplement traditional training. Below, we describe a strategy for incorporating simulation into plastic surgery education by following the three-phase plan set by the ACS.

4.1 Phase 1- Skills training

The first phase of the ACS's strategy uses simulation to teach the twenty surgical skills, outlined in Table 2, required of postgraduate year 1 and year 2 general surgery trainees. The list, compiled by the National Simulation Committee, includes skills from both general surgery and plastic surgery, though competence in all twenty skills is required for the completion of a general surgery residency. These skills are primarily technical and were chosen to establish in trainees a solid foundation of the motor function and visuospatial coordination that is necessary for more complex procedures learned later in training. For example, suturing skills must be mastered in Phase 1 before the successful completion of cleft-palate surgery is possible. Module templates, developed for each of the twenty skills, will present the trainee with objectives, assumptions, step-by-step instructions, common errors, and error-prevention strategies.

In the ever-changing field of surgery, simulators can be instrumental in updating training curricula in response to new surgical innovations. With the advent of laparoscopic surgery,

Skill	Relevance to:		
	General Surgery	Plastic Surgery	Both
Advanced laparoscopy skills	+		
Advanced tissue handling: flaps, skin grafts		+	
Airway management	+		
Asepsis and instrument identification	+	+	+
Basic laparoscopy skills	+		
Bone fixation and casting		+	
Central line and arterial line insertion	+		
Chest tube and thoracentesis	+		
Colonoscopy	+		
Hand-sewn gastrointestinal anastomosis	+		
Inguinal anatomy	+		
Knot tying	+	+	+
Laparotomy opening and closure	+		
Stapled gastrointestinal anastomosis	+		
Surgical biopsy	+	+	+
Suturing	+	+	+
Tissue handling, dissection, wound closure	+	+	+
Upper endoscopy	+		
Urethral and suprapubic catheterization	+		
Vascular anastomosis		+	

Table 2. **List of 20 skills required of postgraduate year 1 and year 2 general surgery trainees.** The skills on this list were included because of their importance to junior residents as well as their application in at least two specialties (as determined by the National Simulation Committee). (Information on skills in left column reprinted with permission from ACS/APDS Surgical Skills Curriculum for Residents, December 15 2011, <http://www.facs.org/education/surgicalsills.html>). Table adapted by Dr. Rosen.

the McGill Inanimate Systems for Training and Evaluation of Laparoscopic Skills (MISTEL) was developed to teach surgeons and trainees the new skills. The development of MISTEL provides a pathway to follow in the creation of future goal-specific simulators: first the discrete skills needed are identified, then these skills are modeled in a simulator, a set of metrics is established, and finally validity of the simulator is evaluated (Vassiliou *et al.*, 2006). MISTEL was incorporated into the Fundamentals of Laparoscopic Surgery curriculum to teach mechanical skills. In a study by Sroko *et al.*, residents performing laparoscopic cholecystectomy scored higher on the Global Operative Assessment of Laparoscopic Skills after completing the FLS course. This study indicates that training with the MISTEL system can positively affect OR performance (Sroko *et al.*, 2009).

In plastic surgery, several systems have emerged following the example set by MISTEL. Mimic Technologies (Seattle, WA) has responded to the introduction of surgical robots by adapting their simulation platform MSim™ to train surgeons on the use of Intuitive Surgical's *da Vinci*® robot system. Mimic's dV-Trainer™, released in 2007, is a tabletop

