

DEVELOPMENT OF FORCE-FEEDBACK TECHNOLOGY FOR TRAINING CLINICIANS TO DELIVER MANUAL CERVICAL DISTRACTION

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ABSTRACT

Objective: Neck pain is a prevalent musculoskeletal (MSK) complaint and costly societal burden. Doctors of chiropractic (DCs) provide manual therapies for neck pain patients to relieve discomfort and improve physical function. Manual cervical distraction (MCD) is a chiropractic procedure for neck pain. During MCD, the patient lies face down on a specially designed chiropractic table. The DC gently moves the head and neck in a cephalic direction while holding a gentle broad manual contact over the posterior neck, to create traction effects. MCD traction force profiles vary between clinicians making standardization of treatment delivery challenging. This paper reports on a bioengineering technology developed to provide clinicians with auditory and graphical feedback on the magnitude of cervical traction forces applied during MCD to simulated patients during training for a randomized controlled trial (RCT).

Methods: The Cox flexion-distraction chiropractic table is designed with a moveable headpiece. The table allows for long axis horizontal movement of the head and neck, while the patient's trunk and legs rest on fixed table sections. We instrumented this table with three-dimensional force transducers to measure the traction forces applied by the doctor. Motion Monitor software collects data from force transducers. The software displays the magnitude of traction forces graphically as a function of time. Real-time audible feedback produces a steady tone when measured traction forces are <20N, no tone when forces range between 20-50N, and an audible tone when forces exceed 50N. Peer debriefing from simulated patients reinforces traction force data from the bioengineering technology.

Results: We used audible and graphical feedback to train and certify DCs to apply traction forces to the cervical spine of

simulated patients within three specific ranges. This technology supports a RCT designed to assess the ability of clinicians to deliver MCD within specified force ranges to patients randomized to different force dosages as an intervention. Future applications may include training chiropractic students and clinicians to deliver the MCD treatment.

INTRODUCTION

Musculoskeletal conditions are common causes of pain and disability [1,2] with neck pain representing a prevalent complaint and costly societal burden [3-8]. Doctors of chiropractic (DCs) treat neck pain patients to relieve discomfort and improve physical function. DCs may deliver several types of chiropractic adjustments or spinal manipulation therapy (SMT) to the spine for the treatment of musculoskeletal (MSK) conditions. SMT includes manual high velocity low amplitude spinal manipulative (HVLA-SM) procedures, handheld instrument assisted techniques, low-velocity distraction procedures, drop piece high-velocity techniques, etc.[9].

Chiropractic students traditionally learn the technique of delivering SMT procedures by watching someone skilled in a procedure. The expert teacher demonstrates a technique and the student then practices its delivery on other students or volunteer patients. The teacher observing the student delivering may provide hands-over-hands guidance, and give verbal feedback as the student develops proficiency. Experienced DCs provide training in a similar manner with student interns in academic health centers or in private practice clinics.

Chiropractic techniques are measurable biomechanical events involving the application of forces to specific regions of interest, causing vertebral movements [10-13]. Several investigators [10-13, [14-19] have measured the forces delivered by DCs during manipulations of the lumbar, thoracic and cervical spine. HVLA-SM is characterized by clinical force

delivery, loading durations, loading rates, coordination index, and transmitted loads to the spine.

Over the past decade, educators have incorporated innovative bioengineering technologies into the training of chiropractic students and licensed doctors to give feedback on the forces, durations, loading rates, and coordination indexes. Mechanical instruments, mannequins, and human volunteers also are used for training. Subsequently, researchers have demonstrated quantified force-time profile characteristics [16,20-24]. Most of these studies focused on HVLA-SM, with the majority evaluating the thoracic and lumbar spine [16,20-23]. Few studies have measured the biomechanical characteristics of HVLA-SM delivery to the cervical spine [23-25], and even fewer on these parameters with non-HVLA-SM techniques[26].

James Cox, DC developed manual cervical distraction, or the flexion distraction procedure, to treat patients with neck pain [25]. Several case reports and case series have been published for treating neck problems using this procedure [27-30]. During MCD, the patient lies face down on a specially designed chiropractic table. The DC gently moves the head and neck in a cephalic direction while holding a broad manual contact over the posterior neck, to create traction effects.

We have observed that MCD traction force profiles vary between clinicians making standardization of treatment delivery challenging. MCD technique is practiced by using variable manual distraction forces, in part based on practitioner experience and individual patient tolerance. However, it is not known whether variable forces are necessary, or if a specific force range has a greater potential therapeutic value. No studies have reported the delivery of forces during MCD.

