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Development of a mannequin lab for clinical training in a chiropractic program

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ABSTRACT

Objective: Faced with COVID-19 safety protocols that severely limited the ability to conduct chiropractic technique instruction in the usual manner, our university invested the resources to develop a new mannequin lab for hands-on training, which would help supplement the loss of person-to-person contact.

Methods: Training mannequins could enable student learning of palpation and adjustment skills while avoiding close human–human contact. The university had developed a mannequin over the previous 4 years consisting of a full-sized human torso with individually movable and palpable vertebrae, pelvis, and thighs. In the mannequin, 64 pressure sensors are attached to particular vertebral and skeletal landmarks and provide feedback on palpation location and level of force applied. We assembled 3 teams to produce 20 copies of that mannequin for student use.

Results: Mannequins were produced in 7 weeks, and space was built out for a special lab. Faculty members are developing classroom procedures to introduce the mannequin to students, phase in the skills from static and motion palpation, and practice thrust performance.

Conclusion: The production run was successful, and the resulting equipment, well-received by students and faculty. In addition to helping teach manual skills, the lab serves as a platform for educational research to test the efficacy of mannequin-based training protocols. With the pressure sensors on known locations along the spine, future research may be able to test the ability of students to identify and contact specific target locations for adjustive thrusts.

Key Indexing Terms: Chiropractic; Education; Spine; Simulation

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INTRODUCTION

The COVID-19 pandemic led to campus closure 2 weeks before the end of the winter session in 2020. Because of the need for social distancing, education and exams were switched to remote delivery and continued for the spring session. However, clinical education for chiropractic students requires psychomotor skills and close physical contact with practice patients, often other students.

With the school closed for on-campus activities, we considered how the use of mannequins could provide a way to continue adjustment skills training while limiting interpersonal contact. The school committed to funding the construction of 20 copies of a previously developed mannequin for use in summer session, 15 weeks away.

Chiropractic educators have increasingly used new technology to aid student learning, particularly of psychomotor skills such as the adjustive or manipulative thrust.[1] New training equipment chiefly consists of force plates to measure transmitted loads during training. Most technological efforts have been aimed at providing force and rate feedback at the preload and peak load phases of the thrusts.[2–6] Owens et al[7] used a force plate to also study the precise vectors of manipulative thrusts. The Force-Sensing Table Technology (FSTT) produced at Canadian Memorial Chiropractic College (Toronto, Canada) has been used in several studies of the educational efficacy of using such tools.[6,8,9]

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Mannequins (or manikins) provide another type of technology often used in nursing and surgical education. Mannequins, especially in early education, can provide an element of safety for the recipient of the thrust generated by novices who may have difficulty controlling the thrust magnitude. Owens et al reviewed the recent uses of mannequins in chiropractic education and pointed out the need for a life-like mannequin that has similar material properties to human spinal tissue.[10] Indeed, Passmore et al[11] used bicycle inner tubes inflated to varying intensities to show that practitioners modulate the force and speed of their manipulative thrusts based on perceptions of the resistance to deformation of the material into which thrusts are delivered. While the FSTT system includes a Human Analog Mannequin (HAM) along with the force-plate table, the developers tested only the soft foam covering over the thoracic section, not the compliance of the undercarriage.[12] Our team has received anecdotal reports suggesting that HAM is very rigid, and other objects are sometimes substituted in practice sessions.

Educators seem to appreciate the need to provide force and rate feedback to students, and attempts have been made to identify training targets for those.[4] Additionally, the location of force application on the spine would seem to be an important factor in student learning as well. However, we have seen no attempts to use technology to help with that aspect of technique education.

In 2014, the university launched an initiative to create a life-like adjusting mannequin for use in chiropractic student education. A senior scientist for the initiative collaborated with faculty in the College of Chiropractic, external contractors, and the university administration to develop the new mannequin for early training in palpation and adjustment skills.

The goal was to develop a mannequin with realistic vertebral kinematics that approximate the motion and compliance of the human spine. We also envisioned the inclusion of force-feedback sensors within the structure, and methods for changing vertebral stiffness—both new features for such devices.