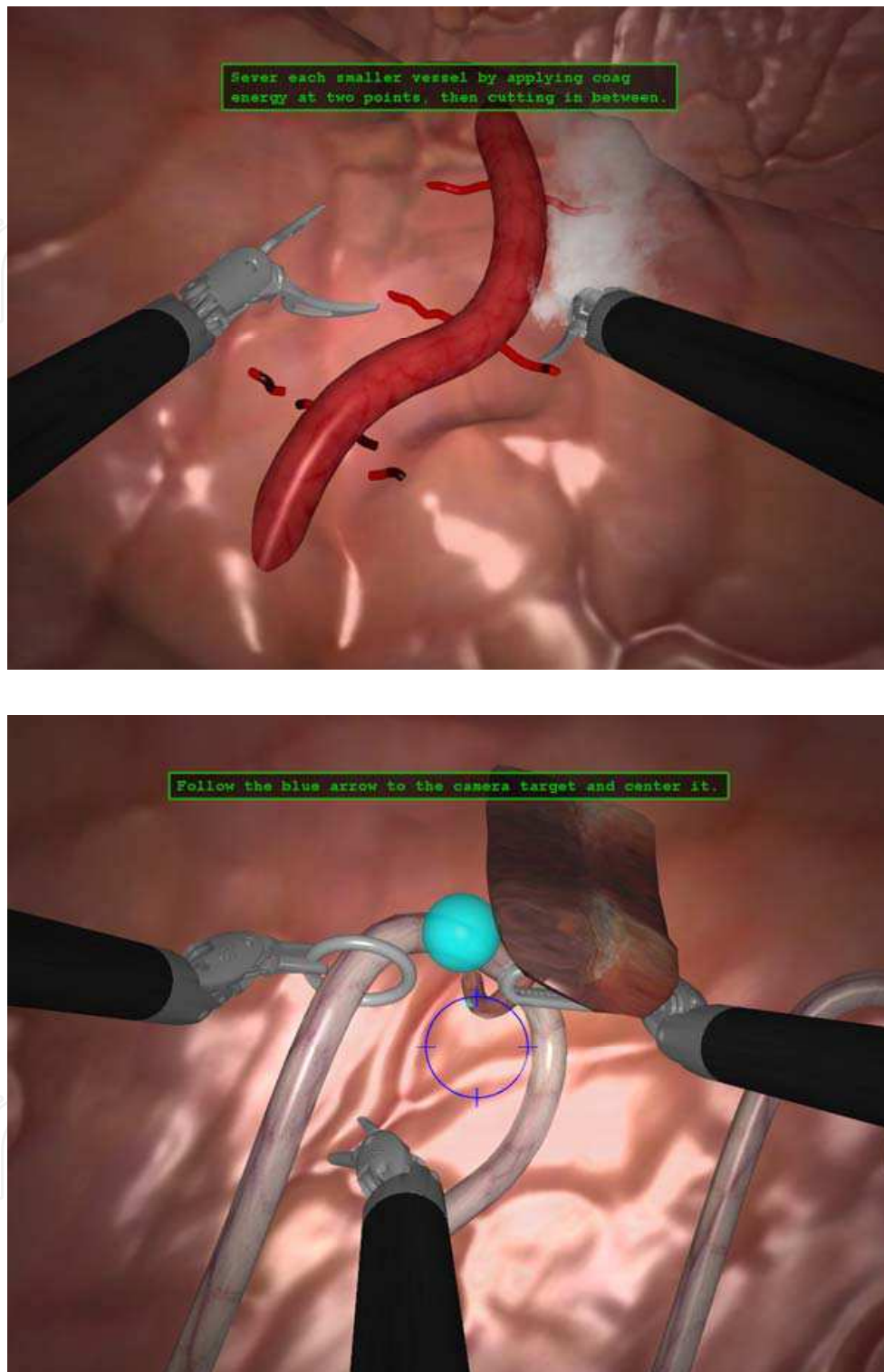


Fig. 1. **The Mimic Technologies dV-Trainer™ Simulator for Robotic Surgery** is designed to allow surgeons to practice the mechanical skills needed to operate Intuitive Surgical's *da Vinci*® robotic surgery system, including manipulating instruments and needles. Images courtesy of Jeff Berkley, PhD; copyright 2012, Mimic Technologies, Inc.

system that provides a realistic representation of the *da Vinci* experience, including Intuitive's EndoWrist™ instruments, foot pedals, and robot kinematics. The system includes a comprehensive set of metrics, MScore™, by which trainees can track their progress (dV-Trainer-Skills Training for Robotic Surgery, December 15 2011, <http://www.mimic.ws/products/>). The face, content, construct, and concurrent validity of the dV-Trainer have been confirmed in several studies (Lerner *et al.*, 2010; Kenney *et al.*, 2009).

Brown *et al.* have developed a virtual environment in which real surgical tools mounted on trackers can be used to interact with and manipulate models of tissue. The software system, which integrates a deformable object simulator, a tool simulator, and a collision-detection module, has been applied as a microsurgery simulator that allows trainees to practice suturing blood vessels. The microsurgery simulator demonstrates novel features of the software system that will make further applications of this software valuable in simulating additional skills and, potentially, procedures (Brown *et al.*, 2010).

Other research has focused on improving the software required for accurate virtual representation of skin. Lapeer *et al.* conducted a number of experiments with the aim of developing a deformable soft-tissue model that responds in real time to user manipulation. Tensile stress tests were carried out on human skin samples, and the resulting data were incorporated into a hyperelastic computer model. Ultimately this lab anticipates coupling the software with a haptic feedback device to create a real-time plastic surgery simulation in an interactive virtual environment (Lapeer *et al.*, 2010). Alteration of the geometry and topology of skin is central to plastic surgery; another new simulator accurately models these changes in response to surgical intervention. Sifakis *et al.* have used finite-element modeling to create a comprehensive real-time virtual surgical environment, enabling the surgeon to practice tissue cutting and manipulation. With incision, retraction, and suturing tools, trainees can practice current techniques for closing defects, while experts can experiment with and assess the efficacy of new techniques (Sifakis *et al.*, 2009).

Though many surgical skills are taught during general surgery residencies, there remain skills specific to plastic surgery that could benefit from simulation. By applying the ACS's plan for integrating simulation into curricula to plastic surgery, we can address those skills in a safe, efficient, and effective training environment.

4.2 Phase 2- Procedure training

In procedure training, there are many applications for plastic surgery-specific simulation. In post-graduate years 3, 4 and 5, competency in several procedures is expected of plastic surgery residents. Table 3 outlines these procedures, as defined by the Accreditation Council for Graduate Medical Education.

