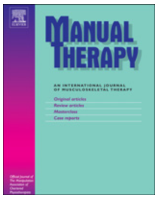
Manual Therapy 15 (2010) 212–219

Contents lists available at ScienceDirect

Manual Therapy

journal homepage: www.elsevier.com/math



Masterclass

Why do spinal manipulation techniques take the form they do? Towards a general model of spinal manipulation

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ARTICLE INFO

Article history:
Received 20 November 2008
Received in revised form
21 March 2009
Accepted 28 March 2009

Keywords:
Spinal manipulation
Biomechanics
Kinematics

ABSTRACT

For centuries, techniques used to manipulate joints in the spine have been passed down from one generation of manipulators to the next. Today, spinal manipulation is in the curious position that positive clinical effects have now been demonstrated, yet the theoretical base underpinning every aspect of its use is still underdeveloped. An important question is posed in this masterclass: why do spinal manipulation techniques take the form they do? From the available literature, two factors appear to provide an answer: 1. *Action of a force upon vertebrae*. Any 'direct' spinal manipulation technique requires that the patient be orientated in such a way that force is applied perpendicular to the overlying skin surface so as to act upon the vertebrae beneath. If the vertebral motion produced by 'directly' applied force is insufficient to produce the desired effect (e.g. cavitation), then force must be applied 'indirectly', often through remote body segments such as the head, thorax, abdomen, pelvis, and extremities. 2. *Spinal segment morphology*. A new hypothesis is presented. Spinal manipulation techniques exploit the morphology of vertebrae by inducing rotation at a spinal segment, about an axis that is always parallel to the articular surfaces of the constituent zygapophysial joints. In doing so, the articular surfaces of one zygapophysial joint appose to the point of contact, resulting in migration of the axis of rotation towards these contacting surfaces, and in turn this facilitates gapping of the other (target) zygapophysial joint. Other variations in the form of spinal manipulation techniques are likely to depend upon the personal style and individual choices of the practitioner.

1. Introduction

For centuries, techniques used to manipulate joints in the spine have been passed down from one generation of manipulators to the next (Anderson, 1992; Harris, 1993; Bartol, 1995; Wiese and Callender, 2005). Once the domain of laymen, spinal manipulation is now, for the most part, provided by organised professional groups. Whilst these techniques have no doubt evolved over time, their progression has largely been empirical; their form today is most likely a culmination of demonstration, imitation, and iterative adaptation. This is in contrast to most modern healthcare interventions, such as pharmaceuticals or medical devices, which are usually developed upwards from a theoretical base.

Much has been written about joint manipulation in recent years, and the volume of research has grown steeply during this period. In fact, for low back pain, there are now more randomised controlled trials evaluating spinal manipulation than any other intervention (Bronfort et al., 2008). In contrast, basic science studies are relatively uncommon. Hence, spinal manipulation is in the curious position that some positive clinical effects have now been demonstrated (Assendelft et al., 2003; Bronfort et al., 2004, 2008; Gross et al., 2004), yet the theoretical base underpinning every aspect of its use is still underdeveloped (Cramer et al., 2006).

A careful exposition of currently available data (Evans and Lucas, submitted for publication) has provided a proposed list of features that are necessary and collectively sufficient for the occurrence of (and which may be used to define) manipulation of any individual joint (Table 1). Hence, something of a general model, incorporating both the physical action of the practitioner and mechanical response of the recipient, may be derived from these features.

For a general model of manipulation to be valid, it must be representative of manipulation in all synovial joints of the body. Indeed, spinal manipulation is simply manipulation of synovial joints in the vertebral column. However, the motion of an entire spinal motion segment (and the synovial joints within) is usually much more complex than motion of an independent, peripheral synovial joint. Consequently, whilst the general model formed from the above features may well be valid, further explanation is

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doi:10.1016/j.math.2009.03.006

Table 1
Proposed necessary features of joint manipulation (from Evans and Lucas, submitted for publication).

Action (that which the practitioner does to the recipient)
A force is applied to the recipient
The line of action of this force is perpendicular to the articular surface of the affected joint
Mechanical response (that which occurs within the recipient)
The applied force creates motion at a joint
This joint motion includes articular surface separation
Cavitation occurs within the affected joint

required to provide an understanding of how these features operate during manipulation of joints in the spine.

For this purpose, a different question can be asked: why do spinal manipulation techniques take the form they do? Indeed, if all manipulation techniques encompass these fundamental features, additional factors must give rise to the forms of the techniques that are consistently applied to the various spinal regions (Fig. 1). Despite displaying clear similarities, these techniques are still usually taught as an eclectic collection, rather than being unified by a general theory, or model, that explains their form. This paper examines such factors and presents a first attempt at constructing such a general model from the available scientific data.

2. Discussion

2.1. Action of a force upon vertebrae

At a very basic level, spinal manipulation requires the action of an externally applied force upon one or both vertebrae of a chosen ('target') spinal motion segment. Unlike bones in the non-axial skeleton, vertebrae are relatively inaccessible. Indeed, with the exception of the cervical spine, only the most posterior features of vertebrae are close to the skin surface. Fig. 1A illustrates how some cervical manipulation techniques take advantage of the relative accessibility of the cervical spine by utilising two contact points. To apply forces 'directly' to vertebrae in the thoracic and lumbar regions, there is no non-invasive option other than doing so through the posterior overlying skin.

Forces applied at the skin surface in any spinal region must usually pass through substantial superficial tissue, which readily deforms as a result (McGregor et al., 2001; Powers et al., 2003; Kulig et al., 2004). Skin itself is a non-linear viscoelastic tissue, which demonstrates directionally dependent mechanical properties (Alexander and Cook, 1977; Stark, 1977; Daly, 1982; Reihsner et al., 1995). Furthermore, there is negligible friction between the skin and the connective tissues that lie superficial to the spine (Bereznick et al., 2002), irrespective of whether force is applied through an irregular shaped contact (such as a hand) or not. The implications of these basic science data for the form of spinal manipulation techniques are important: only when applied