Over the past few years, several prototypes of spinal mannequin sections have been developed and presented at talks for various conferences. These presentations described the fixation mechanisms and compliance testing of the lumbar and thoracic sections.[10,13–15] The first full-spine and pelvis mannequin was produced by combining those parts along with a newly developed cervical section in June of 2019. It was named PAT, the Palpation and Adjustment Trainer. The single prototype was used in research projects studying adjustment forces and rates as a surrogate for human subjects.

This brief paper started as a 6-minute narrated slideshow presentation at the Chiropractic Educators Research Forum conference in December 2020. The authors attempted to tell an engaging story about how the university adapted to the pandemic by creating a new mannequin lab for manual skills and technique instruction, limiting the need for close physical contact between the student and another human. The following is not a data-driven investigation but, rather, is meant to be a qualitative report of how we addressed a sudden need and how the users' experienced the result.

METHODS

Project Development

The mannequin design consists of a fully articulated skeletal system including a skull, spine, rib cage, pelvis, and thighs. All the skeletal components began as 3-dimensional (3D) models that were altered to enable interconnections. Skeletal elements are connected with cords, tubing, and elastic elements and mounted into a central armature. An array of 64 pressure sensors mounted directly on bony landmarks interfaces with a logic network managed by a microcontroller. The electronics are mounted on a custom-designed printed circuit board.

The first challenge was how to build multiple copies of the prototype in the timeframe requested, considering the original model took 5 months to construct. This provided an opportunity to improve on the design and software, reworking some of the construction methods and 3D computer models. We made one significant improvement to the electronics design by having a custom-designed circuit board made in China specifically for this application. The circuit board had connectors for ribbon cable and sockets for microprocessor chips built in, along with all the internal connections required from the chips to the other components. Another significant improvement was the creation of 3D models for internal structural elements, which enabled the use of a computerized numerical control (CNC) device to make identical copies of those elements.

We quickly identified 3 teams that could work in parallel to complete the project: artists to create parts and cast the final mannequin, assemblers to combine dozens of parts into completed internal skeletons, and electronics technicians and programmers to assemble the sensor arrays, circuit boards, and display computers.

Coincidentally, the COVID-19 shutdowns made workers who otherwise had been doing other tasks available for this project. Work–study students and campus employees had altered schedules due to campus closure. Also, a local special effects studio had increased availability because of the pandemic-induced loss of work in the film industry.

Off campus, artists created silicone molds of the original 3D-printed skeletal components and then cast multiple copies of each mold using a hard plastic resin. Those parts included the thoracic and lumbar vertebrae, the skull, and the pelvis. The cervical vertebrae were considered too small and complex to create with the mold/cast method, so each of them was individually printed in Polylactic acid plastic with a 3D printer.

The central armature was rendered as a 3D model and cut from high-density plastic using a CNC machine. This included a large box to interface with the rib cage on the sides, and with C7 on the top and T12 on the bottom. It also included a smaller internal box to house the circuit board. A set of scapulae were also cut from the high-density plastic using a CNC machine.

Figure 1 - An array of cast and manufactured parts ready for assembly. This represents enough parts for 4 mannequins.

We built a construction studio in an open warehouse area on campus and then brought in students, employees, and faculty to staff it. The raw cast and precut parts were all laid out in the construction studio. Some parts needed additional machining with drill presses and high-speed cutting tools. The ribs were cut from plastic tubing. One very intense construction task was the assembly of the thoracic spine section, including the ribs mounted in the armature, and the vertebrae attached to the ribs, to each other, and to the top and bottom sections of the armature. Figure 1 shows the complete components laid out for 4 mannequins.

Meanwhile, the electronics team assembled circuit boards and wiring harnesses using microprocessors and multiplexer components mounted on a custom-designed circuit board, ribbon cable, and small pressure sensors. Assembly and testing, especially soldering heat-sensitive sensors to very fine ribbon cable, was intense, occupying 3 people full time. Each wiring harness had 64 sensors attached to it. The sensor harnesses were then delivered to the construction studio and combined with the skeleton core. Wiring had to be routed through the internal structure and each sensor, hot-glued to the correct skeletal process. We performed exhaustive testing to be sure all sensors were functional and in the right place.