In 2008 the American College of Academic Plastic Surgeons (ACAPS) established an *Ad Hoc* Committee on Virtual Reality and Simulation for Plastic Surgery Education. The goal of this committee is to adapt virtual reality technology to standardize teaching, specifically with respect to procedures in four main areas of expertise: craniofacial, reconstructive, cosmetic and hand surgery. Cognitive task analysis, defined as "the process of deconstructing an expert's knowledge of a task and adapting it to the needs of the educational model," can be used to break procedures into steps weighted according to their relevance to outcomes, which can then become the basis of a computer simulation (Grunwald *et al.*, 2004). Cognitive

task analysis has been demonstrated to be an effective training tool; one study showed that residents who had received a curriculum based on cognitive task analysis for flexor tendon repair were better equipped to make appropriate surgical decisions than those who had not received such training (Luker *et al.*, 2008).

PGY3	PGY4	PGY5
-Metacarpal fracture	-Mandible fracture	-Rhinoplasty
-Skin graft	-Tissue expander/implant	-Cleft palate repair
-Z-plasty	-Pressure ulcer coverage	-Cleft lip repair
-Harvest of iliac crest bone graft	-Microtia	-Iliac bone graft
-Extensor tendon repair	-Flexor tendor repair	-Face lift
-Excision of skin malignancy	-Abdominoplasty	-Otoplasty
-Local flap coverage of soft-tissue defect	-Breast augmentation	-Blepharoplasty
	-Reduction mammoplasty	-Lower extremity coverage
		-Autologous breast reconstruction

Table 3. **Procedures required of plastic surgery residents in post-graduate years 3, 4 and 5.** Table from Rosen, J.M., Long, S. A., McGrath, D. M., & Greer, S. E. (2009). Simulation in plastic surgery training and education: the path forward. Plastic and Reconstructive Surgery, Vol. 123, No. 2, (Feb 2009), pp. (729-740), 1529-4242. Reprinted with permission.

Several simulators that model plastic surgery procedures are currently available. BioDigital has partnered with SmileTrain to develop a cleft lip simulator that can be run on a standard PC or laptop (Figure 2). Their simulator, which uses data from CT scans to model unilateral or bilateral cleft lips, allows the user to navigate the anatomy and explore each layer of tissue. The user is also able to create and transpose tissue flaps, as the computer can accurately model tissue properties (Oliker and Cutting, 2005). BioDigital’s Cleft Lip and Palate simulator is currently available for download as a beta version (SmileTrain Cleft Lip and Palate Viewer, December 15 2011, <http://www.biodigital.com/smiletrain/download.htm>).

BioDigital’s simulators for other specialized procedures include a simulator for latissimus dorsi myocutaneous flap with tissue expander for breast reconstruction following mastectomy. Their newest and most comprehensive product, the BioDigital Human, was released in 2011. This simulator models the full human anatomy and also incorporates motion (a beating heart) and biomechanics (a golf swing). It can now be run directly from the web from any computer. Sample images are shown in Figure 3, although this product is best viewed interactively on the website (BioDigital Human, December 15 2011, <http://www.biodigitalhuman.com>).

BioDigital has also developed a library of animations, which are highly realistic, non-interactive computer models that illustrate procedures for educational purposes. Table 4 presents the procedures for which BioDigital has already built animations.

Joseph McCarthy, MD, professor of plastic surgery at the NYU Langone Medical Center, has spearheaded the creation of the Interactive Craniofacial Surgical Atlas, a collection of simulators ranging from a frontal orbital advancement simulator to the Le Fort III

advancement/distraction simulator. The computer simulations are supplemented with features such as videos of live surgeries, audio voiceover animations, and 3D visualization to better illustrate the procedure and facilitate learning. (Flores et al., 2010, Parts I and II.)