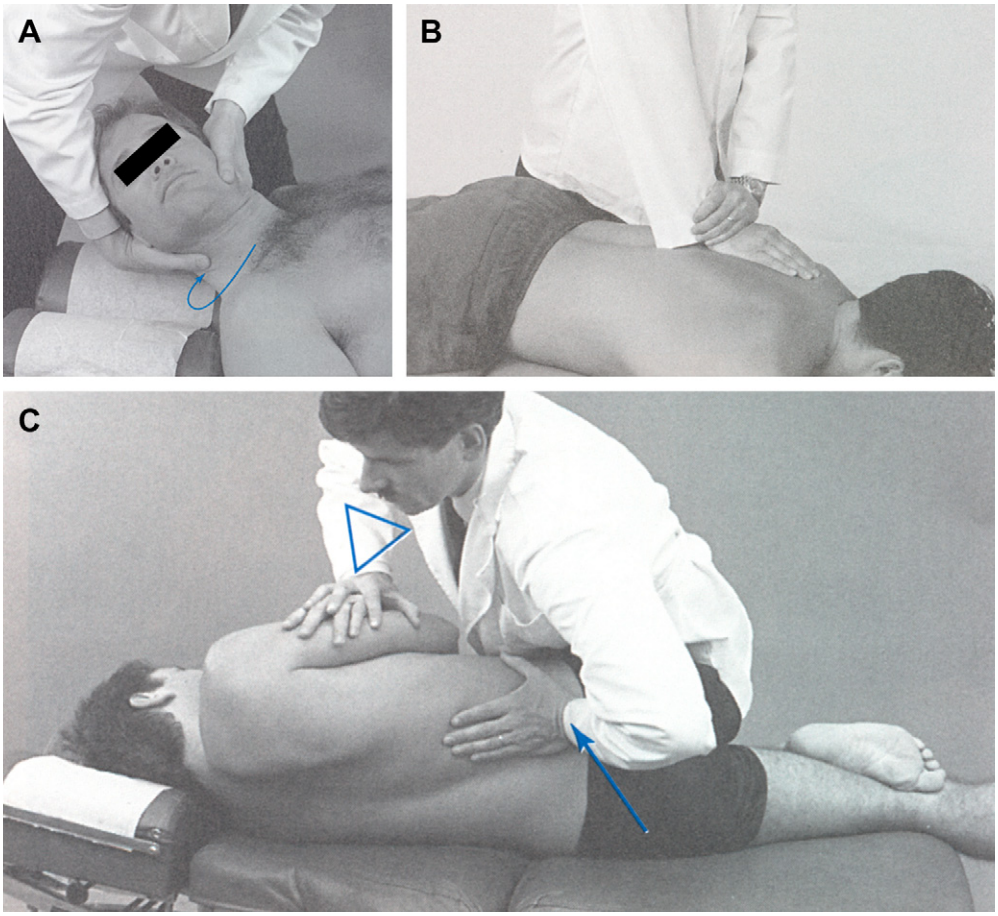

Fig. 1. Typical forms of spinal manipulation techniques. **A.** Supine 'rotatory' mid-cervical manipulation. **B.** Prone unilateral 'posterior–anterior' lower thoracic manipulation. **C.** Side-posture 'rotational' lumbar manipulation. All figures reproduced from Peterson and Bergmann (2002).

perpendicular (at 90°) to the skin surface is force likely to act significantly on internal structures (see also Kawchuk and Perle, 2009), and a proportion of any applied force is always likely to be dissipated by superficial tissues.

The results from these laboratory studies are supported by data from studies of actual spinal manipulation. Three-dimensional contact forces, applied by a clinician to the skin surface during cervical, thoracic and lumbosacral manipulation, have been directly measured using a small hand-held force sensor (van Zoest et al., 2002; van Zoest and Gosselin, 2003). Technically, the sensor measured the reaction force from the skin upon the device, as force was applied to the skin (with the aim of acting on tissues beneath). Hence, if friction between the skin and the underlying connective tissues was negligible, little reaction force parallel to the skin surface would be applied to the device. Predictably, the results from these studies confirmed that the only significant component of force applied to the skin was that which was perpendicular to the skin surface.

In a study of lumbar spine manipulation, Bereznick (2005) demonstrated that forces applied by hand contact towards lumbar vertebrae, through the posterior overlying skin (Fig. 1C), did not significantly contribute to the production of cavitation (which manifests as the 'audible sound', mentioned in Table 1); neither the magnitude or location of applied force was as important as the magnitude of rotational torque in the transverse plane. In order to create this rotational torque, the majority of force had to be applied 'indirectly' to the vertebrae, via the pelvis and thigh of the recipient.

Collectively, these data mean that any 'direct' spinal manipulation technique requires that the patient be orientated in such a way that force is applied perpendicular to the overlying skin surface so as to act upon the vertebrae beneath. If the vertebral motion produced by 'directly' applied force is insufficient to produce the desired effect (e.g. cavitation), then force must be applied 'indirectly', often through remote body segments such as the head, thorax, abdomen, pelvis, and extremities. Equally, if the body weight of the clinician is to be fully exploited during a technique, then the patient must be orientated in such a way that the point of contact at the skin surface is horizontal and that the clinicians' centre of mass is aligned directly above.

Fig. 2 depicts the typical time histories of forces applied perpendicular to the skin surface of a patient during spinal manipulation (Herzog, 2000; Evans and Breen, 2006). That this temporal kinetic profile is similar with manipulation techniques used at all spinal levels is notable given the anatomical variation between spinal regions.

2.2. *Spinal segment morphology*

To be consistent with features common to manipulation in other synovial joints (described in Table 1), the motion induced in a spinal segment during spinal manipulation must result in the separation of the articular surfaces (gapping) of one, or both, of the posterior synovial (zygapophysial, atlantoaxial, occipitoatlantal, or lumbosacral) joints.

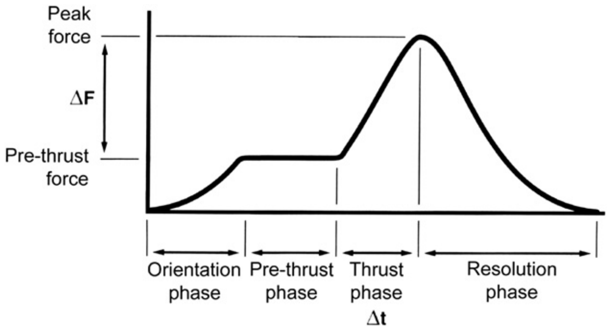

Fig. 2. Typical pattern of applied forces during spinal manipulation. A similar force profile occurs during manipulation of joints in all spinal regions. Figure reproduced from Evans and Breen (2006), originally modified from Herzog (2000).

With regard to a single zygapophysial joint, articular surface gapping requires translation of one superior articular process of the lower (caudad) vertebra in a direction opposite to that of the articulating inferior articular process of the upper (cephalad) vertebra of that segment. In contrast, symmetrical gapping of both zygapophysial joints within a single segment would require an anterior translation of the entire caudad vertebra relative to its cephalad neighbour. Importantly, several studies have shown that significant bilateral zygapophysial joint gapping usually only follows failure (injury) of restraining tissues in that segment (Levine et al., 1988; Tohme-Noun et al., 2003; Carrino et al., 2006). Consequently, it is likely only to be possible to gap one zygapophysial joint in any single spinal segment without exceeding tissue failure limits. As a result, the required motion of the target spinal segment during spinal manipulation will always be asymmetrical (a criterion that excludes motion purely in the sagittal plane), which is consistent with observation (Fig. 1). Accordingly, the manipulation force must be applied along a line of action such that the existing morphology of the target spinal segment is exploited to induce separation of the articular surfaces of one (target) zygapophysial joint. There are several hypotheses that attempt to explain how this transpires.

