Review Articles

Sawbones laboratory in orthopedic surgical training

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ABSTRACT

عظام المنشار هي عظام صناعية تشبه في تركيبها وخصائصها الفيزيائية عظم الإنسان. إن إدخال معامل عظام المنشار في برامج تدريب جراحة العظام قد أضاف مرونة في تدريس الأطباء المقيمين تتماشى مع ساعات عملهم المضغوطة. هذا البحث يلقي الضوء على آلية تدريب المحاكاة بإستخدام عظام المنشار لإنماء مهارات الأطباء المتدربين في جراحة العظام. كما يستعرض البحث دور هذا النوع من العظام في تدريس وتقييم آداء الجراحين المتدربين. أيضاً يناقش البحث مدى صلاحية تدريب المحاكاة باستخدام عظام المنشار لرفع كفاءة متدربي جراحة العظام. وأخيراً سوف نطرح توصيات مستقبلية لتطوير التدريب بالمحاكاة باستخدام عظام المنشار في برامج تدريب جراحة العظام.

Sawbones are artificial bones designed to simulate the bone architecture, as well as the bone's physical properties. The incorporation of sawbones simulation laboratories in many orthopedic training programs has provided the residents with flexibility in learning and scheduling that align with their working hour limitations. This review paper deliberates the organization of sawbones simulation in orthopedic surgical training to enhance trainee's future learning. In addition, it explores the implications of sawbones simulation in orthopedic surgical teaching and evaluation. It scrutinizes the suitability of practicing on sawbones at the simulation laboratory to improve orthopedic trainee's learning. This will be followed with recommendations for future enhancement of sawbones simulation-based learning in orthopedic surgical training.

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Traditional surgical education was embedded in the master-apprentice model, in which senior staff taught trainees with the involvement of patients.[1] The rapid evolution of surgical techniques and the changes in healthcare system uncovered important limitations to the previous teaching model. These include limited surgical time, increased costs, and concerns pertaining to patient safety, which may limit a learner's experience.[2] While hospital administrators accentuate the efficient use of surgical time, traditional training dictates the surgeons to concurrently teach trainees in the operating room while performing safe surgery within a limited timeframe. Furthermore, the higher costs of the sterilized surgical equipment in the operating room in comparison with the simulation laboratories restrict the margin of error for trainees. Besides, increasing surgical time to accommodate orthopedic resident's training may expose the patient to unnecessary risk of complications, such as infection and thromboembolism.[3,4] As a result, modern orthopedic trainees face the challenge of acquiring more complex and diverse surgical skills compared with their predecessors, and must do so in less time.[5] Moreover, the restrictions of available working hours for surgical resident to enhance their safety have resulted in reduced direct surgical exposure and training time.[6] The incorporation of surgical simulation laboratories in many orthopedic training programs has provided the residents with flexibility in learning and scheduling that aligns with their working hour limitations.[7] Sawbones, or composite bone models, are artificial bones designed to simulate the bone architecture, as well as the bone's physical properties. The basic components of the sawbones are plastics and epoxies.[8] They are increasingly used in orthopedic biomechanics research and surgical education-applications that traditionally relied on cadavers. Although the cadaveric models are the gold standard simulators, they suffer from major drawbacks, including the risk of disease transmission, high cost, and prolonged preparation time, all of which affect their availability in education centers.[9] Furthermore, cadaveric samples disproportionately represent the elderly population whose bone quality may not be representative of most of the orthopedic population.[10] The purposes of this review are to discuss the organization of sawbones simulation in orthopedic surgical training to enhance trainee's future learning; explore the implications of sawbones simulation in orthopedic surgical teaching and evaluation; scrutinize the suitability of practicing on sawbones at the simulation laboratory to improve orthopedic trainee learning; and to propose some recommendations for future enhancement of sawbones simulation-based learning in orthopedic surgical training.

The organization of sawbones simulation. Throughout the last decade, several orthopedic surgical training programs established surgical skills laboratories to enhance their orthopedic trainees' future learning. Moreover, orthopedic associations all over the world have introduced many hands-on courses and workshops to expose learners to the available tools and new techniques for the management of orthopedic cases. The previous learning modalities allowed trainees to practice basic surgical skills in a risk-free, low-stress atmosphere, thereby affording the trainees the opportunity to become familiar with different surgical approaches before performing them on patients in the operating room.[11] Practicing on sawbones became a major component of laboratory-based education and hands-on orthopedic workshops. The ability of the sawbones to represent anatomical details of each bone of the human body encouraged orthopedic instructors to incorporate them into surgical teaching. Furthermore, the availability of multiple vendors of the synthetic bones reduced both costs and efforts involved in setting up the sawbones training sessions at the simulation centers. In the past, the instructor had to struggle with the construction of each sawbones learning station, which was time- and effort-intensive. Competition between providers led to manpower and financial support to orthopedic learning centers to launch the sawbones simulation training.