This paper reports on an innovative bioengineering technology developed at the Palmer Center for Chiropractic Research, which provides clinicians with auditory and graphical feedback on the magnitude and duration of cervical traction forces. This novel training tool was used while MCD was applied to simulated patients while training clinicians to deliver the procedure within specified force-ranges for a randomized controlled trial. The original training tool has broad implications for teaching students and experienced practitioners to deliver the MCD procedure in a quantifiable and reproducible manner, as well as providing a means of measuring chiropractic dose in randomized controlled trials (RCTs) studying manual therapies.

METHODS

The Palmer College of Chiropractic (PCC) institutional review board approved this study. Human simulated patient volunteers and the doctors of chiropractic volunteers signed written informed consent to participate in the study.

Recruitment

Eighteen volunteers served as simulated patients, recruited from PCC employees and students. DCs screened volunteers for any contraindications and safety considerations relative to receiving the MCD procedure before study inclusion. Five DCs completed training and certification as reported here.

Figure 1. Flow diagram of the force-feedback technology development process

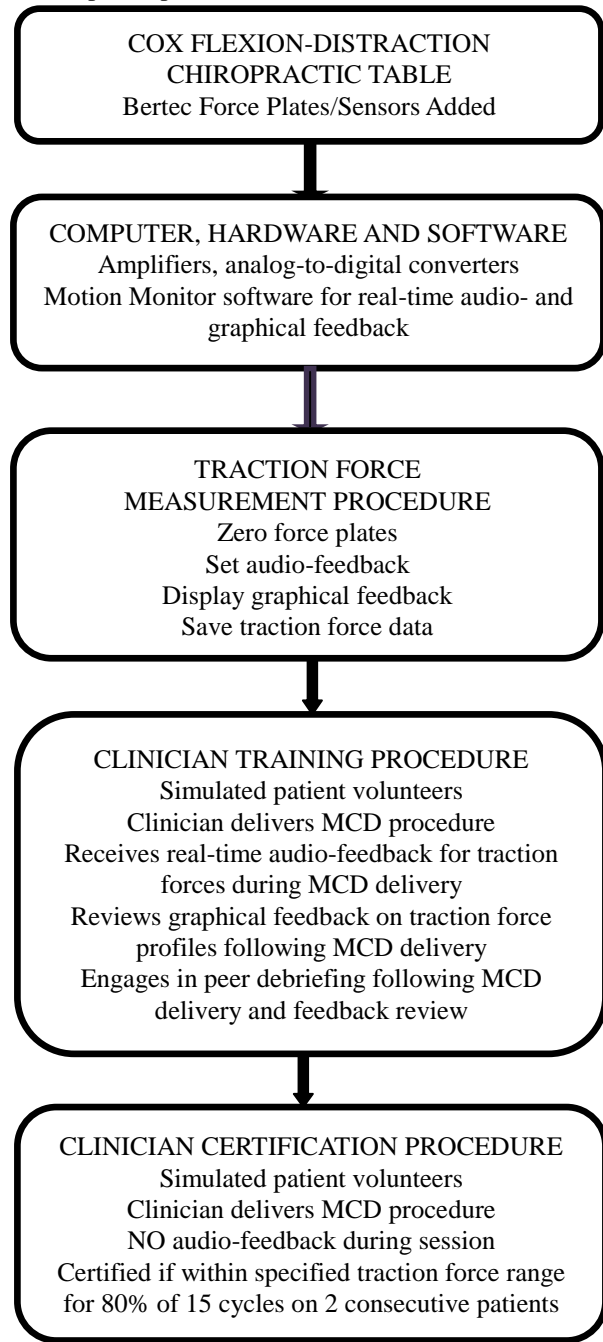


Figure 1 shows the development process for training and certification of doctors of chiropractic using force feedback. This consists of treatment table modifications instrumented with force plates and force sensors, connecting the force sensors to the computer through amplifiers and analog-to-digital converters, configuring the software to provide audio tone for different force ranges, graphical feedback, and training and certification of clinicians.

Biomechanical Principles of Force Feedback Technology

The MCD procedure applies traction to the cervical spine in a prone position. Application of traction force is the key input thought to produce therapeutic benefit. In this study, we are quantifying the traction force the clinician applies to the patient (asymptomatic volunteer in this particular training study). The objective is to provide audio feedback during the delivery of traction force corresponding to a pre-defined magnitude range. After the treatment is delivered, the computer displays the traction force graph as a function of time, which the clinician is able to review. The measurement of traction force is achieved with the help of force plates, amplifiers, analog-to-digital converters, desktop computer, and motion monitor software. Magnitude of traction force is the outcome measure for clinicians.