Hypothesis 1. Segmental motion that opposes coupling.

Several authors have proposed that the basis of spinal manipulation kinematics is that the induced motion of the target segment directly opposes normal segmental coupling (Nyberg, 1993; Gibbons and Tehan, 2001; McCarthy, 2001). An example where this is clearly evident is in the cervical spine.

It is well known that transverse rotation in typical cervical segments (C3–C7) is accompanied by ipsilateral lateral flexion, and vice versa (Lysell, 1969; Penning and Wilmink, 1987; White and Panjabi, 1990; Cook et al., 2006). Of the various elements of a spinal segment, the geometry of zygapophysial joints has most bearing on the kinematic behaviour of that segment (Malmivaara et al., 1987; Singer et al., 1988; Panjabi et al., 1993; Bogduk and Mercer, 2000; König and Vitzthum, 2001; Pal et al., 2001). Hence, the coupling pattern seen in typical cervical segments arises primarily because the articular surfaces of the zygapophysial joints are orientated some 40° ventrad to the frontal plane (Penning and Wilmink, 1987; Milne, 1991). This means that unilateral (non-sagittal) rotation occurs between neighbouring cervical vertebrae about an oblique axis that lies in the sagittal plane, passing upwards and backwards through the front of the disc and through the posterior part of the moving vertebral body, perpendicular to the surfaces of the zygapophysial joints (Milne, 1991). This is illustrated in Fig. 3A.

As a further upshot of this configuration, isolated lateral flexion at a cervical motion segment is not possible as rotation about an axis parallel to the plane of the zygapophysial joints is precluded by the impaction of the joints (Bogduk and Mercer, 2000). Therefore, of those described by the three 'cardinal' planes, only two natural forms of motion are permitted by the morphology of a typical cervical segment; sagittal rotation and a combined 'transverse and frontal' rotation about an axis perpendicular to the plane of the zygapophysial joints (Fig. 3B).

A variety of cervical spine manipulation techniques are available (Kawchuk and Herzog, 1993). Even so, irrespective of the minutiae variation employed in different cervical spine manipulation techniques, the fundamental kinematics are always the same. Studies that have measured global cervical spine kinematics during cervical manipulation consistently demonstrate transverse rotation

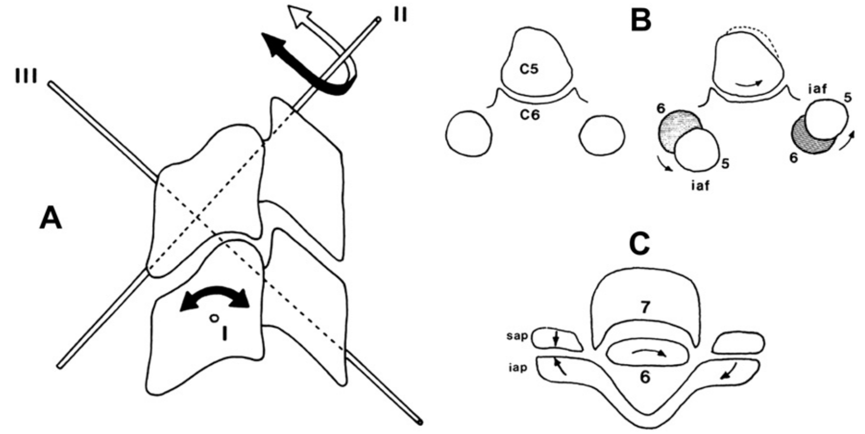

Fig. 3. **A**. The three mutually perpendicular axes of rotation in typical cervical motion segments. **B**. Rotation of a typical cervical segment (C5–C6) occurring about axis II. The figure shows a cross-section of the segment, viewed from above, along the same axis. Rotation of the C5 vertebra about this axis allows its inferior articular facets (iaf) to freely glide across the superior articular facets of C6. **C**. Rotation to the left of a typical cervical segment occurring about axis III. The figure shows a cross-section of the segment, viewed from above, along the same axis. Rotation to the left of the C6 vertebra about this axis results in the immediate impaction of its right inferior articular process (iap), en face, into the superior articular process (sap) of C7, which precludes further rotation of C6 about this axis. All figures modified from Bogduk and Mercer (2003).

accompanied by contralateral lateral flexion (Triano and Schultz, 1994; Klein et al., 2003; Ngan et al., 2005). Despite not revealing exactly what happens at individual segments, this motion pattern is in direct contrast to normal coupling patterns and, in effect, equates to forced rotation about the ‘blocked’ axis of a typical cervical segment (axis III in Fig. 3). A typical mid-cervical ‘rotatory’ manipulation that clearly demonstrates this motion pattern is shown in Fig. 1A.

Although rather elegant, this hypothesis falls down when other spinal regions are considered. Recent studies have shown that both thoracic and lumbar spinal segments do not demonstrate consistent coupling behaviour (Legaspi and Edmond, 2007; Sizer et al., 2007). However, a reinterpretation of the kinematics of cervical spine segments offers an alternative hypothesis that can be tested in other spinal regions: the arrangement of restraints for every spinal segment results in rotation that is ‘blocked’ about a particular axis, and this is exploited by manipulation techniques.

Hypothesis 2. Rotation about a ’blocked’ axis, parallel to zygapophysial joint surfaces.

A spinal segment has two rather obvious functionally distinct sections; the anterior and posterior elements. In the absence of the posterior elements (principally the zygapophysial joints), the spine would be a relatively simple and easily deformable structure, consisting mainly of a column of vertebral bodies and intervertebral discs, surrounded by anterior and posterior longitudinal ligaments. Hence, motion of these segments would be entirely a function of these isolated anterior elements and would be available, to some extent, in all six degrees of freedom: rotation about and translation along three mutually perpendicular axes (White and Panjabi, 1971; Adams and Hutton, 1983; McGlashen et al., 1987; Stokes, 1988; Abumi et al., 1990; Nägerl et al., 1990; Spenciner et al., 2006).

