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JAOA and AACOM

Teaching and Assessment of High-Velocity, Low-Amplitude Techniques for the Spine in Predoctoral Medical Education

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Although national didactic criteria have been set for predoctoral education and assessment in osteopathic manipulative treatment, there is no criterion standard for teaching methods and assessments of osteopathic manipulative treatment competence in colleges of osteopathic medicine. This issue is more pressing with the creation of the single graduate medical education accreditation system by the American Osteopathic Association and Accreditation Council for Graduate Medical Education, which introduced the creation of "osteopathic recognition" for residencies that want to incorporate osteopathic principles and practice into their programs. Residencies with osteopathic recognition may include both osteopathic and allopathic graduates. Increased standardization at the predoctoral level, however, is recommended as osteopathic principles and practice training applications are expanded. The objectives of this article are to review the standards for teaching osteopathic medical students high-velocity, low-amplitude (HVLA) techniques for the spine; to review and discuss the methods used to assess medical students' proficiency in using HVLA; and to propose baseline standards for teaching and assessing HVLA techniques among medical students.

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As of 2015, there were 96,954 practicing osteopathic physicians and 26,121 osteopathic medical students (25% of the medical student population) in the United States.[1,2] With the American Osteopathic Association (AOA) and Accreditation Council for Graduate Medical Education single graduate medical education accreditation system expected by 2020[3] comes a new designation of "osteopathic recognition." This designation will create the opportunity for not only osteopathic graduates to be trained in osteopathic manipulative treatment (OMT), but allopathic graduates as well. It should be expected that training in OMT will come under increased scrutiny. Consequently, there is a need to standardize the teaching and assessment methods of OMT competence throughout all 4 years of medical education and training.

The current article focuses on the need for standardization in educating and evaluating osteopathic medical students in high-velocity, low-amplitude (HVLA) techniques for the spine. High-velocity, low-amplitude spinal manipulation techniques are designed to restore motion to a joint exhibiting a restricted range of motion.[4,5] These techniques are indicated for a variety of conditions[6] but are most frequently used to treat low back and neck pain.[7] Evidence shows that spinal manipulation is as effective for these 2 conditions as other forms of treatment.[8,9] Although all OMT techniques carry some risk for adverse effects, HVLA is perceived to confer greater risk to patients, owing to the high-velocity thrust of this technique.[10] The risks to patients range from benign, self-limiting events (eg, soreness) to serious adverse events such as exacerbation of undiagnosed vertebrobasilar artery disorders. However, the vast majority of adverse events are the former, supporting the conclusion that the potential benefits of these techniques outweigh the possible risks.[11] The low likelihood of adverse events is one of the reasons why the AOA has recommended that OMT for the cervical spine, including HVLA, should be offered to patients with neck pain and taught to osteopathic medical students at all levels of education.[12]

For patients to reap the benefits of HVLA and be protected from possible adverse events, proper training and skill development of future osteopathic physicians are paramount.[4,10] High-velocity, low-amplitude techniques for the spine are taught at every US college of osteopathic medicine (COM), but the standards for teaching and assessing these skills are broad. The range in these standards makes it difficult to determine whether graduates of COMs have comparable levels of procedural skill acquisition when they enter residency programs.

The purpose of this article is to review the standards for teaching osteopathic medical students HVLA techniques for the spine, to review and discuss the methods used to assess medical students' proficiency in using these techniques, and to propose baseline standards for teaching and assessing HVLA techniques.

Current Predoctoral Teaching Standards for HVLA

As of 2015, 31 US COMs offered instruction at 44 locations in 29 states.[13] The Educational Council on Osteopathic Principles (ECOP) is a committee of the American Association of Colleges of Osteopathic Medicine (AACOM) consisting of osteopathic manipulative medicine (OMM) department chairs or their representatives from every US COM. Part of ECOP's mission is to develop consensus in the teaching of osteopathic principles and practice among the COMs. Although there is consensus among the COMs regarding national curricula, variability regarding demonstration styles, trainer-to-student ratios, and how and with whom students practice remains.