The educational level of the learning has a substantial impact on the organization of the sawbones learning station in the orthopedic skill laboratory. Medical student and junior orthopedic resident classes are focused on basic orthopedic knowledge and surgical skills. For instance, instructors allocate different human body parts at each sawbones station with labels attached to the anatomical landmark to enhance junior learners' knowledge. As the learner progress in training, there is an increase in the level of complexity of the sawbones' activities. For example, in order to challenge the learners, the anatomical landmarks in each sawbones may no longer be labelled. In addition, the sawbones utilized at this stage of learning have artificial soft tissue coverage that requires dissection to identify the underling bone structure or fracture location. The aforementioned approach to the organization of the skill laboratory is aligned with Guadagnoli et al[12] and their challenge point framework (CPF). The framework demonstrated that appropriate cognitive and physical challenges must be provided for optimal learning to take place. This framework showed consistent enhancement of long-term learning through exposing the learners to short-term stress and failure.[12]

Battig[13] described the contextual interference effect (or intra-task interference) as a condition resulting from training on a variety of tasks within the framework of a single practice setting. Practice under conditions of high degree contextual interference, such as random practice enhances learning retention and future transfer.[14] However, instructors should consider appropriate levels of contextual interference when planning the sawbones simulation-based training. Guadagnoli and Lee[15] suggested applying random practice for teaching simple tasks, or for fine-tuning a well-practiced skill. On the other hand, blocked practice is more beneficial for training on a complex task or learning a new skill.[15] Therefore, the organization of the sawbones laboratory should incorporate a higher level of contextual interference (such as, random practice) as the trainee progresses through the level of training. For instance, practicing a variety of skills on sawbones, such as fracture reduction, application of the plate, drilling, and insertion of the screw in random order would represent high contextual interference in comparison with practicing a single skill on a repetitive basis. The increase in level of cognitive challenge through appropriately higher levels of contextual interference will enhance trainee learning of the skill.

Implications in teaching and assessment. Sawbones offers several implications for orthopedic surgery training and assessment. Orthopedic instructors incorporate sawbones in teaching bone anatomy and underlying soft tissue (such as, muscles and ligaments) attachment. The active learning and transfer of the theoretical anatomy knowledge from the didactic lectures or textbooks into hands-on sawbones simulation laboratory augments trainee cognitive perception and reduces the extraneous load effect on trainee working memory.[16]

In addition, the orthopedic resident has the opportunity to practice different orthopedic surgical skills (such as, fracture reduction, drilling, plate fixation, and screw insertion) repeatedly on sawbones until a level of proficiency is achieved. Egol et al[17] studied the effect of orthopedic residents' participation in sawbones fracture fixation courses on their future performance on a simulated fracture fixation model. Their results showed that participation in sawbones surgical skills courses significantly improved practical operative skills as assessed by the objective structured assessment of technical skill (OSATS) system in simulation laboratory. The residents demonstrated positive enhancement to their long-term learning retention after 6 months of practicing sawbones fracture fixation.[17] Sonnadara et al[18] demonstrated that sawbones surgical skills courses can be highly effective at teaching and developing targeted basic surgical skills in orthopedic trainees. They compared a group of orthopedic interns who were given sawbones surgical skills laboratory courses for 30 days with another group exposed to standard orthopedic training. Pre-training OSATS standard checklist and global rating scale (GRS) scores were equivalent for both groups. Following a one-month skills training program, the scores were significantly higher in the laboratory-trained group compared with the standard training group on both the OSATS checklist and GRS.[18]