Instrumentation

The Cox flexion-distraction chiropractic table (Model 7, Haven Innovation, Grand Haven, MI) is designed with a moveable headpiece that allows for long axis horizontal movement of the head and neck, flexion, lateral flexion, and rotation while the trunk and legs of the patient rest on fixed table sections. We instrument-modified this table (Figure 2) with three-dimensional force transducers (Model # 2850-06, Bertec Inc., Columbus, OH, USA) to measure the traction forces applied by the clinician. A 3-D force sensor (Model Py6-100, Bertec Inc., Columbus, OH) is placed under the table headpiece. Force sensors are connected by means of amplifier and 16 bit analog-to-digital converters to a desktop computer. Traction force applied by the clinician is obtained as a function of time using the force plates embedded in the table (Figure 2). The force plates are capable of measuring three-dimensional forces and moments; however, traction is the key force component for this procedure. Force plates and force transducers are accurate to within 5% as determined by the manufacturer. We have independently tested the force measures against a 3-D force sensor[31] (Model: Mini45, ATI industrial Automation, Apex, NC) in both normal and shear directions and found good agreement (less than 3% difference). We are determining the traction amount applied by the clinician by measuring the shear forces gathered from the two force plates. During MCD, traction forces are delivered in a gentle slow manner at a rate of approximately 0.5 Hz. The force plates used in this study have a

natural frequency of 400Hz resulting in no adverse effects on force measurements.

Motion Monitor Software (Version 7, Innovative Sports Training Inc., Chicago, IL, USA) collects data from the force transducers and potentiometers and displays the information graphically as a function of time and produces audible feedback in real-time on the amount of traction forces used during MCD.

The audible feedback produces a steady tone when measured traction forces are <20N, no tone when forces range between 20-50N, and an audible tone again when traction forces exceed 50N. Audible feedback is reinforced through graphic displays of the magnitude and duration of MCD delivery, as well as through debriefing simulated patients who received the MCD.

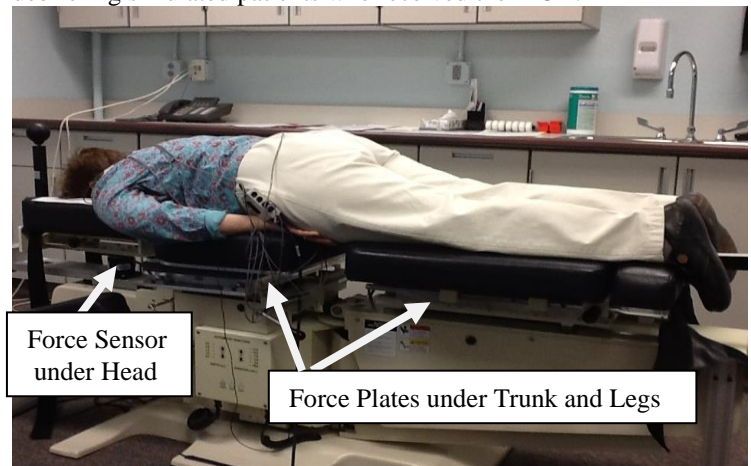


Figure 2. Photograph of the instrumented table with the participant lying in prone position

MCD Procedure

Manual cervical distraction is a form of low velocity variable amplitude spinal manipulation (LVVA SM). The MCD procedure is performed with a participant lying prone on a load instrumented table with a moveable headpiece that allows guided head movement. The clinician gently grasps the posterior aspect of the participant's neck with a broad contact (contact hand) between the thumb and index finger at a specific vertebral level. With the opposite hand, the clinician grasps the control handle of the headpiece. Using the contact hand, the clinician exhibits superior traction while attempting to maintain a contact at a single vertebral level and ensuring a gentle movement of the headpiece via contact with the control handle. The goal is to create a slow rhythmic (1-3 sec) localized distractive movement. The amount of distractive force is determined by the clinical scenario and therapeutic intent, but never does it exceed participant tolerance.