The Educational Council on Osteopathic Principles recommends that HVLA be taught in COMs and specifies regions of the body to which HVLA may be administered.[14] However, for HVLA, as for other OMT techniques, ECOP does not specify the number of lecture and laboratory hours per topic, the number of procedures a student must perform, or in what environment it must

be taught (eg, adjustable tables or observed execution by table trainer). These criteria are left to individual COMs.

Most osteopathic medical students are provided instruction in OMT in the first and second years of medical school.[13] Education in OMT techniques can vary from COM to COM, as the Commission on Osteopathic College Accreditation guidelines specify that COMs support the development of skills and competencies "through the use of standardized patients, skills testing and clerkship training"[15] but do not offer recommendations on how best to develop these skills and competencies. For example, students may observe a demonstration at the center of the laboratory, in small groups, or via video. They may either have a directed laboratory in which they are executing the techniques at the same time as the demonstrator or they may be asked to execute the techniques after 1 full observation. In either case, students may or may not be directly observed at the time of execution and thus may or may not be given formative feedback at that time.

Another area in which COMs can vary is in the trainer-to-student ratio in OMM instruction. Currently no mandated trainer-to-student ratio is maintained by the Commission on Osteopathic College Accreditation. Preliminary evidence exists for the number of students a trainer can adequately instruct and supervise. A review of trainer-to-student ratios for teaching psychomotor skills among various health-related disciplines recommended a 1:8 ratio for teaching most OMT techniques; a lower ratio is needed for cranial and HVLA techniques.[16] In addition, the level of the experience of the trainers is also left up to individual COMs. As noted by Snider et al,[16] the levels of experience among table trainers vary significantly (eg, second-year medical students, third- or fourth-year OMM predoctoral fellows, residents).

In these hands-on exercises, students are partnered with other classmates and practice techniques on one another. Students may be partnered with the same person throughout their school year or change weekly depending on the COM they attend. Aside from the concern that practicing on one person throughout the year can lead to students becoming proficient in executing techniques on one body type, the body size differentials between partners may be large. In regard to HVLA, proper execution of these techniques necessitates that physicians are able to position themselves over patients, which can be difficult if the difference in body size is large. Adaptations may be needed in some cases, including adjustable OMT tables or, less optimally, riser steps.

Current Predoctoral Assessment Standards of HVLA

Students may be assessed through written, practical, and, less commonly, oral examinations. The scope of this paper focuses on practical examinations. The treatment portion of these examinations is evaluated based on several components, which may include initial positioning of student and patient, correct localization to the articulation, vector and amount of activating force, and reassessment. Students are usually tested using one another as patients. Although some COMs use standardized patients (SPs) for practical examinations, I know of no COM that allows for HVLA to be performed on SPs.

The use of objective structured clinical examinations (OSCE) for student assessment is well established as a valid means to assess clinical skills in the practice of medicine.[17-21] The OSCE consists of a circuit of stations that test a range of skills and knowledge. Although many COMs incorporate OSCEs into their curricular assessments,[22] it is unclear how many, if any, incorporate OMT into these assessments. However, as previously stated for safety and appropriateness, it would not be expected that HVLA would be allowed to be performed on an SP. Boulet et al[23] showed that OMT can be validly assessed using the OSCE format. In this study, fourth-year medical students' use of OMT was assessed by faculty from a number of specialties after 4 hours of training using a rating tool. That model, however, excluded HVLA.