Joint aspiration is a common procedure in orthopedic surgery. Sawbones allowed the trainees to practice these procedures on multiple joints until they reached a comfortable level of performance without harming a patient in the process. Sterrett et al[19] investigated the influence of hand-on sawbones training on 141 medical trainees' in terms of their comfort level with performing various joints aspirations. Pre-training and 6 month post-training self-assessment surveys permitted the participants to rate their comfort level with joint aspiration on a scale of 1-5. Their conclusion revealed that using sawbones simulators is an effective method of improving comfort level with joint aspiration among participants from all levels of medical training.[19] Nevertheless, the ability of the trainees to transfer the surgical skills from the simulator into a true clinical setting would represent actual motor learning.[20] Several studies have consistently shown that individuals self-rate themselves with higher scores and in a more positive light than when rated by others.[21,22] Therefore, future studies are needed to explore the transfer of joint aspiration skills from sawbones simulators into real patients through the use of objective assessment tools. Arthroscopic training on a bench-top model is another potential educational use for sawbones in orthopedic surgery training programs. The bench model consists of synthetic bones covered with elastic foam to represent intra- and extra-articular joint structures. The literature discussed the impact of arthroscopic knee bench-top simulator training on the transfer of surgical trainee skills to the operating room. For instance, in a randomized study, Howells et al[23] scrutinized the effect of knee simulator training on the ability of surgical trainees to perform diagnostic knee arthroscopy in the operating room. The OSATS GRS was the major assessment method used in this trial. Results showed better performance by the simulator-trained group than the non-simulator-trained group.[23] However, the generalizability of their result is limited because of the poorly defined control group (non-simulator-trained) who didn not receive any training. The improvement of performance in the intervention group (simulator-trained) may be correlated to the additional training they received rather than the intervention, specifically arthroscopy simulation training.

A Miller pyramid was developed as a clinical assessment framework that could be applied in evaluating medical trainees in 4 major areas (knowledge, competence, performance, and action).[24] The base of this pyramid is supported by knowledge assessment (knows), while the top part is occupied by the evaluation of the physician action in their practice (does). Assessment of orthopedic trainee surgical skills through the use of sawbones simulation station in Objective Structured Clinical Examination (OSCE) falls within the trainee performance evaluation (shows how) in Miller's pyramid[24] (**Figure 1**). Synthetic bone models are advantageous devices for exploring the ability of the orthopedic trainee to "show how" to perform certain skills, such as fracture fixation technique in a simulated environment.

A national survey of 185 orthopedic surgery residency-training program directors revealed that 58% believed that improvement in surgical skills by orthopedic residents was not objectively measured in their training programs.[25] The introduction of validated assessment instruments into the evaluation of orthopedic trainee surgical skills enhanced the ability to measure the components of surgical competencies. Numerous assessment tools that incorporate task-specific checklists and global rating scales have been involved in the assessment of surgical skills in the sawbones simulation contexts. In addition, objective assessments through validated motion analysis tracking devices were integrated into the evaluation process. However, Leong et al[5] studied the construct, content, face, and predictive validity of sawbones simulation exercises in comparison with cadavers. Their results identified that composite bone model exercises were deficient in discriminating between novice and expert surgeons using an objective motion capture analysis and a modified OSATS GRS.[5]

An objective assessment instrument helps surgical trainees to understand their degree of improvement and recognize, which techniques they need in order

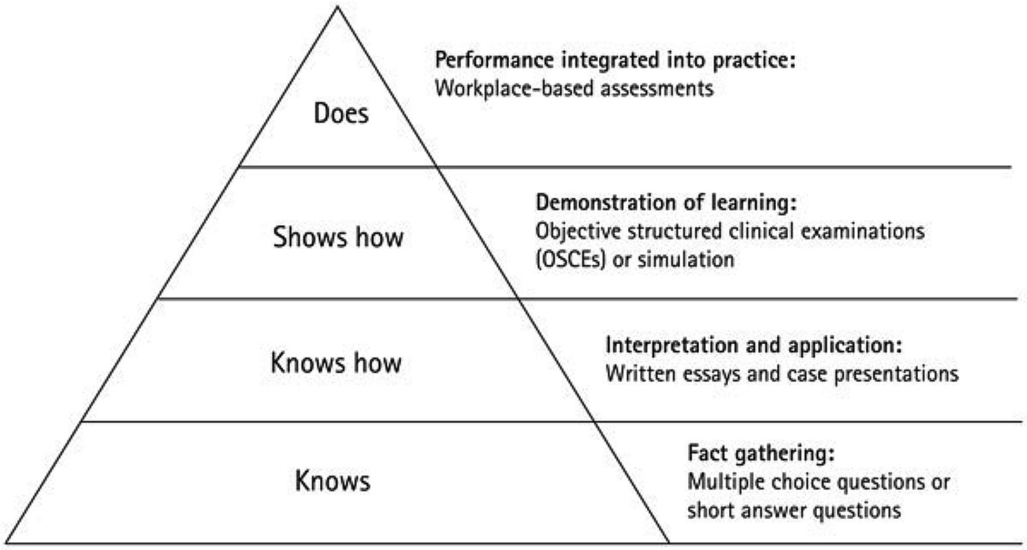

Figure 1 - Miller's Assessment Pyramid. Reproduced from: Kalsi HK, Kalsi JS, Fisher NL. An explanation of workplace-based assessments in postgraduate dental training and a review of the current literature. ***Br Dent J*** 2013; 215: 519-524. With permission from Nature Publishing Group.[24]

to enhance their performance. Several researchers have incorporated sawbones in the development of objective assessment instruments to evaluate orthopedic trainees' motor skills in the simulation laboratory and the operating room. For instance, Alvand et al[26] investigated the validity of GRS in the assessment of 19 orthopedic trainees during simulated sawbones arthroscopic knee meniscal repair. When compared using an objective assessment tool (motion analysis), an arthroscopic GRS showed construct validity (with similar result to the motion analysis) and excellent inter-rate reliability (Cronbach alpha 0.88).[26] Arthroscopic GRS offers a feasible method for monitoring an orthopedic resident's learning curve and has the potential for use as an assessment tool in the operating room.