Finally, the completed skeletal core and electronics package was delivered to the special effects studio for casting. We had 2 fiberglass trunk molds made from the same male form. The torso was cast into that mold with a gel-like silicone to simulate soft tissue and a tough elastic outer silicone skin. Special care was taken to recycle any material that was left over from each pouring. So, hardened material from all the tools and containers used in one casting was collected, ground up, and used in the next casting. That saved on cost and material use.

The finished cast models were returned to the construction studio where excess material was removed, thigh sections were connected, and electronics interface boards were installed. Computer display systems were connected to the mannequins, and the sensor systems were finally programmed and tested.

The assembly process was truly a parallel effort between the 3 teams. Once the parts were all manufactured to complete a mannequin, we assembled 1 skeletal core per day, 5 days a week, for 4 weeks. Electronic components were assembled continuously at the same pace. Skeletal cores were moved to the casting studio every day as they were produced, and finished mannequins were brought back to the construction studio for final cleanup and assembly each day.

The final stage was to assemble the display computers using a small, economical Raspberry Pi computer and LCD screen (Raspberry Pi Foundation, Cambridge, England). We attached each mannequin to its own Raspberry Pi mounted on the back of the monitor. These were all placed in a teaching classroom for initial introduction to the teaching faculty and a selection of students.

Mid-Project Developments

As each mannequin came from the molding process, we noticed certain irregularities that we could address in the construction and molding processes. The central armature fit too tightly in the mold, which required some cutting down of the CNC-cut box pieces. We also noticed a tendency for the lower thoracic vertebrae to slip out of the center of the mold. The mold had a central ridge along which the spinous processes were positioned. That ridge would become the spinal groove in the lower thoracic and lumbar spinal regions after casting. At the same time, those spinous processes were the most posterior elements and needed to be balanced on that ridge. Consequently, some of the early models have pronounced lower thoracic scoliosis.

We improved the final product by using a Dremel tool (Mt. Prospect, Il) to reduce the length of the spinous processes of T19-T11 by 0.5 cm. We also altered the casting process by adding extra silicone "rails" to the edges of the central ridge, so the spinous processes would stay better centered on the spinal groove.

When we palpated the initial set of mannequins, we noted that the skin felt a little too tough compared with human tissue. The lead artist added a softener to the mixture for future models.

We also thought that the head seemed a little too light. The mass of the head consisted of a hard orb, cast in plastic resin, and weighing 1.13 kg, plus the weight of the silicone surrounding it. The typical human head weighs 6% of the total body weight, which would be on the order of 4.1 kg for a person weighing 68 kg.[16] We increased the weight of the head by adding a metal weight to the anterior.

While typical manufacturing processes aim to produce identical results each time, the collaborative nature of the production process provided the opportunity for iterative refinement of each consecutive mannequin. In that sense, slight differences exist between individual units. Humans, after all, vary in shape, size, color, and tissue compliance. For educational purposes, it may be of value for students to be able to detect individual differences in the models, especially in the area of spinal contours.

Project Deployment

The university built out a new teaching lab called the Technique Lab of the Future to house 13 of the mannequins and their electronics (Figs. 2 and 3). In this lab, state-of-the-art smart technology was installed to

Figure 2 - The Technique Lab of the Future with wall-mounted display screens and mannequins on adjusting benches.

allow students to both experience the palpation and technique mannequins and use a force-plate table to further hone their skills on the forces and vectors needed to perform the thrust of an adjustment. Faculty can network additional documents, x-rays, case management, and testing, and conduct data collection for future research using the PAT lab. The other 7 units were placed in other classrooms on campus.

Initially, faculty were trained in the various functions of the mannequin along with the possibilities of incorporating the additional technology. Ideas quickly formed from all faculty who participated. A small pilot group of students were also included in the initial training.