The diagnosis portion of practical examinations usually consists of physician trainers verifying the diagnosis established by a student examinee as determined on their partner. Students may be scored on simply finding the levels of dysfunction, or they may be

required to determine an exact diagnosis with points given for each aspect that is accurate (ie, flexion or extension, sidebending, rotation, level of dysfunction). Additionally, because of safety and ethical issues, HVLA is not tested and is explicitly excluded from the Comprehensive Medical Licensing Examination-USA Level 2-Performance Evaluation (COMLEX-USA Level 2-PE) out of concern that SPs may be injured as a result of several students administering this technique to them throughout the examination day.[24]

Models of Teaching and Learning Motor Skills

With regard to motor skill learning, several models affect learners' performance[25,26]: observational practice, focus of attention, and feedback. In observational practice, a student learns through watching someone else perform a task. When combined with physical practice, observational practice can make important contributions to learning. Neuroimaging experiments have shown common neural structures being activated in both observation and action.[27] Observational practice may afford the learner opportunities to observe subtleties of tasks that would be otherwise lost if they were asked to execute a task simultaneously to it being demonstrated or read from a static manual.[28] Alternating between physical and observational practice in pairs is best. Even when given half the trials of execution by someone not in a pair, students who worked in pairs performed as well as unpaired students doing twice as many repetitions of a technique. Thus, teaching in pairs is time and cost effective.[29]

Focus of attention is concerned with how the movements of certain body parts should be coordinated with others in space and time. An example would be executing a supine HVLA spinal manipulation to T6-8 neutral, rotated right, sidebent left: The physician stands to the left of the supine patient and the physician places his or her thenar eminence under the right transverse process of T7. Multiple studies, particularly in the field of sports, have shown that directing the learners' attention to their own movements and body parts (ie, an internal focus) is relatively ineffective.[30-33] Instead performers should be directed to the effects of their movements (ie, an external focus) and what the patient position looks like when correctly situated, resulting in more accurate and effective long-term learning. Focus of attention externally leads to the use of unconscious and automated processes.

Feedback in motor-skill learning involves providing a learner with information about the outcome or quality of a movement. The rate at which feedback is given and the focus of that feedback have also been found to have positive effects on long-term learning. Multiple studies have shown that intermittent feedback is more effective than constant feedback. Students given constant feedback after performing chiropractic tasks were found to have reduced errors during practice but also lower long-term retention rates.[34] Studies have also shown that when given negative feedback on trials, performers did worse on long-term retention compared with those given feedback on their best performances.[14,35]

Although these models of teaching and learning are important for all OMT techniques, they are especially important for HVLA of the spine. Given the thrust of this technique, some students may be uncomfortable performing HVLA. Using these teaching and learning models may facilitate students' understanding of how to properly execute this technique.

Accurate palpatory assessment of the spine is a concern for a number of health care professionals, including osteopathic physicians; certain medical specialties, including physiatrists, anesthesiologists, and sports medicine physicians; chiropractors; physical therapists; and manual therapists. Several studies from these fields have evaluated interexaminer reliability of spinal palpation.[37-39] Osteopathic physicians are trained to evaluate somatic dysfunction using 4 diagnostic criteria: tissue texture changes, asymmetry, restriction of motion, and tenderness (TART).[36]

Reviews of the literature on the interexaminer reliability of spinal palpation have demonstrated that, in general, the rate of agreement between examiners is

low,[37,38] with more experienced examiners being no more reliable than less experienced examiners.[37,39] Although no statistical differences have been found between different palpation methods,[38] the highest level of agreement has been found among examiners using pain palpation (palpation used to elicit pain),[37-39] which is the equivalent of the tenderness component of TART.[36]

The results of these reviews raise concerns about how medical students are taught to use OMT techniques, especially HVLA. As Seffinger et al[37] noted, given the generally low reliability, "one has the question whether the palpatory tests are indeed measuring what they are intending to measure." Similarly, Haneline and Young[38] noted that the reason pain palpation is the most reliable palpation method may be that patients are able to accurately remember their sites of pain. However, when instructing students on HVLA techniques, there must be confidence on the part of the instructor and the student in the diagnoses being discussed.