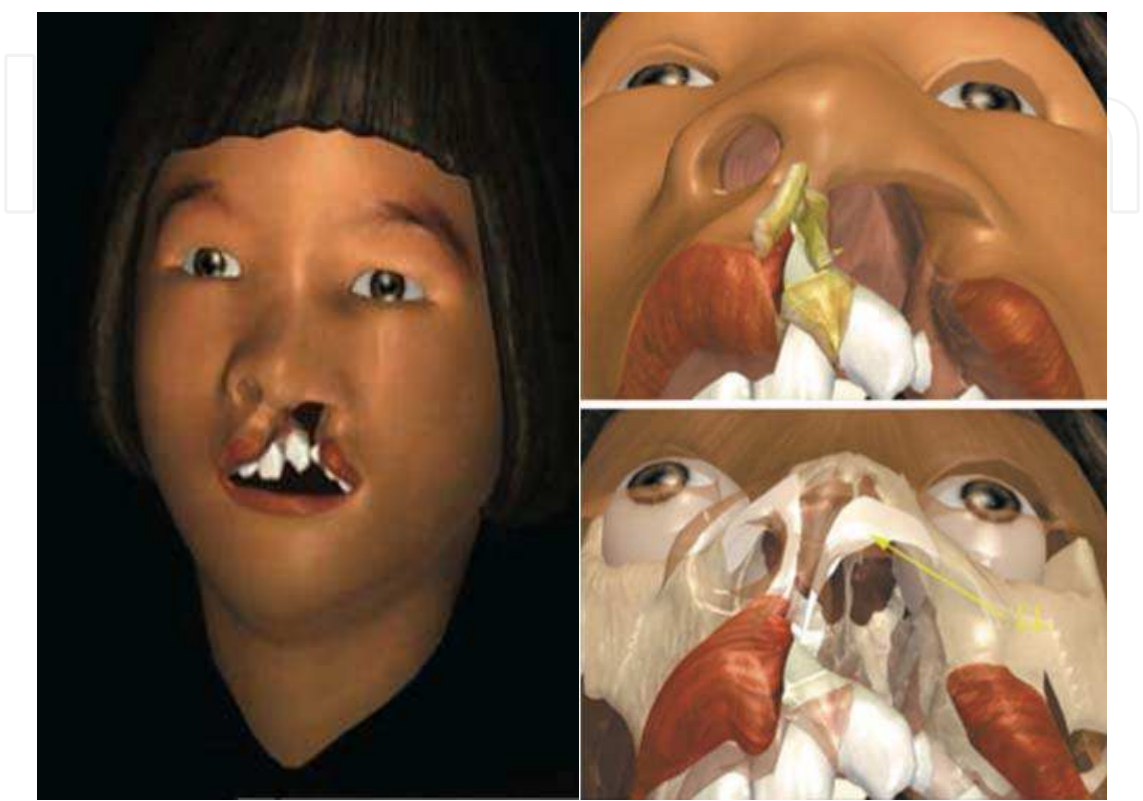


Fig. 2. (left). BioDigital/SmileTrain; Cleft Lip Simulator Image. (right). 3D graphic animations to illustrate cleft lip and palate surgery. Courtesy of SmileTrain, Court Cutting, MD, and BioDigital Systems, LLC. Copyright 2012 BioDigital Systems.

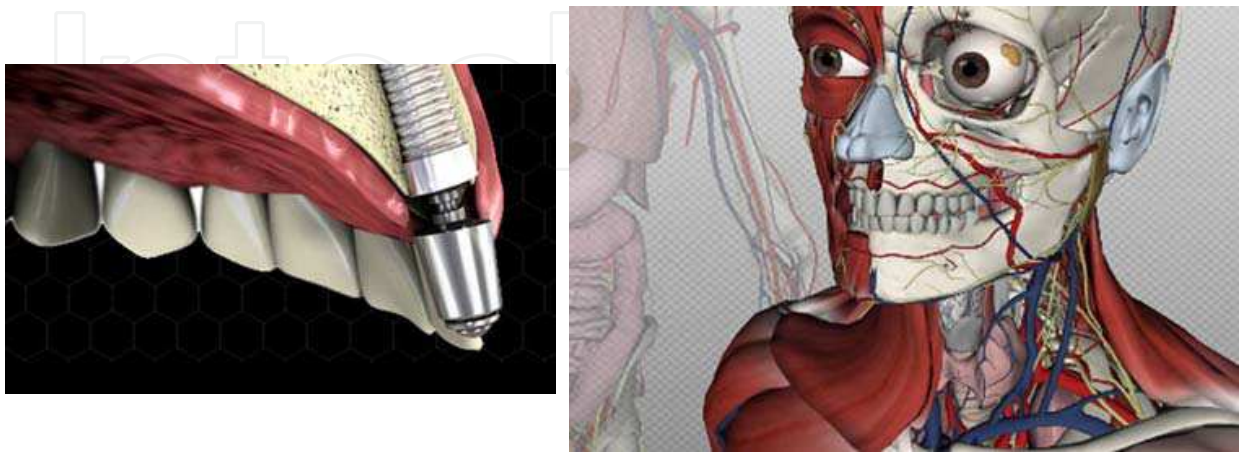


Fig. 3. BioDigital human 3D animated simulator. Images of mouth anatomy with implant and craniofacial anatomy. Courtesy of BioDigital Systems, LLC. Copyright 2012 BioDigital Systems.

SimQuest has recently developed the first platform for simulation of open surgical procedures (as opposed to the relatively more simple laparoscopic procedures). Their SurgSim Trainers will offer an anatomically precise model of tissue and tissue behavior, which can be manipulated with real surgical instruments attached to a haptics interface. The platform will also allow for trainers to create scenarios and content specific to their needs (Simquest SurgSim Trainers, December 15 2011, <http://www.simquest.com/opensurgery.html>).

Condition	Animated Procedure	
Genoplasty	Genoplasty-Sliding	
Prognathia	Bilateral Saggital Split Osteotomy	
	Vertical Ramus Osteotomy	
Micrognathia	Mandibular Distraction	V-Vector
		H-Vector
		O-Vector
TMJ Ankylosis	Transport Distraction	
Maxillary Hypoplasia	Le Fort I	
Midface Hypoplasia	Le Fort III	
Upper 2/3 Hypoplasia	Monobloc	
Craniosynostosis	Cranial Vault/Frontal Orbital Advancement	
Breast Reconstruction	Pedicle TRAM Reconstruction	
	DIEP Flap Reconstruction	
	Latissimus Dorsi Flap Reconstruction	
	Free TRAM Reconstruction	
	Tissue Expander	

Table 4. **BioDigital has completed animations for these plastic surgery procedures.**
Courtesy of BioDigital Systems, LLC. Copyright 2012 BioDigital Systems.