RESULTS

The project produced 20 full-spine mannequins in 7 weeks. All the mannequins are identical from the outside in the shape of a trim man but with 3 different skin tones represented. The individual vertebrae can be palpated from the surface and have human movement characteristics. Each mannequin has a display screen to show contact points and amount of pressure overlaid on a skeletal image. The embedded sensors are activated upon palpation. Shading of the contact point indicates a softer or harder touch in 256 gradations from light green to solid red.

The mannequins are intended to be used in static and motion palpation classes as well as introductory adjustment training. Mechanical testing shows that the compliance is much like that of a human torso and can be influenced by internal controls.[17]

The mannequin can be employed at several different stages of the curriculum, from early static and motion palpation through adjusting, including cervical spine, thoracic spine, and lumbo-pelvic regions. Five of the core chiropractic adjustment and palpation courses were scheduled twice a quarter in the lab. Timing was structured to allow students to begin using the lab to develop their palpation and adjusting skills as early as the first 6 months in the doctor of chiropractic (DC) program.

DISCUSSION

We have not yet made any attempts to collect satisfaction ratings from the faculty or students regarding their experiences in the lab. Plans are also being developed to test the effects of mannequin use on student learning. This paper sought to describe our process for creating the resource, not its eventual use.

Figure 3 - Students in the lab practice cervical adjustment skills.

PAT was first presented to a group of undergraduate pre-DC students. They were able to observe simple chiropractic thrusts and position-based procedures, and they could successfully repeat the observed procedures. Current DC students were next to utilize the Technique Lab of the Future. They were able to make use of one benefit of using a mannequin for practice, as opposed to each other, in that they could repeat thrusts over and over without fear of harm. Consequently, faculty members observed that students who were previously timid about how adjustments are to be done were able to gain skills at a high rate. In addition, all students, even seasoned upper-quarter students, felt they were able to hone their skills using the mannequin.

We can say that students were very excited and asked for more lab access times, so additional open lab times were scheduled to meet the demand and practice times available. In open lab settings, faculty members also observed students working in teams, providing observations and feedback to co-learners. In end-of-the-term course evaluations, several students referred to the mannequins as being the highlight of the quarter; many appreciated having a very informative, hands-on experience after so much remote learning, commented on the on-screen feedback, and expressed a desire to get back into the lab as soon as possible.

It is important to note that the addition of the PAT units to the curriculum are in addition to traditional training, and the program still utilizes many other avenues of teaching palpation and technique skills to address all types of learning styles.

While the mannequin provides feedback about contact forces over bones and relative pressure, it is not intended to sample the total force applied, so it cannot provide total force and speed feedback. Force can be applied to the mannequin that might completely miss any sensor. Although not precisely calibrated, the system does display relative pressure over contact points by showing shadings of green and red colors. If a student is searching for a contact point by palpation and is not getting any signal of pressure, it is because they have not yet located the target. As they near the target, there will be an increase in pressure and a brighter color at the target sensor location on screen. Students can use that approach to "zero-in" on the location directly over the contact point that produces the brightest indication on screen.

Sampling across 64 sensors is time-consuming, so the sampling rate is not sufficient to accurately capture a thrust that may last only 20 milliseconds. For that reason, some force-measuring tool such as a force plate or contact-load cell should be used to give the best feedback about peak thrusts and speed of adjustment.

CONCLUSIONS

Faced with COVID-19 safety protocols that severely limited the university's ability to conduct technique instruction in the usual manner, the administration quickly invested the resources and funds to develop a brand-new lab for hands-on training, which helped limit person-to-person contact. The university had an advantage because development of the mannequin had already been in progress for more than 4 years.

Faculty are developing new classroom procedures to introduce the mannequin to students and phase in the different skills from static palpation to motion palpation and finally to actual adjustive thrusting.

The lab can also serve as a platform for future educational research to test the efficacy of mannequin-based training protocols. With the pressure sensors on known locations along the spine, we may be able to test some factors that have been very difficult to study, such as the ability of students to identify and contact specific target locations for adjustive thrusts.