Technology Integration

The use of technology in teaching OMT lags behind other disciplines. Simulators are commonly used to teach all levels of learners in the fields of cardiology, surgery, and gynecology.[40-44] At the simplest level, the use of video demonstrations that the learner has control over (eg, ability to replay, slow, etc) has been shown to greatly enhance movement performance.[45] A few studies have used force pads and manikins, separately and combined, to teach spinal manipulation.[46-49] In these studies, students using the simulators had significantly less variability in the execution of force and were just as proficient as the control group. These studies show that students can avoid the potential risk of strains and limited access that occurs with the model of practicing solely on fellow students. Moreover, they suggest a model that might be used by COMs and certifying bodies to determine proficiency.

In addition to aiding students in learning how to administer spinal HVLA, simulators may also facilitate instruction in palpatory diagnosis. To address the difficulties in educating osteopathic medical students on palpation to diagnose aliments, researchers have developed the virtual haptic back, a simulation that mimics tissue abnormalities so that students can practice palpation.[50] It also provides feedback to students on whether they have correctly located the abnormalities. So far, research on the virtual haptic back has shown that after six 15-minute practice sessions with the simulation, the accuracy and speed of students' diagnoses improved. The average detection time decreased from a mean (SD) of 39 (19.8) to 17 (11.7) seconds. The ability to discern changes in simulated compliance improved from a mean (SD) of 28% (9.5%) to 14% (4.4%).[50]

It is important to note that this recommendation for using simulators should not be construed to mean that manikins or other mechanical teaching aids should replace the method of students practicing OMT on each other or the use of SPs. Rather, simulators should supplement what the learning students gain from practicing OMT on human beings. A review of the literature on training in the use of spinal manipulation concluded that students should have the opportunity to practice this manipulation using simulators and volunteer patients.[51] A similar approach should be taken to teaching HVLA with a combination of practice using simulators and human beings.

Proposed Recommendations for Teaching HVLA of the Spine at the Predoctoral Level

Four aspects of the teaching and assessment of spinal HVLA need to be addressed to create a more adept population of students: standardization of the training environment, standardized training of trainers, increased use of simulation technology, and standardization of testing.

Standardized Training Environment

The Educational Council on Osteopathic Principles represents the leaders in OMT education at the pred-

octoral level. Their stance on student-to-teacher ratios should be heeded. With respect to teaching HVLA, this proposal recommends a 4:1 ratio of students to faculty.[16] This proposal is based on the importance of supervision of a technique which, in the hands of a novice, may be more prone to injure, particularly the cervical spine. To my knowledge, it is unknown how the trainer-to-student ratio varies among COMs. Although many schools use adjustable tables, which are recommended, some do not have them (verbal communication, ECOP meeting with OMM department chairs, 2015). With the large body size variability of both students and patients, allowing adjustments of positioning to suit individual circumstance becomes critical.

Teaching Methods (7 hours)
Models of teaching and learning motor skills (1 hour)[27-33]
Evidence-based diagnosis of the spine (1 hour)
Safety and efficacy of HVLA with focus on the cervical spine (1 hour)[4-12]
Effective coaching/teaching for manual techniques (2 hours)[34,35]
Utilizing innovation and technology in the OMT laboratory (2 hours)[40-51]
Assessment and Evaluation Methods (3 hours)
Validating assessment tools (1 hour)
Utilizing subjective and objective assessment tools in OMT (2 hours)[17-20]

Figure.
Proposed curriculum (10 hours) for osteopathic medical educators teaching osteopathic manipulative treatment (OMT) at the predoctoral level.
Abbreviation: HVLA, high-velocity, low-amplitude.

Standardized Training of Trainers

Most physicians do not have formal training in being educators. Many COMs have combined programs with master's in public health, master's in business administration, and law degrees.[52] A.T. Still University College of Osteopathic Medicine offers combined programs with master of science in medical education leadership and doctor of health education. The Costin Institute at Midwestern University/Chicago College of Osteopathic Medicine and AACOM's faculty development continuing medical education program Training Osteopathic Primary Care Educators[53] are designed to expose osteopathic educators to educational theory. However, each of these programs is generalized to all medical educators at both the predoctoral and postgraduate levels, and they are also directed at all specialties of medicine.