Conversely, in the absence of the anterior elements (above all, the intervertebral disc), the motion of each spinal segment would be entirely a function of its posterior elements, principally the superior and inferior articular processes and the zygapophysial joints that they form. The orientation and morphology of the zygapophysial joints vary greatly, usually predictably, according to spinal level. Typical lumbar zygapophysial joints (L1–L5) are almost planar in nature and their articular facets are approximately aligned to the sagittal plane (Fig. 4A). As such, the geometry of these articular surfaces when viewed in the transverse plane (effectively a cross-section of the zygapophysial joints) can be approximated by a circle, drawn perpendicular to the articular surfaces, whose circumference passes between the articular surfaces of each joint (van Schaik et al., 1997). Hence, in the absence of anterior elements, the centre of this circle will effectively represent a ‘natural’ axis for rotation of the isolated posterior elements in the transverse plane; the axis being parallel to the plane of the zygapophysial joint surfaces (Fig. 4A). Uninterrupted, the surfaces of each zygapophysial joint would freely glide over one another on the circumference of this circle, limited chiefly by the restraint provided by the joint capsule and surrounding ligaments, which when intact (Zdeblick et al., 1993; Sim et al., 2001) ensure the joint surfaces do not ‘slide off’ one another. In reality, the surfaces of zygapophysial joints are not perfectly congruent and consequently the precise location of this axis would vary slightly during transverse rotation (Kubein-Meesenburg et al., 1991; Nägerl et al., 1992), but the use of a ‘facet orientation circle’ (van Schaik et al., 1997) suffices for the present discussion.

When anterior and posterior elements are combined, as in a complete spinal segment, something of a mechanical ‘tussle’ ensues between the two elements, and motion is constrained as a result (Berkson, 1977; Nägerl et al., 1992; Thompson et al., 2003; Mansour et al., 2004). In lumbar spinal segments, an immediate upshot of this complete articular arrangement (the ‘articular triad’) is an anterior migration of the axis of transverse rotation to a location within the posterior third of the anulus fibrosus of the intervertebral disc (Cossette et al., 1971) (Fig. 5A), where the axis of minimal torsional stiffness lies (Adams and Hutton, 1981). As a result, the range of lumbar transverse rotation is very limited (approximately 1–2° in each direction), being effectively ‘blocked’ by the articular surfaces of the ipsilateral zygapophysial joint approximating to the point of contact (Singer et al., 1989; Singer and Giles, 1990; Shirazi-Adl, 1994) (Figs. 4A and 5B).

If transverse rotation in lumbar spinal segments is forced beyond this physiological range, compressive forces are generated on the impacted surfaces of the ipsilateral zygapophysial joint (Adams and Hutton, 1981) and rotation will occur about a new axis of transverse rotation, parallel to the previous one, but now located within the impacted joint (Nägerl et al., 1992; Mansour et al., 2004). Effectively, the axis of transverse rotation is forced to migrate to where the impacted surfaces of this joint meet. As a result, the

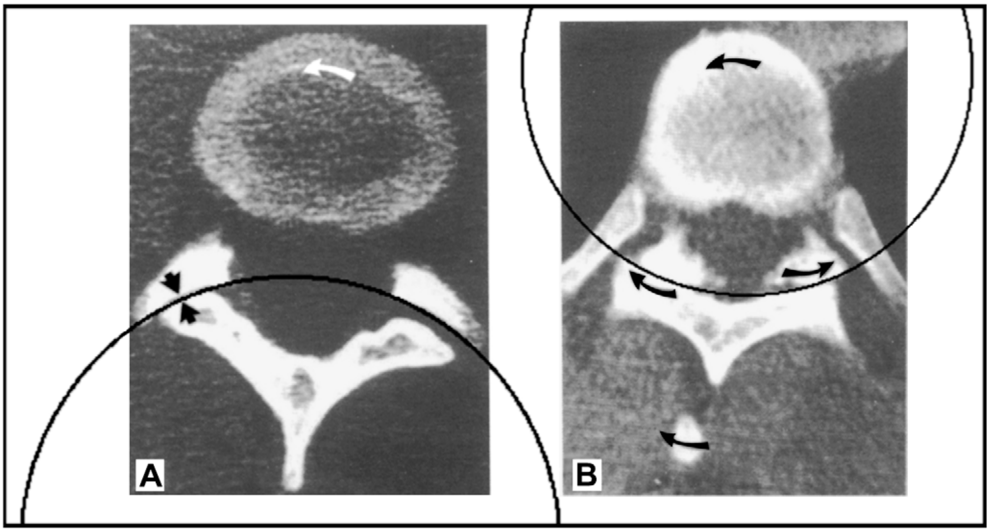

Fig. 4. Transverse rotation in (**A**) lumbar and (**B**) thoracic spinal segments, viewed in the transverse plane. The axis of rotation is perpendicular to the surfaces of the zygapophysial joints in both cases and a 'facet orientation circle', which represents the cross-sectional geometry of a pair of zygapophysial joints in the transverse plane, is superimposed on each image. The centre of this circle clearly lies posterior to the intervertebral disc in the lumbar segment, whereas it lies within the intervertebral disc in the thoracic segment. Modified, with permission, from Singer (1994).

surfaces of the contralateral zygapophysial joint separate (Singer et al., 1989; Fazey et al., 2006), with little resistance from the joint capsule and surrounding ligaments (Adams and Hutton, 1981). This can clearly be seen in Fig. 4A. Intriguingly, this is precisely what appears to occur during lumbar spine manipulation (Singer and Giles, 1990; Cramer et al., 2000, 2002) (Fig. 1C).

There is evidence from other spinal regions to support the hypothesis that forced rotation about a 'blocked' axis of rotation, parallel to the articular surfaces of the zygapophysial joints, is associated with joint gapping. The coupling patterns of cervical segments are obscured when the conventional 'cardinal' axes reference framework is used to describe the motion of spinal segments (Fig. 6). However, Fig. 3A clearly illustrated that rotation about an axis parallel to the zygapophysial joint surfaces is blocked in typical cervical segments (C3–C7). Furthermore, Fig. 6 shows that rotation about one cardinal axis is blocked also in atypical cervical (C0–C2) and lumbosacral segments. Closer scrutiny reveals that each of these blocked axes is parallel to the articular surfaces of the respective posterior joints (Werne, 1958; White and Panjabi, 1990; Taylor and Twomey, 1994; Worth, 1994; Bogduk and Mercer, 2000; Bogduk, 2005).

This hypothesis clearly performs well. That is, until the thoracic spine is considered. With frontally orientated zygapophysial joints, the axis parallel to the zygapophysial joint surfaces corresponds to that of transverse rotation. However, when considering anterior and posterior elements separately, the centre of transverse rotation relating to both elements lies fairly close to the location of minimal torsion of the intervertebral disc synarthrosis (Nägerl et al., 1990; Molnár et al., 2006). Consequently, transverse rotation is not naturally blocked in thoracic segments (Fig. 4B). In fact, no axis of segmental rotation is naturally blocked, even outside of the cardinal reference system. Thus, the hypothesis that gapping of a zygapophysial joint within a complete spinal segment is always a result of forced rotation about a naturally blocked axis appears to be insufficient.