Simulation has been applied as a useful tool for minor, office-based procedures. In one approach to hybrid simulation, Kneebone *et al.* combined an inanimate mechanical model with a human actor posing as a patient to integrate the teaching (and practice) of technical and non-technical skills. Trainees interacted with the patient actor as they performed a procedure on the anatomical model, which was positioned over the actor to maximize realism. Initial trials indicated that covering the junction between patient and model with a simple drape offered a surprisingly high level of realism (Kneebone *et al.*, 2010).

Schendel and Lane designed the Patient-Specific Anatomic Reconstruction (PSAR), a fusion of CT, MRI, and surface-image scans combined with relevant biomechanical properties, which results in an anatomically valid 3D virtual patient that will help simulate the effects of surgical manipulation during procedures. The PSAR is intended for procedure planning, and could be a valuable addition to resident training (Schendel and Lane, 2009). In a similar vein, Kim *et al.* have developed a novel template-based facial muscle prediction program for computationally efficient simulation of soft-tissue deformation following surgery (Kim *et al.*, 2010). Such advances will increase the potential for high-fidelity simulations required for teaching more nuanced, subtle procedures.

4.3 Phase 3- Team training

In addition to proficiency in surgical skills and procedures, the success of an operation depends on organized and coordinated teamwork among all participants involved. The third and final phase in ACS's strategy introduces simulators to team training. In a team that may include a senior surgeon, a resident, a scrub nurse, a circulating nurse, and an anesthesiologist, efficient teamwork can help avoid medical errors while elevating staff morale. Simulation is now beginning to be recognized as a valuable tool for improving communication, leadership, and distribution of work in various areas of medicine. As surgical teams are often multi-disciplinary, the priorities and considerations of team training are quite similar across specialties. As such, the success of simulators in team training within one field of medicine is predictive of similar success within the realm of plastic surgery.

The simulators currently in use for team training primarily employ patient mannequins or live actors. Gaba *et al.* have developed the Anesthesia Crisis Resource Management (ACRM), which is based on aviation's Crew Resource Management training of cockpit teams. Emphasizing decision-making and teamwork principles, the ACRM curriculum advances mannequin-based patient simulators and has resulted in more realistic anesthesia training (Gaba *et al.*, 2001). Recently the ACRM program has been adapted for *in situ* simulation training for otolaryngology teams at Children's Hospital Boston (Volk *et al.*, 2011). While the ACRM curriculum appears to be effective in team training, there remains a need for objective, measurable indicators of team performance. Mica Endsley developed the Situation Awareness Global Assessment Technique (SAGAT) to fill this void (Endsley, 2000). Situational awareness, defined by Hogan *et al.* as "the perception of elements in the environment...the comprehension of their meaning, and the projections of their status in the near future," is a crucial dimension of performance (Hogan *et al.*, 2006). Using SAGAT, educators can "freeze" simulated actions in the middle of procedures to assess, debrief, and ask participants about their perceptions and comprehension. This method of assessment is more direct than traditional checklists, which can only infer data from participants' actions or secondary measures. This technique has been applied to many fields of medicine, from trauma life support (Hogan *et al.*, 2006) to otolaryngology (Volk *et al.*, 2011).

TeamSTEPPS, the product of collaboration between the Agency for Healthcare Research and Quality (AHRQ) and the US Department of Defense, is a relatively new multimedia curriculum designed to improve teamwork and communication. Standing for Team Strategies and Tools to Enhance Performance and Patient Safety, TeamSTEPPS offers a flexible, evidence-based toolkit with four key areas of competency: leadership, situation monitoring, mutual support, and communication (Clancy and Tornberg, 2007). Recently, Riley *et al.* presented a study in which perinatal morbidity at one community hospital decreased by 37% following a didactic TeamSTEPPS program with several simulation sessions. In contrast, a second hospital receiving no training intervention and a third that received only the didactic program both showed no improvement. This study is among the first to demonstrate a positive correlation between simulation training and patient outcomes (Riley *et al.*, 2011). Since the initial release of TeamSTEPPS, AHRQ and the Department of Defense have teamed with the American Institutes for Research to create a training and support network called the National Implementation of TeamSTEPPS project (Agency for Healthcare Research and Quality, December 16 2011, <http://teamstepps.ahrq.gov/>).

Currently, investigators under Eugene Santos at Dartmouth's Thayer School of Engineering are involved in research aimed at enhancing communication and ensuring patient safety. The goal is to develop a computational team-training simulation that will seamlessly monitor medical operations (Santos *et al.*, 2011). Santos's team is using Bayesian Knowledge Bases (BKB) to simulate clinical decision-making prior to, during, and after surgical interventions, with the goal of detecting and alerting the team of any discrepancies. By measuring gaps in perception between physicians, nurses, and patients, errors caused by miscommunication and misaligned intent can be predicted and thus avoided. To analyze how accurately the simulations predict participants' decisions, BKBs have been built to model completed medical procedures. One such scenario involved a case in which the plastic surgeon and general surgeon had different understandings of the procedure to be done (whether a simple or subcutaneous mastectomy), and the patient's nipple was mistakenly discarded. In another case, a patient underwent a circumferential panniculectomy in which both a plastic surgeon and a general surgeon were involved. Once home, the patient experienced significant pain at the site of the surgery. Disagreement between the plastic and general surgeons over readmission versus home care was not resolved, and as a result diagnosis of the infected wound was delayed by several days. This case introduces another layer of complexity, in that the patient's condition is dynamic within the timeframe of interest. By integrating gap analysis and intent inferencing, the Santos team hopes to contribute to team training in health care by supplying individuals involved in complex situations the targeted information that will help them make the best decision for the patient (Santos *et al.*, In press).