I recommend a focused continuing medical education program specifically directed at osteopathic medical educators who are teaching OMT at the predoctoral level. A baseline of educational theory and practice should be required at all COMs (*Figure*). Moving toward a model of positive, intermittent feedback with an external focus in coaching could facilitate students learning HVLA. Many faculty are overwhelmed and uninformed regarding medical education pedagogy,[54-56] learning through trial and error and reinventing the wheel every time the faculty change.[54] Although what is discussed in this article is in the context of teaching HVLA, such training could largely be applied to other OMT techniques.

Given the limited resources of time and financial support for physician training after residency, I propose the training of trainers to be a relatively short continuing medical education program that could be provided in both webinar and live formats. Webinars would allow access to the largest base of physician teachers and possibly require laboratory supplementation at a later time. A live forum at several national conventions, specifically AACOM, the American Academy of Osteopathy, the American College of Osteopathic Family Physicians, and the AOA would also be desirable, as these are highly attended meetings. These meetings would yield the largest exposure to physicians who are most likely to be teaching OMT at the predoctoral level. This program would be required of at least 1 current attending physician at every OMM department nationally. It is also recommended that all residents in neuromusculoskeletal medicine/OMM programs be required to participate in the program once during their residency, because these

residents are likely to be involved in teaching osteopathic medical students either in the laboratory or during clinical clerkships. These efforts to grow faculty specialized in teaching OMT would increase the number of trained physicians at each institution and the number of trained physicians teaching OMT during all 4 years of osteopathic medical education.

Greater Use of Simulation Technology

A teaching guide for OMT that outlines the basic science of OMT techniques, including HVLA, was recently published by ECOP. Although COMs test students' proficiency in HVLA, no descriptions of how technique proficiency should be assessed exist. It is suggested that COMs not abandon the use of training and testing students on one another, but they should augment that method with the use of simulators, which can give the objective feedback lacking in current methods. It is recommended that students be tested at least annually on HVLA techniques applied to all 3 levels of the spine. Consideration should be given to developing local and national standards for thrust. Additionally, research into the development of HVLA simulators is encouraged.

Standardization of Testing

At the national testing level, HVLA is excluded because it represents a safety issue for SPs. As mentioned previously, repeatedly performing HVLA on an SP by multiple students places the SP at risk for injury. The issue of a reproducible experience for each tested candidate is also a concern. Currently, the COMLEX-USA Level 2-PE does not test specific procedures such as phlebotomy, advanced cardiac life support, laceration repair, etc. Therefore, it would not be advisable to disrupt the continuity of the examination to specifically test the execution of this particular technique given the obstacles previously listed. However, at some point the National Board of Osteopathic Medical Examiners will likely test these procedures, and at that time they, too, would probably include HVLA and the use of simulators.

Conclusion

There are a number of teaching methods for HVLA techniques that COMS are executing well. The use of manuals, video demonstrations, students working in pairs, and observation of performance by an expert are some examples. All of these methods are consistent with the current literature regarding motor skill learning, and should be encouraged at the formative stages of task acquisition. Standardization of teaching HVLA is needed on multiple levels, however, including the OMT laboratory environment, the number and skill level of table trainers, the use of technology, and testing to stay current with educational standards and to increase the pipeline of proficient OMT practitioners.

