Investigation of reaction force magnitude and orientation during supine thoracic thrust manipulation applied to intervertebral and costovertebral regions.

Citation APA:

DOI: 10.1016/j.msksp.2020.102217

Also available at: http://hdl.handle.net/2013/ULB-DIPOT:oai:dipot.ulb.ac.be:2013/313424

Cet article publié par ELSEVIER provient du Dépôt institutionnel de l’Université Libre de Bruxelles, DI-fusion http://difusion.ulb.ac.be. Il n’est accessible qu’aux membres de la communauté universitaire de l’ULB sur le réseau sécurisé de l’ULB.

Tout utilisateur autorisé peut lire, télécharger ou reproduire cet article à des fins d’usage privé ou à des fins non commerciales d’enseignement ou de recherche scientifique. Il ne peut être atteint à l’intégrité de l’article, et les noms des auteurs et de l’éditeur doivent être conservés. Tout téléchargement systématique des articles publiés par ELSEVIER mis à disposition dans DI-fusion est interdit.

This article published by ELSEVIER comes from the Institutional repository of Université Libre de Bruxelles, DI-fusion http://difusion.ulb.ac.be. It is accessible only to the members of the university community of ULB on the ULB secure network.

Any authorized user may read, download or reproduce this article for private usage, or for non commercial research or educational purposes. The integrity of the article and identification of the author and copyright owner must be preserved. Systematic downloading of articles published by ELSEVIER that are available in DI-fusion is not permitted.
Investigation of reaction force magnitude and orientation during supine thoracic thrust manipulation applied to intervertebral and costovertebral regions.

B. Beyer\textsuperscript{a,b,*}, A. Michaud\textsuperscript{a}, T. Oliver\textsuperscript{a}, V. Feipel\textsuperscript{a}, P.-M. Dugailly\textsuperscript{a,c}

\textsuperscript{a} Laboratory of Functional Anatomy, Faculty of Motor Sciences, Université Libre de Bruxelles, Brussels, Belgium
\textsuperscript{b} Lymphology and Rehabilitation Research Unit, Faculty of Motor Sciences, Université Libre de Bruxelles, Brussels, Belgium
\textsuperscript{c} CESPU-Escola superior de Saúde do Vale do Ave, Famalicão, Portugal

**ARTICLE INFO**

**Keywords:**
Thrust
Preload
Costovertebral
Supine thoracic manipulation
Reaction force

**ABSTRACT**

**Background:** Spinal manipulative techniques are commonly used in manual therapies but quantified descriptive and reliability data are lacking considering supine thoracic thrust manipulation.

**Objectives:** The purpose of this study is to explore and compare kinetic parameters during supine thoracic thrust manipulation performed at two different thoracic regions. Intra-rater task repeatability and influence of practitioners were estimated.

**Design:** Exploratory and agreement study.

**Methods:** Kinetic parameters were assessed by examining reaction force magnitude and orientation (on the basis of the zenithal angle) using force platforms. Manipulative procedure (consisting in the application of 3 preloads followed by one thrust adjustment) at both intervertebral and costovertebral region was performed by different practitioners at three sessions. Application of thrust was allowed for experienced practitioners only. Preload force, peak force magnitude and vector force orientation were compared between anatomical sites, sessions and practitioners, and bias with limit of agreement were estimated.

**Results:** Repeatability analysis showed that practitioners achieved similar preload and peak force independent of the session, with comparable force orientation. Differences between practitioners were observed for preload and peak force but not regarding the zenithal angle during the thrust phase.

**Conclusions:** The present study is the first that explores kinetic parameters for supine thoracic thrust manipulation applied on two different regions of the thorax. Results confirm consistency of performance among practitioners for supine manipulative techniques at intervertebral and costovertebral region. While task repeatability was confirmed, several differences were observed between practitioners. Further investigations would examine velocity, acceleration and potential neurophysiological effect of such manipulative technique.

1. **Introduction**

Spinal manipulative techniques have been suggested as a cost-effective treatment tool and are frequently used in multimodal therapeutic programs for management of various musculoskeletal complaints of the spine (Michaleff et al., 2012). A previous model suggests that clinical outcomes are related to the interplay between biomechanical and neurophysiological effects of manual therapy (Bialosky et al., 2009). Spinal thrust manipulations have shown to produce such biomechanical and neurophysiological outcomes related to joint gapping (Cramer et al., 2011), joint kinematics (Williams and Cuesta-Vargas, 2013), neuromuscular responses (Pagé et al., 2016) and muscle spindle activity (Pickar and Kang, 2006). Several studies investigated biomechanical features of thrust manipulation technique (e.g. kinematics, peak force, time to peak, force rate, type of technique) applied to different treatment sites such as the cervical, thoracic or lumbar region (Dugailly et al., 2014b, 2014a; Haas, 1990; Herzog, 2010, 1994; Herzog et al., 1993; Triano et al., 2012; Williams and Cuesta-Vargas, 2013). Regarding thoracic spine manipulative approaches, most studies have focused on techniques in prone position related to the zygapophyseal joints (Downie et al., 2010) but analysis in supine position and at costovertebral joint remains poorly investigated, whereas each specific joint

---

* Corresponding author. L.A.B.O, Lennik Street 808, CP 619, 1070, Brussels, Belgium.
E-mail address: bbeyer@ulb.be (B. Beyer).