Hypothesis 3. Migration of the axis of rotation to the contralateral zygapophysial joint.

In general, rotation of a complete spinal segment is available about an axis that is perpendicular to the plane of the zygapophysial joint surfaces. In contrast, if a naturally blocked axis exists, it lies parallel to the plane of the zygapophysial joint

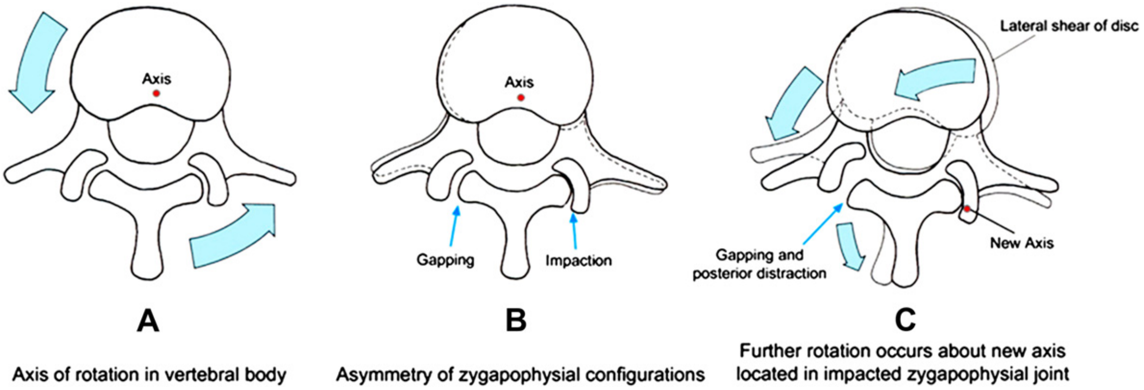

Fig. 5. Transverse plane cross-sections of a typical lumbar segment during stages of transverse rotation. The figure depicts the configuration of the zygapophysial joints viewed along the axis of transverse rotation, which is parallel to the articular surfaces of the zygapophysial joints. Reproduced from Bogduk (2005).

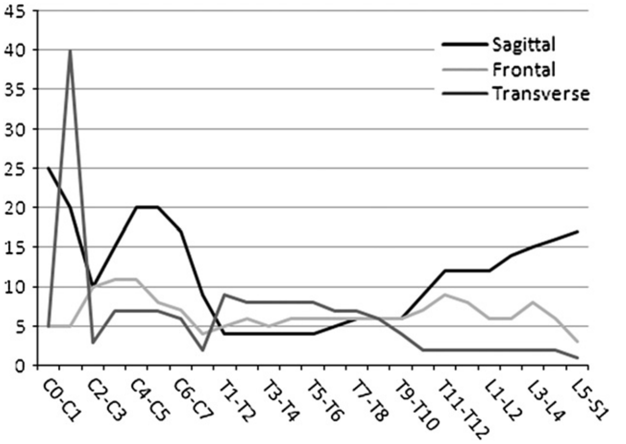

Fig. 6. Superimposed representative angles of sagittal (flexion–extension), frontal (lateral bending), and transverse (horizontal) rotation for all spinal segments. As these ranges of motion were produced from cadavers, they are likely to be representative of passive ranges of motion. Based on data from White and Panjabi (1990).

surfaces. In all spinal regions examined so far, spinal manipulation techniques have been seen to exploit these naturally blocked axes, orientating the target segment such that the line of action of the applied force is perpendicular to the articular surfaces of the target joint; a feature observed as common to all forms of manipulation (Table 1).

Thoracic spinal segments differ from those in other spinal regions in that, particularly when isolated from the ribs, rotation about an axis parallel to the articular surfaces of zygapophysial joints (transverse rotation) is not naturally blocked. Instead, the frontally orientated zygapophysial joint surfaces are free to glide in all directions and allow transverse rotation, which is largely unopposed by the intervertebral disc (Fig. 4B). A modification of Hypothesis 2 is therefore required if a successful general model of spinal manipulation is to be attained.

In all spinal regions examined so far, a consistent relationship has existed between the two zygapophysial joints of the target segment; target joint gapping was always accompanied by contralateral 'non-target' joint surface contact. In the thoracic spine this presents a problem because no naturally occurring axis of rotation is blocked by impacted zygapophysial joint surfaces, even when departing from the cardinal reference system. Hence, if this relationship *is* to occur during manipulation in thoracic segments, the natural configuration of these segments must be changed in some additional way.

As mentioned above, the articular surfaces of zygapophysial joints in typical thoracic segments (T4–T10) are orientated close to the frontal plane. Separation of the surfaces of one of these zygapophysial joints therefore requires a relative anterior translation of the ipsilateral superior articular process of the caudad vertebra. As a result, force can be applied directly over the caudad vertebra in a posterior–anterior direction, perpendicular to the skin surface, without modifying the resting configuration of a patient in prone lying (Fig. 1B).

Only one study with rigorous methodology (Gál et al., 1994, 1995) has provided accurate three-dimensional kinematic data for both absolute and relative vertebral movements during manipulation of the thoracic spine. This study measured vertebral motion using bone pins embedded in the T10, T11 and T12 (atypical thoracic) vertebrae of unembalmed post-rigor human cadavers while a prone unilateral posterior–anterior manipulation was performed using a reinforced hypothenar contact (see Fig. 1B). Several manipulation 'trials' were recorded in the study and only one single cavitation event at T11–T12 was recorded. The kinematic data of all manipulation trials were compared and consistently demonstrated simultaneous transverse and sagittal rotations, combined with a posterior–anterior translation. However, these data also showed that a significantly greater lateral translation of the inferior vertebra (T11), away from the manipulating hand, was associated with the single occurrence of cavitation (Gál et al., 1995). Although these results need verification, because they are based on only one case and because of the variability in the atypical, lower thoracic spine orientation and morphology (Singer et al., 1988), it is tantalising to conclude that this additional lateral translation effectively migrated the axis of transverse rotation towards the contralateral zygapophysial joint. Consequently, the previously free transverse rotation would become blocked due to the now impacted contralateral zygapophysial joint surfaces, and further, forced rotation results in gapping of the other (target) joint (Fig. 7).