References

1. *2015 Osteopathic Medical Profession Report.* Chicago, IL: American Osteopathic Association; 2015. http://www.osteopathic.org/inside-aoa/about/aoa-annual-statistics/Documents/2015-OMP-report.pdf. Accessed July 28, 2016.
2. Preliminary enrollment report fall 2015. American Association of Colleges of Osteopathic Medicine website. http://www.aacom.org/docs/default-source/data-and-trends/2015prelimenrollrpt.pdf?sfvrsn=12. Accessed July 28, 2016.
3. The single GME accreditation system. American Osteopathic Association website. http://www.osteopathic.org/inside-aoa/Pages/ACGME-single-accreditation-system.aspx. Accessed July 28, 2016.
4. Hohner JG, Cymet TC. Thrust (high velocity/low amplitude) approach; "the pop." In: Chila AG, executive ed. *Foundations of Osteopathic Medicine*. 3rd ed. Baltimore, MD: Lippincott Williams and Wilkins; 2011.
5. Nicholas AS, Nicholas EA. *Atlas of Osteopathic Techniques.* 2nd ed. Baltimore, MD: Lippincott Williams & Wilkins; 2012.
6. Gibbons P, Tehan P. Spinal manipulation: indications, risks and benefits. *J Bodyw Mov Ther.* 2001;5(2):110-119.
7. Hurwitz EL. Epidemiology: spinal manipulation utilization. *J Electromyogr Kinesiol.* 2012;22(5):648-654. doi:10.1016/j.jelekin.2012.01.006.
8. Gross A, Miller J, D'Sylva J, et al. Manipulation or mobilization for neck pains. *Cochrane Database Syst Rev.* 2010;(1):CD004249. doi:10.1002/14651858.CD004249.pub3.
9. Rubenstein SM, van Middelkoop M, Assendelft WJJ, de Boer MR, van Tulder MW. Spinal manipulative therapy for chronic low-back pain. *Cochrane Database Syst Rev.* 2011;(2):CD008112. doi:10.1002/14651858.CD008112.pub2.
10. Gibbons P, Tehan P. HVLA thrust techniques: what are the risks? *Int J Osteopath Med.* 2006;9:4-12. doi:10.1016/j.ijosm.2006.02.005.

11. Rubenstein SM. Adverse events following chiropractic care for subjects with neck or low-back pain: do the benefits outweigh the risks? *J Manipulative Physiol Ther.* 2008;31(6):461-464. doi:10.1016/j.jmpt.2008.06.001.

12. American Osteopathic Association Policy Compendium 2015. American Osteopathic Association website. https://www.osteopathic.org/inside-aoa/about/leadership/Documents/policy-compendium.pdf. Accessed July 28, 2016.

13. Osteopathic medical college information book: entering class 2016. American Association of Colleges of Osteopathic Medicine website. http://www.aacom.org/docs/default-source/cib/2016_cib.pdf?sfvrsn=16. Accessed October 27, 2015.

14. Hansel KA. *Teaching Guide for Osteopathic Manipulative Medicine.* Chevy Chase, MD: American Association of Colleges of Osteopathic Medicine; 2015.

15. Commission on Osteopathic College Accreditation. *Accreditation of Colleges of Osteopathic Medicine: COM Accreditation Standards and Procedures.* Chicago, IL: American Osteopathic Association; 2016. https://www.osteopathic.org/inside-aoa/accreditation/COM-accreditation/Documents/com-accreditation-standards-7-1-16.pdf. Accessed July 28, 2016.

16. Snider KT, Seffinger MA, Ferrill HP, Gish EE. Trainer-to-student ratios for teaching psychomotor skills in health care fields, as applied to osteopathic manipulative medicine. *J Am Osteopath Assoc.* 2012;112(4):182-187.

17. Reddy S, Vijayakumar S. Evaluating clinical skills of radiation oncology residents: parts I and II. *Int J Cancer.* 2000;90(1):1-12.

18. Casey PM, Goepfert AR, Espey EL, et al; Association of Professors of Gynecology and Obstetrics Pre-doctoral Medical Education Committee. To the point: reviews in medical education—the objective structured clinical examination. *Am J Obstet Gynecol.* 2009;200(1):25-34. doi:10.1016/j.ajog.2008.09.878.

19. Falcone JL, Schenarts KD, Ferson PF, Day HD. Using elements from an acute abdominal pain objective structured clinical examination (OSCE) leads to more standardized grading in the surgical clerkship for third-year medical students. *J Surg Educ.* 2011;68(5):408-413. doi:10.1016/j.jsurg.2011.05.008.

