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Review

Spinal manipulative therapy and somatosensory activation

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ABSTRACT

Manually-applied movement and mobilization of body parts as a healing activity has been used for centuries. A relatively high velocity, low amplitude force applied to the vertebral column with therapeutic intent, referred to as spinal manipulative therapy (SMT), is one such activity. It is most commonly used by chiropractors, but other healthcare practitioners including osteopaths and physiotherapists also perform SMT. The mechanisms responsible for the therapeutic effects of SMT remain unclear. Early theories proposed that the nervous system mediates the effects of SMT. The goal of this article is to briefly update our knowledge regarding several physical characteristics of an applied SMT, and review what is known about the signaling characteristics of sensory neurons innervating the vertebral column in response to spinal manipulation. Based upon the experimental literature, we propose that SMT may produce a sustained change in the synaptic efficacy of central neurons by evoking a high frequency, bursting discharge from several types of dynamically-sensitive, mechanosensitive paraspinal primary afferent neurons.

1. Introduction

Manually-applied movement and mobilization of body parts as a healing activity has been used for centuries (Wiese and Callender, 2005). A relatively high velocity, low amplitude force applied to the vertebral column with therapeutic intent, referred to as spinal manipulative therapy (SMT), is one such activity. It is most commonly used by chiropractors, but other healthcare practitioners including osteopaths and physiotherapists use it as well. Although SMT has been advocated for a wide range of health problems (Ernst and Gilbey, 2010), currently available best evidence suggests it has a therapeutic effect on people suffering some forms of acute neck and back pain particularly when it is used in combination with other therapies (Brønfort et al., 2004, 2010; Dagenais et al., 2010; Miller et al., 2010; Walker et al., 2010; Lau et al., 2011). Its effect on chronic low back pain is less clear (Rubinstein et al., 2011; Walker et al., 2010).

SMT is typically applied when dysfunctional areas of the vertebral column are found. Clinicians identify these areas based upon palpatory changes in the texture and tone of paraspinal soft tissues, the ability to elicit pain and/or tenderness from these tissues, asymmetries in hard or soft tissue landmarks, and restrictions in spinal joint motion (Kuchera and Kappler, 2002; Sportelli and Tarola, 2005). The clinician's goal in applying a spinal manipulation is to restore normal motion and normalize physiology of the neuromusculoskeletal system in particular and potentially other physiological systems affected by the dysfunction.

The mechanisms responsible for the therapeutic effects of SMT remain unclear. Early theories proposed that the nervous system likely mediates the effects of SMT. For example, Korr (1975) proposed that SMT alters or modulates proprioceptive afferent inputs to the central nervous system. Twelve years later Gillette (1987) provided a speculative description of all afferent input likely to arise from SMT of the lumbar spine. The force–time profile of SMT, based upon the one study available at the time, was trapezoidal in shape, reaching a peak force of nearly 200 N and lasting nearly 400 ms before returning to pre-SMT levels. Identification of afferents likely activated by SMT was based upon a review of the experimental evidence describing the response characteristics of all known somatic mechanosensitive receptors to the mechanical features of the stimuli that activated them (e.g. force magnitude, rate of force application). Much of the data concerning receptor-type and response characteristics were derived from studies involving the appendicular somatosensory system since little was known at the time about the axial somatosensory system. Consequently Gillette's description (Gillette, 1987) provided a hypothetical profile of the afferent activity arising during SMT.

Since Gillette's (1987) benchmark paper, considerably more is known about the morphology of the vertebral column's somatosensory system (for example see Giles and Taylor, 1987; Richmond

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Table 1
Lists the receptors that have been identified in paravertebral tissues of the cervical (C), thoracic (T), lumbar (L), or coccygeal (Cx) regions of the vertebral column using morphological (M) or physiological (P) studies. The species in which the respective receptors have been studies is listed together with one reference to a study involving the species and study type.

Receptor	Region	Study type	Species	Evidence (see for example)
Muscle spindle	C	P	Cat	Richmond and Abrahams (1979)
		M	Cat	Richmond and Bakker (1982)
		M	Human	Boyd-Clark et al. (2002)
	C,T,L	M	Human	Amonoo-Kuofi (1983)
	L	P	Cat	Cao et al. (2009)
Golgi tendon organ	C	P	Cat	Richmond and Abrahams (1979)
		M	Cat	Richmond and Bakker (1982)
		M	Human	Mendel et al. (1992)
	L	M	Human	Roberts et al. (1995)
	Cx	M	Bovine	Roberts et al. (1995)
Paciniform corpuscle	C	M		Richmond and Abrahams (1982)
		M		McLain (1994)
	L	M	Human Fetus	Jackson et al. (1966)
		M	Human	Jackson et al. (1966)
	Cx	M	Bovine	Roberts et al. (1995)
Ruffini ending	L	M	Human	Roberts et al. (1995) Jiang et al. (1995)
Unencapsulated nerve endings	C	M	Human	Mendel et al. (1992)
	C,T,L	M	Monkey	Stilwell (1956)
		M	Human Fetus	Groen et al. (1990)
	L	M	Rat	Nakamura et al. (1996)
		M	Human Fetus	Jackson et al. (1966)
		M	Human	Jackson et al. (1966)

et al., 1988; Groen et al., 1990; McLain, 1994; Jiang et al., 1995; Bolton, 1998). Table 1 summarizes receptor types that have been found in paravertebral tissues. Similarly, more is now known about the mechanical characteristics of SMT. Additionally, *in vivo* and cadaveric studies have better informed us about the kinematics of vertebral motion segments produced by SMT. Together these new data provide a more informed basis for modeling SMT activation of the axial somatosensory system.