The MCD clinical trial, an ongoing clinical research study for which these training procedures were developed, includes three

intervention groups: low force MCD, medium force MCD, and high force MCD. Though there are several potential procedures offered by this treatment technique only neutral distraction, which is the most commonly used MCD procedure, is available for clinicians to use with participants in this study. Clinicians will attempt to deliver distraction forces of less than 20N in the low force group, between 20N and 50N in the medium force group and between 51N and 100N in the high force group. MCD dosing is limited to 3 sets of 5 repetitions with a hand contact over C5 and 3 sets of 5 repetitions with a hand contact on the occiput. Figure 3 shows a manual contact used by DCs while performing the procedure. Because neck stiffness and cervical spine anatomy differ between patients, force-feedback training provides clinicians an opportunity to perceive and gauge force ranges on different body types. Figure 4 shows a screenshot of the graphical display of the traction forces during visual feedback including a single repetition tolerance test performed prior to treatment.



Figure 3. Photograph of a participant on the flexion-distraction table and clinician's hand contact at the C5 vertebra

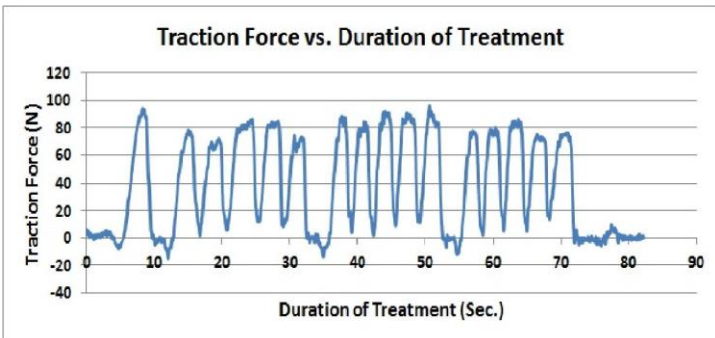


Figure 4. Graphical display of the cervical traction forces for visual feedback on clinician's delivery of MCD procedure

We set a priori criteria for DCs to obtain certification to deliver traction forces during the clinical trial in three ranges (0-20N,

20N-50N, and >50N and <100N) on two consecutive participants for each force range at each hand contact point. Successful completion of a single test occurred when traction forces generated during the procedure stayed within the force range at least 80% of the 15 cycles (minimum of 12 cycles).

RESULTS

Participants who received the MCD procedure consisted of 11 males and 7 females (total of 18 participants). The mean age was 45 years old (SD: 12). The mean height of participants was 172.8cm (SD: 7.7cm) and mean weight was 79.6kg (SD: 22.0kg). Audible and graphical feedback was used to train and certify DCs to apply traction forces within three specific ranges.

Five research clinician DCs (2 males and 3 females) with a wide range of clinical experience (31yr, 28yr, 23yr, 2yr, 1yr) underwent training and certification. DC experience included private-practice, research, and serving as chiropractic college faculty in technique, classroom, and clinical instruction.

During November-December 2012, 5 research clinicians trained approximately three hours per week using the audible and graphical feedback system. Clinicians learned to self-calibrate their force delivery against the information provided by the feedback technology. Peer debriefing following MCD delivery in concert with the technology strengthened the clinicians' ability to fine-tune their hand positions and grips for each of the force ranges. In January 2013 these DC clinicians were certified for the clinical trial without the aid of the audible or graphical feedback under the same conditions as MCD delivery for the RCT. Table 1 lists the number of attempts each clinician made to obtain certification for each force range and contact location (C5 and Occiput). Monthly re-certification for clinicians delivering the MCD treatments will be completed throughout the RCT for quality control and as a means of assuring intervention fidelity throughout the study.

Table 1. Number of certification attempts in given force ranges

Force Range	Contact	DC1	DC2	DC3	DC4	DC5
0-<20N	C5	1	1	1	1	1
	Occiput	3	3	1	1	4
20-50N	C5	2	1	1	2	2
	Occiput	2	1	2	2	3
>50-100N	C5	2	1	1	1	1
	Occiput	1	1	1	1	1

Figure 5 shows the three force components (traction force, posterior-to-anterior force, and lateral force applied by the clinician) measured by force plates under the trunk and legs. Practically, the lateral force is very minimal. Posterior-to-Anterior (PA) force is observed. However, PA force is not used for training purposes. Traction force is the most important component and is used for training.