5. Looking to the future

The American College of Surgeon's initiative to integrate simulation into general residency programs is an excellent demonstration of the recognized power of the technology. Accordingly, this paper proposes that Plastic Surgery follow their model. But this is just the beginning. Simulation has the power to change not merely education, but the entire paradigm of health care delivery. In order to take advantage of its full potential, it is essential to regard simulation as an environment in which the provider understands the disease process and life cycle of the patient, dealing with interruptions in health as they arise. In 1910 Flexner redefined the contract of service between physicians and society with his modifications to the education system. Today, we have the opportunity to reinstate this contract using information technology, namely simulation, applied from research to education to service. This change is not to be seen as an addition to our current system, but as in 1910, a fundamental transformation of the process, delivery, and business of medicine. In this new model of health care, the patient and provider will exist in a mobile, flexible network.

The paradigm shift will start in medical schools, with an integrated curriculum that features a more natural relationship between what is learned in medical schools and the delivery of care. As simulators are being used as training tools in residency and beyond, so too should they be used in medical school. The University of Central Florida College of Medicine, established in 2006, boasts a fully integrated curriculum in which web portals, immersive experiences, and computerized cases demonstrate the school's commitment to innovative technology. Students are assigned virtual families to follow through four years of medical school – just one example of simulation's role in the UCF curriculum. In the future, it is likely that more medical schools will follow the example set by UCF and will incorporate simulation heavily into their programs.

Outside of education, simulation can also help on a larger scale both nationally and internationally. At the population level, integrated large-scale simulation can be an epidemiological tool to anticipate the spread of a disease. Such a model could have been instrumental during 2010-2011 in containing the cholera outbreak in Haiti. At the level of the individual, simulation can facilitate a model of a human body that will predict the effect of a new medication or the combinations of treatments on a patient. Work toward this end has already begun in the placement of abdominal aortic aneurysm grafts by M2S, Medical Data and Image Management Services. The company can make patient-specific models of anatomical parts to predict the success of endovascular grafts (Medical data and image management services, access date: December 16 2011. <http://www.m2s.com/>). In the future, we will be able to include genetic markers in these models to anticipate susceptibility to disease based on individuals' genomes (Figure 4). Electronic medical records may soon include virtual patient holomers and behavioral models to assist physicians in following patient lifecycles (Satava, 2011).

Simulation will facilitate the transition from a past-oriented to a future-focused health care system. Today, evidence-based medicine (EBM) is seen as a standard to strive for, yet in its quest to extract information from completed interventions, EBM is rooted in the past. With simulation, we can predict, prepare for, and plan the future on the level of the cell, the body, or the population and with regard to physical, behavioral, and genetic response. Figure 4 displays the range over which simulation will one day have predictive power.