20. Duvivier RJ, van Geel K, van Dalen J, Scherpbier AJ, van der Vleuten CP. Learning physical examination skills outside timetabled training sessions: what happens and why? *Adv Health Sci Educ Theory Pract.* 2012;17(3):339-355. doi:10.1007/s10459-011-9312-5.

21. Tervo RC, Dimitrievich E, Trujillo AL, Whittle K, Redinius P, Wellman L. The objective structured clinical examination (OSCE) in the clinical clerkship: an overview. *S D J Med.* 1997;50(5):153-156.

22. Langenau EE, Dyer C, Roberts WL, Wilson C, Gimpel J. Five-year summary of COMLEX-USA Level 2-PE examinee performance and survey data. *J Am Osteopath Assoc.* 2010;110(3):114-125.

23. Boulet JR, Gimpel JR, Dowling DJ, Finley M. Assessing the ability of medical students to perform osteopathic manipulative treatment techniques. *J Am Osteopath Assoc.* 2004;104(5):203-211.

24. *2016-2017 Orientation Guide: COMLEX-USA Level 2-PE.* Chicago, IL: National Board of Osteopathic Medical Examiners; 2016. http://www.nbome.org/docs/peorientationguide.pdf. Accessed October 27, 2015.

25. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ.* 2010;44(1):75-84. doi:10.1111/j.1365-2923.2009.03421.x.

26. Shea CH, Wright DL, Wulf G, Whitacre C. Physical and observational practice afford unique learning opportunities. *J Mot Behav.* 2000;32(1):27-36.

27. Grèzes J, Decety J. Does visual perception of object afford action? evidence from a neuroimaging study. *Neuropsychologia.* 2002;40(2):212-222.

28. Shea CH, Wulf G, Whitacre C. Enhancing training efficiency and effectiveness through the use of dyad training. *J Mot Behav.* 1999;31(2):119-125.

29. Sanchez-Ku ML, Arthur W Jr. A dyadic protocol for training complex skills: a replication using female participants. *Hum Factors.* 2000;42(3):512-520.

30. Lohse KR, Sherwood DE, Healy AF. How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Hum Mov Sci.* 2010;29(4):542-555. doi:10.1016/j.humov.2010.05.001.

31. Zachry T, Wulf G, Mercer J, Bezodis N. Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Res Bull.* 2005;30;67(4):304-309.

32. Maas E, Robin DA, Austermann Hula SN, et al. Principles of motor learning in treatment of motor speech disorders [review]. *Am J Speech Lang Pathol.* 2008;17(3):277-298. doi:10.1044/1058-0360(2008/025).

33. Ford P, Hodges NJ, Williams AM. Online attentional-focus manipulations in a soccer-dribbling task: implications for the proceduralization of motor skills. *J Mot Behav.* 2005;37(5):386-394.

34. Pringle RK. Guidance hypothesis with verbal feedback in learning a palpation skill. *J Manipulative Physiol Ther.* 2004;27(1):36-42.

36. Educational Council on Osteopathic Principles. *Glossary of Osteopathic Terminology.* Chevy Chase, MD: American Association of Colleges of Osteopathic Medicine. https://www.aacom.org/docs/default-source/insideome/got2011ed.pdf?sfvrsn=2. Accessed October 27, 2015.

37. Seffinger MA, Najm WI, Mishra SI, et al. Reliability of spinal palpation for diagnosis of back and neck pain: a systematic review of the literature. *Spine.* 2004;29(19):e413-e425.

38. Haneline MT, Young M. A review of intraexaminer and interexaminer reliability of static spinal palpation: a literature synthesis. *J Manipulative Physiol Ther.* 2009;32(5):379-386. doi:10.1016/j.jmpt.2009.04.010.

39. Stochendahl MJ, Christensen HW, Hartviqsen J, et al. Manual examination of the spine: a systematic critical review of reproducibility. *J Manipulative Physiol Ther.* 2006;29(6):475-485.