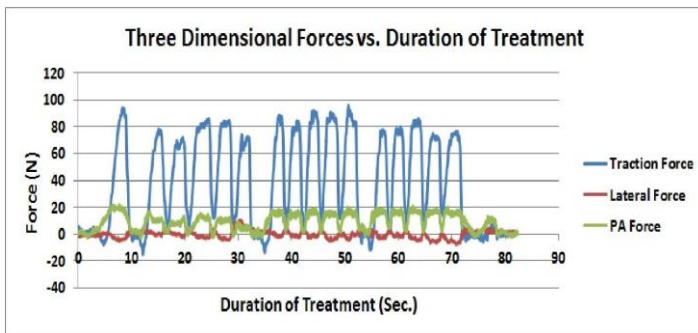


Figure 5. Three-dimensional forces measured from force plates under the trunk and legs during the delivery of MCD procedure

Figure 6 shows the all three force components (traction force, posterior-to-anterior force, and lateral force applied by the clinician) measured by the force sensor under the headpiece. The lateral and traction forces under the head piece are very minimal. Posterior-to-Anterior (PA) force is observed.

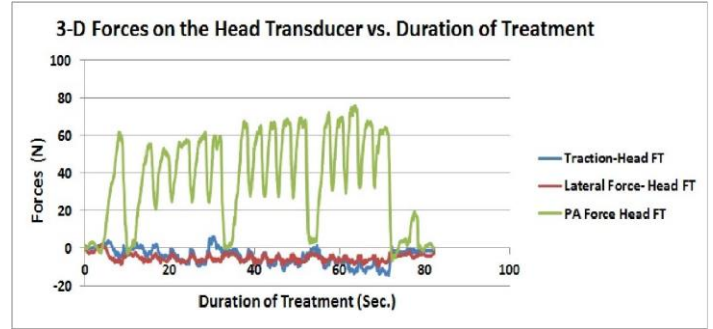


Figure 6. Three-dimensional forces measured from force transducer under the head during delivery of MCD procedure

DISCUSSION

To the best of these authors' knowledge, this is the first investigation in developing combined audio and graphical feedback technology to deliver a prescribed force range during manual cervical distraction. This technology provides a firm foundation for a RCT designed to assess the ability of clinicians to deliver MCD within specified force ranges. This will also allow clinical/physiological outcomes evaluation of patients randomized to different force ranges as an intervention. The use of the technology developed also could be easily implemented in classrooms, teaching clinics, and field settings.

We successfully trained 5 research clinicians to deliver MCD at 3 prescribed force range dosages. The weekly training sessions lasted approximately seven weeks. As seen from table 1 in the results section it took between 1-4 attempts to obtain certification. The high force range required the least number of attempts. Certification in mid-range and low-range proved more challenging represented by the increased number of attempts before certification was obtained. The manual contacts at C5 and Occiput required a different number of attempts to obtain certification suggesting these areas are perceived differently by clinicians. This demonstrates the usefulness of this technology as a training facilitator for DCs with different experience levels and illustrates the variation of forces perceived and occurring at different manual contact areas.

Traditional approaches to technique training for MCD have included observation and feedback by an instructor/mentor. This method is based primarily on the subjective evaluation of distraction technique as a complex psychomotor skill rather than measuring the biomechanical event. The technology developed in this project extends this subjective evaluation process by providing real-time audio and immediate graphical feedback with quantitative force data. This allows clinicians and students the opportunity to hone their ability to deliver specific biomechanical forces. Peer and participant feedback/debriefing, delivered verbally, remained an essential component of clinician training.

Other investigators have used training using instruments and instrumented mannequins to obtain visual feedback on forces and force-time profiles [19-22] during HVLA-SM, comparing force-time characteristics of students and clinicians. Our study is different from these studies in two ways: a) our study is based on combined audio and graphical bioengineering technology, peer-debriefing feedback, and human volunteers; b) our study included training clinicians to deliver treatment within prescribed force ranges for a randomized clinical trial.

Our clinicians expressed that force magnitudes at contact locations C5 and occiput are perceived differently. The quantified force feedback proved helpful in distinguishing this difference.

Manual therapists apply forces to the spine for several reasons including improving joint mobility, reducing muscular hypertonicity, stimulating proprioceptive activity, and to relieve pain [25]. Force-magnitude related therapeutic effects have not been studied, but this technology enabled us to train clinicians to deliver treatment within specified ranges. Applying treatment within specific force ranges is the first step toward developing clinical studies designed to investigate optimum force-dosage in clinical settings.

CONCLUSIONS

Audible and graphical feedback was used to train and certify DCs to apply traction forces to the cervical spine of simulated patients within three specific ranges. This technology provides a firm foundation for training for clinical settings and students. This technology can also be used to conduct RCTs investigating force-related dose responses.

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