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REFERENCES

1. Triano J, Giuliano D, McGregor M, Howard L. *Enhanced learning of manipulation techniques using Force-Sensing Table Technology (FSTT)*. Toronto: Higher Education Quality Council of Ontario; 2014.
2. Descarreaux M, Dugas C, Raymond J, Normand MC. Kinetic analysis of expertise in spinal manipulative therapy using an instrumented manikin. *J Chiropr Med*. 2005;4(2):53–60.
3. Descarreaux M, Dugas C. Learning spinal manipulation skills: assessment of biomechanical parameters in a 5-year longitudinal study. *J Manipulative Physiol Ther*. 2010;33(3):226–230.
4. Owens EF, Hosek RS, Sullivan SGB, Russell BS, Mullin LE, Dever LL. Establishing force and speed training targets for lumbar spine high-velocity, low amplitude chiropractic adjustments. *J Chiropr Educ*. 2015;30(1):7–13.
5. Owens EF, Russell BS, Hosek RS, Sullivan SGB, Dever LL, Mullin LE. Changes in adjustment force, speed, and direction factors in chiropractic students after 10 weeks undergoing standard technique training. *J Chiropr Educ*. 2017;32(1):3–9.
6. Starmer DJ, Guist BP, Tuff TR, Warren SC, Williams MG. Changes in manipulative peak force modulation and time to peak thrust among first-year chiropractic students following a 12-week detraining period. *J Manipulative Physiol Ther*. 2016;39(4):311–317.
7. Owens EF Jr, Hosek RS, Mullin L, Dever L, Sullivan SGB, Russell BS. Thrust magnitudes, rates, and 3-dimensional directions delivered in simulated lumbar spine high-velocity, low-amplitude manipulation. *J Manipulative Physiol Ther*. 2017;40(6):411–419.
8. Triano JJ, Lester S, Starmer D, Hewitt EG. Manipulation peak forces across spinal regions for children

using mannequin simulators. *J Manipulative Physiol Ther*. 2017;40(3):139–146.

9. Duquette SA, Starmer DJ, Plener JB, BSc DAG. A pilot study to determine the consistency of peak forces during cervical spine manipulation utilizing mannequins. *J Chiropr Educ*. 2021;35(1):8–13.
10. Owens EF, Hosek RS, Russell B. Mechanical properties of a thoracic spine mannequin with variable stiffness control. *J Chiropr Educ*. 2021;35(1):1–7.
11. Passmore S, Gelley G, MacNeil B. Tactile perception of pressure and volitional thrust intensity modulate spinal manipulation dose characteristics. *J Manipulative Physiol Ther*. 2019;42(5):335–342.
12. Starmer DJ, Duquette SA, Stainsby BE, Giuliano AM. The examination of soft tissue compliance in the thoracic region for the development of a spinal manipulation training mannequin. *J Can Chiropr Assoc*. 2015;59(2):150–156.
13. Owens EF, Hosek RS. A physical model of lumbar spine fixation for use in palpation and adjustment training. Abstracts and conference proceedings of the 2016 World Federation of Chiropractic/Association of Chiropractic Colleges Education Conference; Oct 19–22, 2016; Montreal, Quebec. *J Chiropr Educ*. 2016; 30(2):e–173 (https://doi.org/10.7899/1042-5055-30.2.165).
14. Owens EF, Hosek RS, Russell B. Mechanical properties of a lumbar spine mannequin with simulated intervertebral fixation. Abstracts of Association of Chiropractic Colleges Research Agenda Conference Proceedings; Mar 9–10, 2018; Dallas, TX. *J Chiropr Educ*. 2018;32(1):50–81.
15. Owens EF, Hosek RS, Russell B. Mechanical properties of a thoracic spine mannequin with variable stiffness control. Abstracts of Association of Chiropractic Colleges Research Agenda Conference Proceedings; Mar 15–17, 2019; Baltimore, MD. *J Chiropr Educ*. 2019; 33(1):63–64.
16. Chafin D, Anderson B, Martin B. *Occupational Biomechanics*. 3rd ed. New York, NY: Wiley and Sons Inc; 1999.
17. Owens EF, Hosek RS, Salman M, Russell BS. Spinal posterior-to-anterior stiffness measurements can be affected by padding on the support table. 44th Meeting of the American Society of Biomechanics; 2020 Aug 4–7; Atlanta, GA; p. 712.