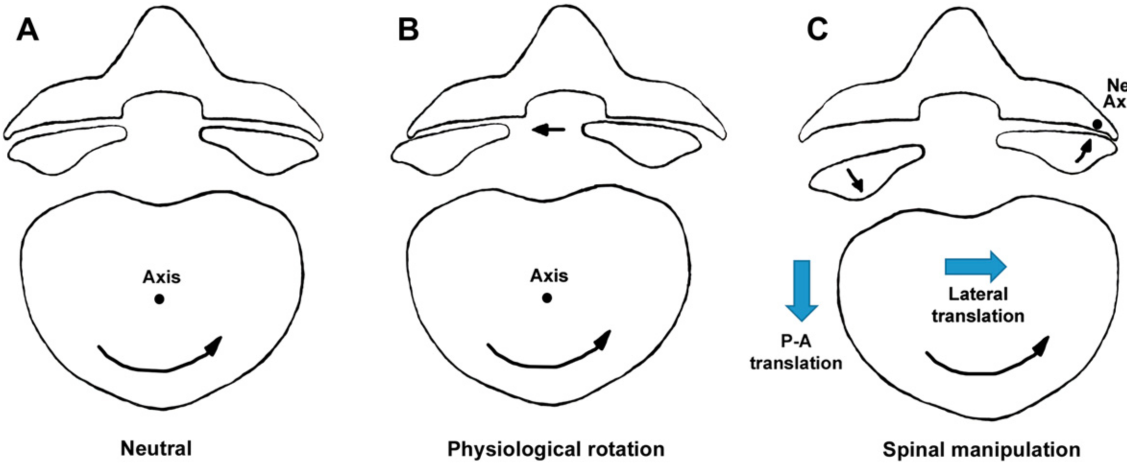

Fig. 7. Transverse plane cross-sections of a typical thoracic segment during: **A**. Neutral configuration. **B**. 'Physiological' transverse rotation, which occurs about an axis parallel to the articular surfaces of the zygapophysial joints. **C**. The predicted motion that occurs during manipulation at a typical thoracic segment. Separation of the articular surfaces of one zygapophysial joint results from simultaneous sagittal and transverse rotations, combined with posterior–anterior and lateral translation of the caudad vertebra relative to its cephalad neighbour.

3. Conclusions

A question was posed at the beginning of this paper: why do spinal manipulation techniques take the form they do? From the available literature, two factors appear to provide an answer: how an applied force is able to act upon vertebrae of a target spinal segment, and the morphology of those vertebrae.

Any 'direct' spinal manipulation technique requires that the patient be orientated in such a way that force is applied perpendicular to the overlying skin surface so as to act upon the vertebrae beneath. If the vertebral motion produced by 'directly' applied force is insufficient to produce the desired effect (e.g. cavitation), then force must be applied 'indirectly', often through remote body segments such as the head, thorax, abdomen, pelvis and extremities.

The available data from biomechanical studies so far support the hypothesis that spinal manipulation techniques exploit the morphology of vertebrae by inducing rotation at a spinal segment, about an axis that is always parallel to the articular surfaces of the constituent zygapophysial joints. In doing so, the articular surfaces of one zygapophysial joint appose to the point of contact, resulting in migration of the axis of rotation towards these contacting surfaces, and in turn this facilitates gapping of the other (target) zygapophysial joint. There is sufficient evidence to suggest that the alternative hypotheses described previously are insufficient to describe the segmental kinematics occurring during all spinal manipulation techniques and should therefore be rejected. Importantly, the retained hypothesis is consistent with all previously identified necessary features of joint manipulation, listed in Table 1.

Other variations in the form of spinal manipulation techniques are likely to depend upon the personal style and individual choices of the practitioner. Indeed, a general model of spinal manipulation requires the assumption of equivalence of techniques; if successfully applied, any valid spinal manipulation technique should produce the same effect on a target joint as any other. For example, spinal manipulation techniques have historically been divided into direct (or 'short-lever') or indirect ('long-lever') techniques. The former involves the application of force directly over the target segment, whereas during the latter force is delivered to the target segment through its contiguous neighbours, and even from remote body segments such as the head, thorax, abdomen, pelvis and extremities. In both classes of technique, there will be some deformation of both superficial and restraining tissues. The above discussion imposes clear limiting conditions on the segmental motion likely to take place during any spinal manipulation technique. Hence, any distinction between 'long-lever' and 'short-lever' techniques appears to be arbitrary as they will result in very similar motion of the affected spinal segment.

This discussion is based on available basic science data. As such, any conclusions drawn are limited by the relatively small volume of these data and must therefore be considered tentative. Further studies are sorely needed, particularly in vivo studies of cervical and thoracic manipulation, where the influence of all restraining tissues (including the ribs and costal articulations) can be clearly observed. Hopefully then, we will move closer to possessing a valid general model of spinal manipulation.

4. Clinical summary

- Spinal manipulation techniques have been passed from one generation of manipulators to the next as an eclectic collection, rather than being unified by a general model.
- Such a general model would aid in the teaching and execution of these techniques, and provide insight into their likely safety and mechanisms of action.
- The material presented in this masterclass is written as a first attempt at constructing such a general model from available scientific data.
- Manual therapists should find this masterclass useful when learning spinal manipulation techniques, especially when anatomical models are used as teaching aids.

References

Abumi K, Panjabi MM, Kramer KM, Duranceau J, Oxland T, Crisco JJ. Biomechanical evaluation of lumbar spinal stability after graded facetectomies. Spine 1990;15:1142–7.

Adams MA, Hutton WC. The relevance of torsion to the mechanical derangement of the lumbar spine. Spine 1981;6(3):241–8.

Adams MA, Hutton WC. The mechanical function of the lumbar apophyseal joints. Spine 1983;8(3):327–30.

Alexander H, Cook TH. Accounting for natural tension in the mechanical testing of human skin. J Invest Dermatol 1977;69:310–4.

Anderson R. Spinal manipulation before chiropractic. In: Haldeman S, editor. Principles and practice of chiropractic. Norwalk, CT: Appleton & Lange; 1992. p. 3–14.

Assendelft WJ, Morton SC, Yu EI, Suttorp MJ, Shekelle PG. Spinal manipulative therapy for low back pain. A meta-analysis of effectiveness relative to other therapies. Ann Inter Med 2003;138(11):871–81.

Bartol KM. Osseous manual thrust techniques. In: Gatterman MI, editor. Foundations of chiropractic: subluxation. 1st ed. St. Louis: Mosby; 1995. p. 87–104.

Bereznick DE. Lumbar manipulation: quantification and modification of the external kinetics affecting the presence and site of cavitation. PhD thesis, University of Waterloo, Ontario; 2005.

Bereznick DE, Ross JK, McGill SM. The frictional properties at the thoracic skin–fascia interface: implications in spine manipulation. Clin Biomech (Bristol, Avon) 2002;17(4):297–303.

Berkson MH. Mechanical properties of the human lumbar spine flexibilities, intradiscal pressures, posterior element influences. Proc Inst Med Chic 1977;31:138–43.

Bogduk N. Clinical anatomy of the lumbar spine and sacrum. 4th ed. Edinburgh: Churchill Livingstone; 2005.