The goals of this article are to briefly update our knowledge regarding several physical characteristics of an applied SMT and to review what is known about the signaling characteristics of sensory neurons innervating the vertebral column in response to spinal manipulation. Then based upon this data, we describe neurophysiological events that may contribute to the therapeutic effects of spinal manipulation.

2. Physical characteristics of SMT

2.1. Mechanical parameters and forces associated with SMT

The biomechanical characteristics (i.e., force or displacement versus time curves) of a number of SMT techniques involving either manual or instrument-assisted protocols have been determined in studies performed directly on human subjects (for reviews see Lee et al., 2000; Herzog, 2010) or with the use of patient simulation devices (Kawchuk et al., 2006; Graham et al., 2010). Fig. 1 shows examples from both types of studies. As described by Herzog (2010), the profiles may be characterized by a pre-load phase, a thrust phase which rapidly rises to a peak force, and a resolution phase (see Fig. 1A).

The characteristics of these profiles appear to vary depending upon region of the vertebral column to which they are applied (e.g. see Fig. 1B). In human studies the kinematic parameters of SMT have been obtained using a flexible force-sensitive mat interposed between the clinician's hands and the patient to record the force and duration of an SMT. SMT in the cervical region has relatively little pre-load ranging from 0 to 39.5 N (Herzog et al., 1993; Kawchuk et al., 1992; Kawchuk and Herzog, 1993). In contrast, the average pre-load forces during SMT in the thoracic region (139 ± 46 N, ± SD) and sacroiliac region (mean 88 N ± 78 N) are substantially higher than in the cervical region and are potentially different from each other (Herzog et al., 1993). From the beginning of the thrust to end of the resolution phase, SMT duration varies between 90 and 120 ms (mean = 102 ms). The time to peak force during the thrust phase ranges from 30 to 65 ms (mean = 48 ms). Peak applied forces range from 99 to 140 N (mean = 118 N, n = 6 treatments) (Herzog et al., 1993). In the same study with SMT directed at the thoracic (T4) region and applied to three different patients by the same practitioner, the mean (SD) time to peak force was 150 ± 77 ms and mean peak force reached 399 ± 119 N. During the resolution phase, force returned to pre-SMT levels over durations up to two times longer than that of the thrust phase. When SMT was applied to the sacroiliac joint, mean applied peak forces reached 328 ± 78 N (Herzog et al., 1993), with the thrust and resolution phases having similar durations (∼100 ms). The peak force during manipulation of the lumbar spine measured by Triano and Schultz (1997) tended to be higher than during the thoracic or sacroiliac manipulation measured by Herzog et al. (1993) and the force–time profiles resembled half-sine waves with the time to and from peak taking approximately 200 ms. Peak impulse forces during thoracic manipulation measured by Suter et al. (1994) approximated the >400 N peak impulse force measured by Triano and Schultz (1997).

The physical characteristics of an SMT may vary based upon the technique being used and the individual practitioner. While instrument assisted SMT may apply preload forces on the order of 20 N, peak forces vary from approximately 50–380 N depending on the instrument being used and selection of the instrument's settings (Colloca et al., 2005). Up to 38% of the instrument assisted thrusts were reported to produce absolute forces significantly different ($P \leqslant 0.05$) from each other (Kawchuk et al., 2006). In addition, the difference in applied force duration between two operators using instrument-assisted SMT can be as much as 75% (Kawchuk et al., 2006). Similarly, measurements of SMT forces and displacements applied to a non-biological device simulating the SMT's contact site also show variability. In a study measuring force and displacement over the duration of a toggle recoil SMT both force and displacement varied by 50% when performed by an individual practitioner while, between practitioners, force varied by up to 100% and displacement by up to 50% (Graham et al., 2010). These findings presumably identify practitioner-related variability since neither the instrument's nor the simulator's mechanical properties change. During a non-instrument-assisted, predominately rotatory manipulative procedure applied to the neck, practitioners did not consistently perform the procedure in that peak thrust velocities were different. However, better inter-practitioner than intra-practitioner consistency was observed for thrust duration (Ngan et al., 2005). Interestingly, a spinal mobilization (low velocity) manual technique (cervical lateral glide) performed on the neck demonstrated very small intra-practitioner variability (Vicenzino et al., 1999).

It is clear that the mechanical parameters of SMT vary significantly depending on the manipulated region of the vertebral column, the type of procedure being performed, and characteristics