Feasibility and acceptability. The latest generation of sawbones provides an accurate reproduction of the biomechanical features of human bone when placed under variable loads (such as, axial, torsional, and bending forces).[27] Moreover, it offers excellent representations of the bone's anatomical landmarks with comparable cortical wall thickness to the real bone. In addition, sawbones models are much cheaper than the cadaveric models and do not expose trainees to any diseases transmission risks. These models do not require the specialized storage or preparation procedures that are mandatory for the cadaveric samples. Sawbones biomechanical studies demonstrate marked reductions in inter-specimen variability compared with their cadaveric counterparts.[28] For these reasons, recent generations of sawbones represent a feasible and acceptable alternative to cadaveric specimens in orthopedic surgical education. Moreover, the built-in mentor and motion analysis assessment system in sawbones simulation helps protect faculty time.[29] Faculty involvement is limited to the approval of model setup and viewing of video recording of resident training to provide formative assessment and feedback.

In addition, orthopedic residents preferred practicing fracture fixation on sawbones rather than on the high fidelity virtual reality (VR) simulator. In a randomized trial of 22 orthopedic trainees, LeBlanc et al[30] investigated the feasibility and fidelity (environment, equipment, and psychological) of both sawbones and VR simulator through cost analysis and simulation fidelity questionnaire. Their result showed that sawbones had higher levels of fidelity and were significantly more cost effective than VR simulator.[30] Multiple factors could explain these results, including the realism of the instruments being used, the capability of using both hands simultaneously, and the ability to hear sounds as the fracture fixation is completed on sawbones. Furthermore, sawbones can present strong interactivity, which is an overriding factor that leads to its successful application in orthopedic surgical training. Thus, if sawbones can be integrated into the high fidelity VR simulator, which provide navigation in some complicated operations, such as arthroscopy, can be more suitable for minimal invasive training of orthopedic surgery.

Future directions. Although sawbones simulation-based training showed some improvements in orthopedic trainee motor skills learning, advanced directions could be applied to enhance future learning. These include the following: first, the instructor should clearly define the learning objectives for each training session through well-articulated identification of learners and simulation role, contexts, and logistics.[31] This approach helps to determine learning shortfalls based on the trainee's achievement, which supports the objective assessment process in simulation practice.

Second, engagement of the trainees in the learning activity must be a central focus during the sawbones simulation training.[32] The appropriate challenge level and variability of practice with gradual integration of the real operating room environment (such as, anaesthetic machine sound) would increase the authenticity of learning, and therefore, learner engagement.

Third, augmented feedback in the simulation laboratory should include modeling and observational learning, which enhance learner engagement and provide the opportunity to observe learner errors. Orthopedic programs should emphasize post-training augmented feedback, which provides better improvement in learning retention in comparison to pre-training.[33]

Fourth, the instructor should integrate well-structured debriefing, such as Rudolph et al's[34] 2007 debriefing with good judgment, as well as guided reflection to enhance trainee cognitive and professional development after sawbones training sessions. Debriefing with good judgment helps explore behaviors that reveal performance gaps and share these experiences to discover trainee mental models. Thus, instructors may close these gaps through pointed discussions and targeted instructions to enhance future performance. This process requires faculty involvement in development of courses to augment their debriefing skills.

Fifth, the evidence indicates that certain non-technical skills can enhance, or if lacking, contribute to deterioration of surgical trainees' technical performance.[35] We recommend incorporation of non-technical skills training (such as, communication, teamwork, and decision making) during sawbones simulation-based education. The teaching scheme should align with the learner's level of training to avoid excessive cognitive load on trainee working memory during technical skills learning in simulation laboratory. While the trainee progress in his level of technical skills, the non-tech skills add appropriate challenge that will augment his future learning.

In conclusion, sawbones simulation laboratories provide the residents with flexibility in learning that align with their working hour limitations. This review disclosed the constructive educational impacts of sawbones simulation in orthopedic surgical training. Future directions were discussed to enhance the applications of this learning opportunity.

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