Bogduk N, Mercer S. Biomechanics of the cervical spine. I: normal kinematics. Clin Biomech (Bristol, Avon) 2000;15(9):633–48.

Bronfort G, Haas M, Evans RL, Bouter LM. Efficacy of spinal manipulation and mobilization for low back pain and neck pain: a systematic review and best evidence synthesis. Spine 2004;4(3):335–56.

Bronfort G, Haas M, Evans R, Kawchuk G, Dagenais S. Evidence-informed management of chronic low back pain with spinal manipulation and mobilization. Spine 2008;8(1):213–25.

Carrino JA, Manton GL, Morrison WB, Vaccaro AR, Schweitzer ME, Flanders AE. Posterior longitudinal ligament status in cervical spine bilateral facet dislocations. Skeletal Radiol 2006;35(7):510–4.

Cook C, Hegedus E, Showalter C, Sizer PS. Coupling behavior of the cervical spine: a systematic review of the literature. J Manipulative Physiol Ther 2006;29(7):570–5.

Cossette JW, Farfan HF, Robertson GH, Wells RV. The instantaneous center of rotation of the third lumbar intervertebral joint. J Biomech 1971;4(2):149–53.

Cramer GD, Tuck Jr NR, Knudsen JT, Fonda SD, Schliesser JS, Fournier JT, et al. Effects of side-posture positioning and side-posture adjusting on the lumbar zygapophysial joints as evaluated by magnetic resonance imaging: a before and after study with randomization. J Manipulative Physiol Ther 2000;23(6): 380–94.

Cramer GD, Gregerson DM, Knudsen JT, Hubbard BB, Ustas LM, Cantu JA. The effects of side-posture positioning and spinal adjusting on the lumbar Z joints: a randomized controlled trial with sixty-four subjects. Spine 2002;27(22): 2459–66.

Cramer G, Budgell B, Henderson C, Khalsa P, Pickar J. Basic science research related to chiropractic spinal adjusting: the state of the art and recommendations revisited. J Manipulative Physiol Ther 2006;29(9):726–61.

Daly CH. Biomechanical properties of dermis. J Invest Dermatol 1982;79:17–20.

Evans DW, Breen AC. A biomechanical model for mechanically efficient cavitation production during spinal manipulation: prethrust position and the neutral zone. J Manipulative Physiol Ther 2006;29(1):72–82.

Evans DW, Lucas N. What is manipulation? A reappraisal. Man Ther, submitted for publication.

Fazey PJ, Song S, Mønsås S, Johansson L, Haukalid T, Price RI, et al. An MRI investigation of intervertebral disc deformation in response to torsion. Clin Biomech (Bristol, Avon) 2006;21(5):538–42.

Gál J, Herzog W, Kawchuk G, Conway P, Zhang Y-T. Biomechanical studies of spinal manipulative therapy (SMT): quantifying the movements of vertebral bodies during SMT. J Can Chiropr Assoc 1994;38:11–24.

Gál JM, Herzog W, Kawchuk GN, Conway PJ, Zhang Y-T. Forces and relative vertebral movements during SMT to unembalmed post-rigor human cadavers: peculiarities associated with joint cavitation. J Manipulative Physiol Ther 1995;18:4–9.

Gibbons P, Tehan P. Patient positioning and spinal locking for lumbar spine rotation manipulation. Man Ther 2001;6(3):130–8.

Gross AR, Hoving JL, Haines TA, Goldsmith CH, Kay T, Aker P, et al, Cervical Overview Group. A Cochrane review of manipulation and mobilization for mechanical neck disorders. Spine 2004;29(14):1541–8.

Harris JD. History and development of manipulation and mobilization. In: Basmajian JV, Nyberg R, editors. Rational manual therapies. Baltimore: Williams & Wilkins; 1993. p. 7–19 [chapter 2].

Herzog W. The mechanical, neuromuscular, and physiologic effects produced by spinal manipulation. In: Herzog W, editor. Clinical biomechanics of spinal manipulation. New York: Churchill Livingstone; 2000. p. 191–207.

Kawchuk GN, Herzog W. Biomechanical characterization (fingerprinting) of five novel methods of cervical spine manipulation. J Manipulative Physiol Ther 1993;16(9):573–7.

Kawchuk GN, Perle SM. The relation between the application angle of spinal manipulative therapy (SMT) and resultant vertebral accelerations in an *in situ* porcine model. Man Ther 12 Jan 2009;14(5):480–3.

Klein P, Broers C, Feipel V, Salvia P, Van Geyt B, Dugailly PM, et al. Global 3D head-trunk kinematics during cervical spine manipulation at different levels. Clin Biomech (Bristol, Avon) 2003;18(9):827–31.

König A, Vitzthum HE. Functional MRI of the spine: different patterns of positions of the forward flexed lumbar spine in healthy subjects. Eur Spine J 2001;10(5):437–42.

Kubein-Meesenburg D, Nägerl H, Fanghänel J. Elements of a general theory of joints. 4. Coupled joints as simple gear systems. Anat Anz 1991;172(5):309–21.

Kulig K, Landel R, Powers CM. Assessment of lumbar spine kinematics using dynamic MRI: a proposed mechanism of sagittal plane motion induced by manual posterior-to-anterior mobilization. J Orthop Sports Phys Ther 2004;34(2):57–64.

Legaspi O, Edmond SL. Does the evidence support the existence of lumbar spine coupled motion? A critical review of the literature. J Orthop Sports Phys Ther 2007;37(4):169–78.

Levine AM, Bosse M, Edwards CC. Bilateral facet dislocations in the thoracolumbar spine. Spine 1988;13(6):630–40.

Lysell E. Motion in the cervical spine. An experimental study on autopsy specimens. Acta Orthop Scand 1969;(Suppl. 123):41–61.

Malmivaara A, Videman T, Kuosma E, Troup JD. Facet joint orientation, facet and costovertebral joint osteoarthrosis, disc degeneration, vertebral body osteophytosis, and Schmorl's nodes in the thoracolumbar junctional region of cadaveric spines. Spine 1987;12(5):458–63.

Mansour M, Spiering S, Lee C, Dathe H, Kalscheuer AK, Kubein-Meesenburg D, et al. Evidence for IHA migration during axial rotation of a lumbar spine segment by using a novel high-resolution 6D kinematic tracking system. J Biomech 2004;37:583–92.

McCarthy CJ. Spinal manipulative thrust technique using combined movement theory. Man Ther 2001;6(4):197–204.

McGlashen KM, Miller JA, Schultz AB, Andersson GB. Load displacement behavior of the human lumbo-sacral joint. J Orthop Res 1987;5:488–96.

McGregor AH, Wragg P, Gedroyc WM. Can interventional MRI provide an insight into the mechanics of a posterior–anterior mobilisation? Clin Biomech (Bristol, Avon) 2001;16(10):926–9.