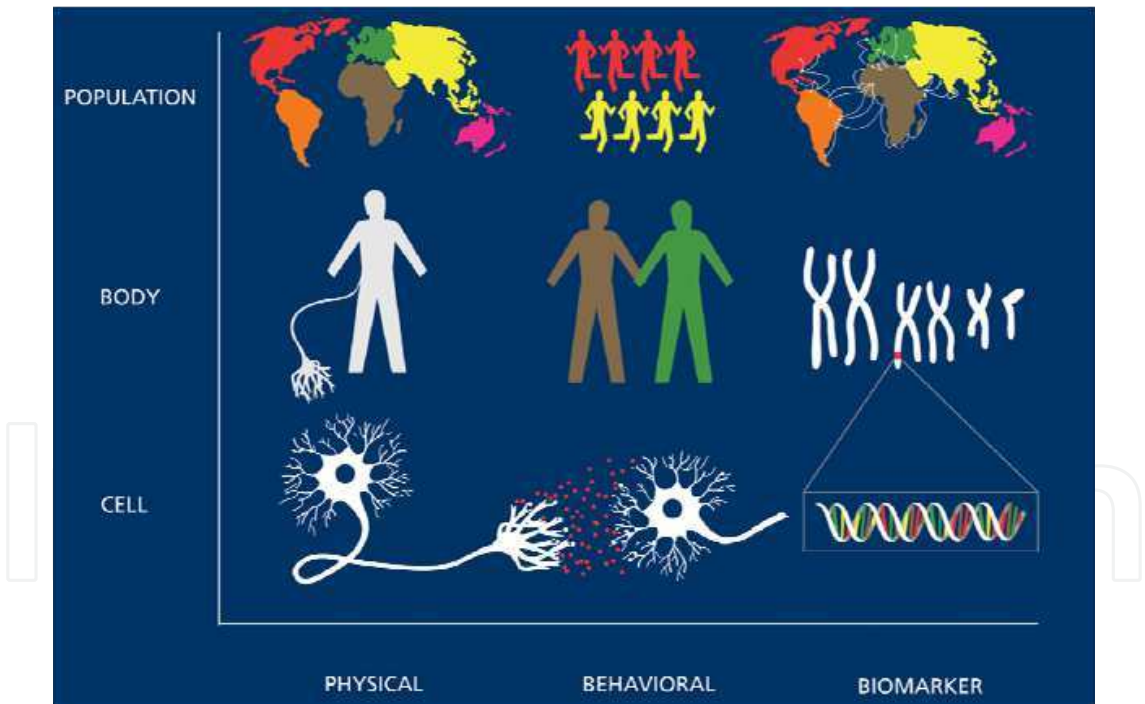


Fig. 4. **Physical-Behavioral-Genomics Model.** Dr. Joseph Rosen and colleagues are developing a model that would contain data on the physical body, behavior, and genetic information of an individual. This model could potentially include a person's cells, tissues and organs, vital signs, biomechanics, physiology, behavior and genetic traits, and link to epidemiological data of the population. It is hoped that such a model will simulate and predict the individual's behavior and health. Image courtesy of Joseph Rosen, MD, copyright 2012, used with permission.

Simulation will be instrumental in shifting health care from a platform-based to a network-based structure, in which the provider is removed from the patient and thus convenience, accessibility, and pathogen control are increased. A key role of simulation will be training physicians to practice in an increasingly digital world. When a new technology like a robotic surgical assistant is developed, there is initially an understandable shortage of experts. In the absence of experts, the apprenticeship model of training breaks down. A virtual expert must be simulated and built into or alongside the new device. Similarly, when distributing current technology to rural or underdeveloped areas, there may be no one to fill the role of expert *in situ*. The device then must act as the expert, training novices to competency through simulation (Aggarwal *et al.*, 2010). The idea that technology itself can instruct the trainee on its use opens the door to training at the point of care. Inclusion of the expert within the technology may enable a shift in the time, in addition to the manner, of medical education.

The US Army's combat philosophy of "train as you fight" can be applied to medicine as simulators become capable of turning surgical instruments into performance machines, providing targeted, organized, accessible information to surgeons as they operate. The recently launched Plastic Surgery Education Network website has the potential to move in this direction; already it demonstrates a centralization of relevant information specific to the plastic surgeon. With the proper organization and user interface, such a website could become a tool inside the operating room, walking a surgeon through a procedure with spoken instruction. While it may sound far-fetched and unrealistic to rely on a "train as you fight" model in medicine, the automated external defibrillator (AED) is a shining example of point-of-care training with enormous success. AEDs are designed to be used by non-medical personnel (i.e., first-time users with minimal training). All AEDs approved in the US have spoken prompts to instruct the user on how to safely deliver electric charges in order to restore a regular heartbeat in a patient, and many also include visual displays. Most models record the patient's ECG data, along with the number and strength of the shocks delivered. This information can be downloaded to a computer after the event to debrief responders and assess the efficacy of the device.

As simulators continue to be incorporated across medicine, they will become more advanced, more powerful, and more realistic. The training environment will become a closer replication of the actual environment until, eventually, the simulation is indistinguishable from reality and passes the "Virtual Turing Test". Introduced by Alan Turing in 1950, the Turing Test is a measure of a machine's ability to imitate human behavior. A human judge engages in a conversation with two hidden "partners", one human and one machine. If the judge cannot correctly identify the computer, the computer is said to have passed the Turing test (Turing, 1950). See Figure 5.

Low-fidelity simulators will continue to be useful for novices looking to practice generic skills, but experts will benefit from hyper-realistic models capable of accurately representing nuances of a procedure, from tissue interactions to potential complications. (Aggarwal *et al.*, 2010). See Figure 6.

Modern innovation needs to prepare physicians for the future, not the past. In order to train physicians today, we need to anticipate how medicine will look in thirty years. As the best way to predict the future is to invent it, our focus today should be on using simulation to

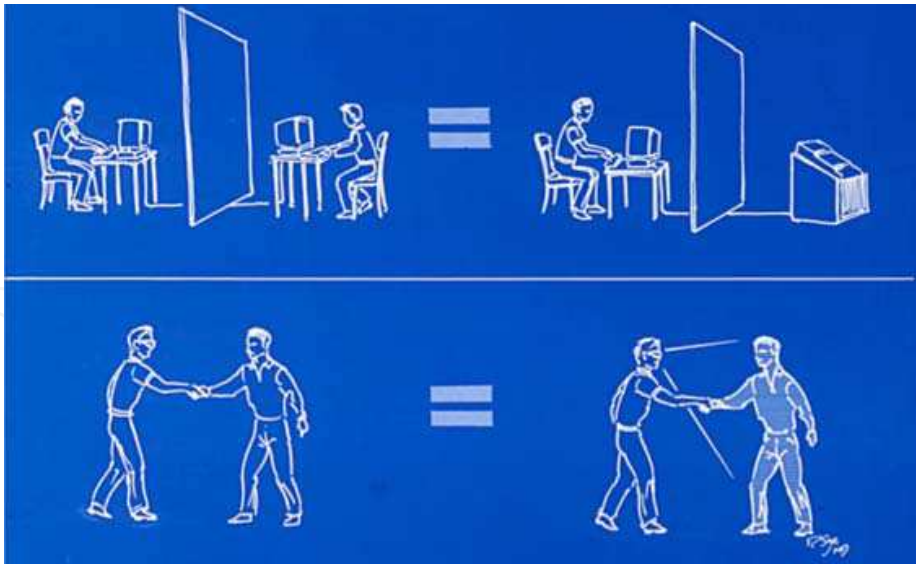


Fig. 5. **Virtual Turing Test.** A human observer (seated at left in each diagram in the top row) engages in a conversation with two hidden “partners”, one human and one machine. If the human judge cannot correctly identify the computer, the computer is said to have passed the Turing Test (Turing, 1950). Image courtesy of Joseph Rosen, MD, copyright 2012, used with permission.