40. Burden C, Oestergaard J, Larsen CR. Integration of laparoscopic virtual-reality simulation into gynaecology training [review]. *BJOG.* 2011;118(suppl 3):5-10. doi:10.1111/j.1471-0528.2011.03174.x.

41. Ahmed K, Amer T, Challacombe B, Jaye P, Dasgupta P, Khan MS. How to develop a simulation programme in urology [review]. *BJU Int*. 2011;108(11):1698-1702. doi:10.1111/j.1464-410X.2011.010420.x.

42. Ma IW, Brindle ME, Ronksley PE, Lorenzetti DL, Sauve RS, Ghali WA. Use of simulation-based education to improve outcomes of central venous catheterization: a systematic review and meta-analysis. *Acad Med*. 2011;86(9):1137-1147. doi:10.1097/ACM.0b013e318226a204.

43. Tan SS, Sarker SK. Simulation in surgery: a review. *Scott Med J*. 2011;56(2):104-109. doi:10.1258/smj.2011.011098.

44. Clifton N, Klingmann C, Khalil H. Teaching otolaryngology skills through simulation [review]. *Eur Arch Otorhinolaryngol*. 2011;268(7):949-953. doi:10.1007/s00405-011-1554-6.

45. Wulf G, Raupach M, Pfeiffer F. Self-controlled observational practice enhances learning. *Res Q Exerc Sport*. 2005;76(1):107-111.

46. Young TJ, Hayek R, Philipson SA. A cervical manikin procedure for chiropractic skills development. *J Manipulative Physiol Ther*. 1998;21(4):241-245.

47. Descarreaux M, Dugas C, Lalanne K, Vincelette M, Normand MC. Learning spinal manipulation: the importance of augmented feedback relating to various kinetic parameters [published online January 30, 2006]. *Spine J*. 2006;6(2):138-145.

48. Triano JJ, Rogers CM, Combs S, Potts D, Sorrels K. Quantitative feedback versus standard training for cervical and thoracic manipulation. *J Manipulative Physiol Ther*. 2003;26(3):131-138.

49. Triano JJ, Rogers CM, Combs S, Potts D, Sorrels K. Developing skilled performance of lumbar spine manipulation. *J Manipulative Physiol Ther*. 2002;25(6):353-361.

50. Howell JN, Conatser RR, Williams RL II, Burns JM, Eland DC. The virtual haptic back: a simulation for training in palpatory diagnosis. *BMC Med Educ*. 2008;8:14. doi:10.1186/1472-6920-8-14.

51. Triano JJ, Descarreaux M, Duqas C. Biomechanics—review of approaches for performance training in manipulation. *J Electromyogr Kinesiol*. 2012;2(5):732-739. doi:10.1016/j.jelekin.2012.03.011.

52. Wu P, Siu J. *A Brief Guide to Osteopathic Medicine for Students, by Students*. Chevy Chase, MD: American Association of Colleges of Osteopathic Medicine; 2015.

53. Training the osteopathic professions core educators. American Association of Colleges of Osteopathic Medicine website. http://www.aacom.org/ome/councils/topce. Accessed August 5, 2016.

54. Roos M, Kadmon M, Kirschfink M, et al. Developing medical educators--a mixed method evaluation of a teaching education program. *Med Educ Online*. 2014;19:23868. doi:10.3402/meo.v19.23868.

55. Barrett J, Scott K. Pedagogical and professional compromises by medical teachers in hospitals. *Clin Teach*. 2014;11(5):340-344. doi:10.1111/tct.12190.

56. van den Berg JW, Verberg CP, Berkhout JJ, Lombarts MJ, Scherpbier AJ, Jaarsma AD. A qualitative interview study on the positive well-being of medical school faculty in their teaching role: job demands, job resources and role interaction. *BMC Res Notes*. 2015;8:401. doi:10.1186/s13104-015-1393-4.