Milne N. The role of zygapophysial joint orientation and uncinate processes in controlling motion in the cervical spine. J Anat 1991;178:189–201.

Molnár S, Manó S, Kiss L, Csernátony Z. Ex vivo and in vitro determination of the axial rotational axis of the human thoracic spine. Spine 2006;31(26):E984–91.

Nägerl H, Kubein-Meesenburg D, Fanghänel J. Elements of a general theory of joints. 2. Introduction to a theory of synarthrosis. Anat Anz 1990;171:323–33.

Nägerl H, Kubein-Meesenburg D, Fanghänel J. Elements of a general theory of joints. 7. Mechanical structures of the relative motion of adjacent vertebrae. Ann Anat 1992;174(1):66–75.

Ngan JM, Chow DH, Holmes AD. The kinematics and intra- and inter-therapist consistencies of lower cervical rotational manipulation. Med Eng Phys 2005;27(5):395–401.

Nyberg R. Manipulation: definition, types, application. In: Basmajian JV, Nyberg R, editors. Rational manual therapies. Baltimore: Williams & Wilkins; 1993. p. 21–47 [chapter 3].

Pal GP, Routal RV, Saggu SK. The orientation of the articular facets of the zygapophyseal joints at the cervical and upper thoracic region. J Anat 2001;198(4):431–41.

Panjabi MM, Oxland T, Takata K, Goel V, Duranceau J, Krag M. Articular facets of the human spine. Quantitative three-dimensional anatomy. Spine 1993;18(10):1298–310.

Penning L, Wilmink JT. Rotation of the cervical spine. A CT study in normal subjects. Spine 1987;12(8):732–8.

Peterson DH, Bergmann TF. Chiropractic technique. 2nd ed. St. Louis: Mosby; 2002.

Powers CM, Kulig K, Harrison J, Bergman G. Segmental mobility of the lumbar spine during a posterior to anterior mobilization: assessment using dynamic MRI. Clin Biomech (Bristol, Avon) 2003;18(1):80–3.

Reihsner R, Baloghi B, Menzel EJ. Two-dimensional elastic properties of human skin in terms of an incremental model at the in vivo configuration. Med Eng Phy 1995;17:304–13.

Shirazi-Adl A. Nonlinear stress analysis of the whole lumbar spine in torsion – mechanics of facet articulation. J Biomech 1994;27(3):289–99.

Sim E, Vaccaro AR, Berzlanovich A, Schwarz N, Sim B. In vitro genesis of subaxial cervical unilateral facet dislocations through sequential soft tissue ablation. Spine 2001;26(12):1317–23.

Singer KP. Anatomy and biomechanics of the thoracolumbar junction. In: Boyling JD, Pastalanga N, editors. Grieve's modern manual therapy: the vertebral column. 2nd ed. Edinburgh: Churchill Livingstone; 1994. p. 85–97.

Singer KP, Breidahl PD, Day RE. Variations in zygapophyseal joint orientation and level of transition at the thoracolumbar junction. Preliminary survey using computed tomography. Surg Radiol Anat 1988;10(4):291–5.

Singer KP, Willen J, Breidahl PD, Day RE. Radiologic study of the influence of zygapophyseal joint orientation on spinal injuries at the thoracolumbar junction. Surg Radiol Anat 1989;11(3):233–9.

Singer KP, Giles LG. Manual therapy considerations at the thoracolumbar junction: an anatomical and functional perspective. J Manipulative Physiol Ther 1990;13(2):83–8.

Sizer Jr PS, Brismée JM, Cook C. Coupling behavior of the thoracic spine: a systematic review of the literature. J Manipulative Physiol Ther 2007;30(5):390–9.

Spenciner D, Greene D, Paiva J, Palumbo M, Crisco J. The multidirectional bending properties of the human lumbar intervertebral disc. Spine 2006;6(3):248–57.

Stark HL. Directional variations in the extensibility of human skin. Br J Plast Surg 1977;30:105–14.

Stokes IAF. Mechanical function of facet joints in the lumbar spine. Clin Biomech (Bristol, Avon) 1988;3:101–5.

Taylor JR, Twomey LT. Structure and function of lumbar zygapophysial (facet) joints. In: Boyling JD, Pastalanga N, editors. Grieve's modern manual therapy: the vertebral column. 2nd ed. Edinburgh: Churchill Livingstone; 1994. p. 99–108.

Thompson RE, Barker TM, Pearcy MJ. Defining the neutral zone of sheep intervertebral joints during dynamic motions: an in vitro study. Clin Biomech (Bristol, Avon) 2003;18(2):89–98.

Tohme-Noun C, Rillardon L, Krainik A, Guigui P, Menu Y, Feydy A. Imaging features of traumatic dislocation of the lumbosacral joint associated with disc herniation. Skeletal Radiol 2003;32(6):360–3.

Triano JJ, Schultz AB. Motions of the head and thorax during neck manipulations. J Manipulative Physiol Ther 1994;17(9):573–83.

van Schaik JP, van Pinxteren B, Verbiest H, Crowe A, Zuiderveld KJ. The facet orientation circle. A new parameter for facet joint angulation in the lower lumbar spine. Spine 1997;22(5):531–6.

van Zoest GG, van den Berg HT, Holtkamp FC. Three-dimensionality of contact forces during clinical manual examination and treatment: a new measuring system. Clin Biomech (Bristol, Avon) 2002;17(9–10):719–22.

van Zoest GG, Gosselin G. Three-dimensionality of direct contact forces in chiropractic spinal manipulative therapy. J Manipulative Physiol Ther 2003;26(9):549–56.

Werne S. The possibilities of movement in the craniovertebral joints. Acta Orthop Scand 1958;28:165–73.

White AA, Panjabi MM. The significance of the vertebral posterior elements for the mechanics of the thoracic spine. Clin Orthop 1971;81:2–14.

White AA, Panjabi MM, editors. Clinical biomechanics of the spine. 2nd ed. Philadelphia: JB Lippincott; 1990.

Wiese G, Callender A. History of spinal manipulation. In: Haldeman S, Dagenais S, Budgell B, Grunnet-Nilsson N, Hooper PD, Meeker WC, Triano J, editors. Principles and practice of chiropractic. 3rd ed. New York: McGraw-Hill; 2005. p. 5–22.

Worth DR. Movements of the head and neck. In: Boyling JD, Pastalanga N, editors. Grieve's modern manual therapy: the vertebral column. 2nd ed. Edinburgh: Churchill Livingstone; 1994. p. 53–68.

Zdeblick TA, Abitbol JJ, Kunz DN, McCabe RP, Garfin S. Cervical stability after sequential capsule resection. Spine 1993;18:2005–8.