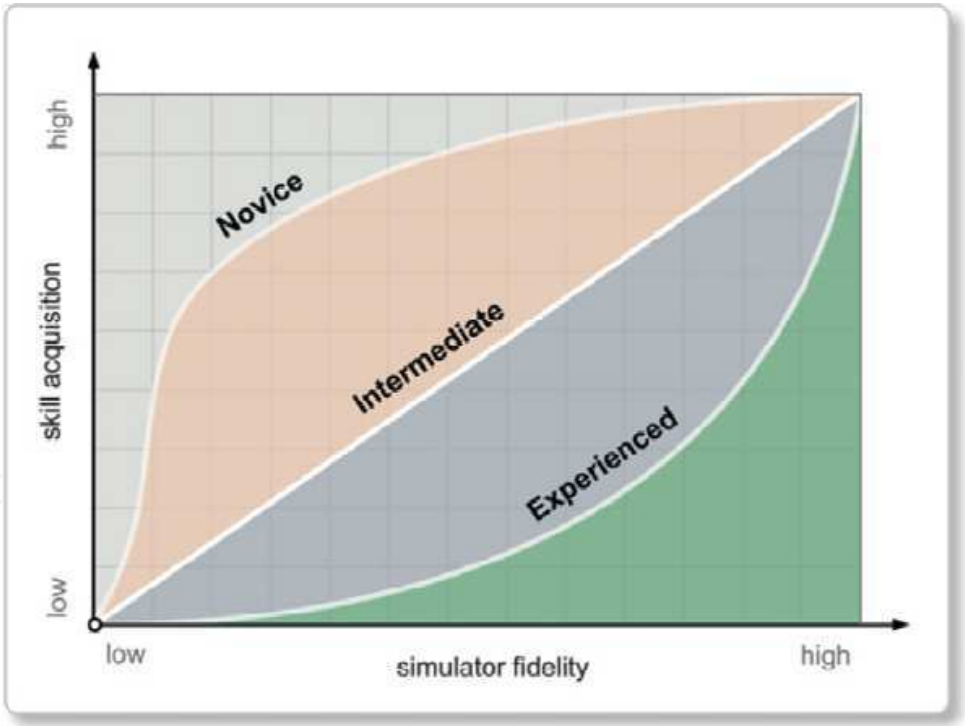


Fig. 6. **Relationship between fidelity of simulator and acquisition of skill at three levels of expertise.** Novices experience the most rapid skill acquisition at a lower level of fidelity, while experts require high fidelity simulators to improve their skills. Reproduced from [Quality and Safety in Health Care, Aggarwal, R., Mytton, O. T., Derbrew, M., Hananel, D., Heydenburg, M., Issenberg, B., MacAulay, C., Mancini, M., Morimoto, T., Soper, N., Ziv, A., & Reznick, R.Vol. 19, Suppl 2, pp. (i34-i43), 1475-3898, Copyright 2010] with permission from BMJ Publishing Group Ltd.

move towards a more functional, less expensive, network-based health care system rooted in telemedicine. By implementing simulation, we can shape a future of medicine in which patients are safe, education is cost-efficient and time-efficient, and the right care is delivered at the right time in the right place.

6. Conclusion

The American College of Surgeons has outlined a proactive and comprehensive plan to improve general surgery training with simulation in three phases: skills training, procedure training, and team training. In this paper, we have proposed to adapt this three-phase strategy for plastic surgery residency, modifying it to address challenges specific to the field. Already, considerable simulation technology exists to augment plastic surgery training at all levels. What is still needed is a unified commitment by medical educators to use simulation to simultaneously standardize the training curriculum, individualize the method of acquiring information, and objectively evaluate the training process. This methodology need not be restricted to residency; simulation has a role to play in medical education from the undergraduate level to the senior physician's maintenance of certification. The incorporation of innovative technology into today's curriculum will be an essential step in not only preparing for the future, but shaping it as well.

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Plastic surgery continues to be a rapidly growing field in medicine. There have been multiple recent advancements in the field. Specifically, there has been a continuously growing interest in fat grafting, body contouring, minimally invasive surgery, and plastic surgery education. At the same time, there have been continued advances and modifications in surgical techniques, which translate into better and improved results for our patients while increasing safety and efficacy. The title of the book is Current Concepts in Plastic Surgery and, as such, it highlights some of the "hot topics" in recent years. We have invited renowned specialists from around the world to share their valued expertise and experience. Most of the chapters will expose the reader to multiple techniques for achieving desired results, with emphasis on the author's preferred methodology.

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51000 Rijeka, Croatia
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Unit 405, Office Block, Hotel Equatorial Shanghai
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Phone: +86-21-62489820
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