https://doi.org/10.1016/j.msksp.2020.102217
Received 4 February 2020; Received in revised form 9 June 2020; Accepted 30 June 2020
Available online 19 July 2020
2468-7812/© 2020 Elsevier Ltd. All rights reserved.
yields different pain patterns and functional impairments (Arroyo et al., 1992; Crane et al., 2018; Dreyfuss et al., 1994; Erwin et al., 2000; Pascual et al., 1992; Wainner et al., 2007; Young et al., 2008). Considering joint manipulation at different anatomical sites (i.e. zygapophyseal and costotransverse joint), focusing on specific joint facet geometry (i.e. orientation and shape), thrust direction and force might be important characteristics for determining success of manipulation techniques (Evans and Breen, 2006; Herzog, 2010), however assessment of reaction force orientation is lacking in the literature. Characterizing such biomechanical features may be useful for teaching and learning supine thoracic thrust manipulation to clinicians for both students and professionals (Wise et al., 2016).

Therefore, the objectives of this study were (1) to investigate the reaction force vector for intervertebral and costovertebral manipulations in supine position, (2) to assess the repeatability of both preload and peak force vector and (3) to compare data obtained at these different anatomical sites.

2. Methods

2.1. Subject sample

Sixteen healthy subjects, 6 female and 10 male (average age: 24 ± 2 years; mean height: 171 ± 7 cm; body mass index (BMI): 23.4 ± 2.6 kg/m²) were enrolled for the exploratory analysis. From this sample, 6 subjects were randomly selected for the reproducibility and reliability analysis.

Exclusion criteria were as follows: history of recent musculoskeletal thoracic pain, scoliosis, hyper-kyphosis, thoracic trauma or surgery, neurological disease, asthma, or osteoporosis.

Ethical approval was provided by the ethical board of the academic hospital (P2015/553; B406001526691). All participants gave their written informed consent before taking part in the study.

2.2. Manipulative interventions

Both manipulative techniques were somewhat similar in their description, only the location of the joint of interest and therefore the contact point were different. The manipulative procedure consisted of a stepwise process described previously (DeStefano, 2011), involving a preload followed by a thrust applied to the subject lying in supine position with the arms crossed, his trunk on a force plate (see data acquisition and processing section). The practitioner kneeled on the side of the subject and rolled him to reach the target joint with his thenar eminence. For the intervertebral manipulation (STTM), the thenar eminence faced the transverse process of the vertebra, while for the costovertebral manipulation (CVTM) the eminence thenar was against the rib angle (same level). Then the subject was rolled back to the supine position onto the hand of the practitioner who applied compression on subject’s chest through his elbows and forearm (Fig. 2). The procedure was performed by different practitioners, two trained practitioners (TP) and two student practitioners (5th grade students, SP). The practitioner was instructed to perform three preloads followed by one single thrust application, which represents the impulse phase. Note that, only TPs achieved both preloads and thrust, while the SPs were not allowed to perform the thrust delivering. Participants should not experience of any pain or discomfort with the manipulation procedure.

The entire protocol involved three different sessions of STTM and CVTM, for which session 1 and 2 (S1 and S2) were achieved on the same day (separated by more than 2 h). As recommended by the ethical board, session 3 (S3) was scheduled 6 months after. Student practitioners and TPs completed their respective protocol in the whole sample for session 1 and in 6 participants for the remaining sessions, while TP2 achieved STTM and CVTM in 6 subjects for all the sessions (Fig. 1).

2.3. Data acquisition and processing

During experimentation, subject was positioned with the pelvis and the trunk on force plates (10000Hz, AMTI, Watertown, USA) integrated in the floor surface to record ground reaction force. These force plates were separated by 2 cm to avoid interference. Data was collected using the Nexus software and consisted in ground reaction force magnitude (RF) and orientation that was examined for the trunk only.

From the RF, three components are given, Fx, Fy and Fz that represent the vertical, medio-lateral and cephalo-caudal force components, respectively (Fig. 2). Taking into account the subject’s trunk weight, RF was corrected by subtracting the Fz component computed when subject was lying alone on the force plates before the manipulation procedure. Additionally, for the orientation of RF, zenithal angle was calculated to assist the interpretation of our results. The latter corresponds to the angle between RF and the z-axis, and was computed as follows:

$$\text{A}_{\text{zenith}} = \cos^{-1}\left(\frac{F_z}{|RF|}\right)$$

2.4. Statistical analysis

For each RF data sets, the mean value was computed from the three sessions for each phase (i.e. preload and impulse). A repeated measures ANOVA was carried out to analyze whether a significant main effect (i.e. of session, technique (STTM and CVTM) or practitioner) and interaction (i.e. technique*practitioner) was present. When ANOVA revealed a significant effect, Bonferroni post-hoc comparisons were performed to identify the source of significant variation.

In addition, repeatability of manipulation tasks was assessed by using Bland and Altman plots (Bland and Altman, 1986). Bias and 95% limits of agreement (LoA) were estimated for each practitioner considering the pooled differences between all sessions (S1–S2; S1–S3 and S2–S3).

3. Results

3.1. Repeatability

ANOVA for repeated measures revealed that there was no effect of session (p = 0.754) and session*technique interaction (p = 0.376) on RF magnitude during the preloading.

Concerning the impulse phase, ANOVA showed no effect of session (p = 0.24) nor session*technique interaction (p = 0.11) for each
practitioner (see Fig. 3). However, regardless of the session, a significant practitioner*technique interaction ($p = 0.015$) was demonstrated. Post-hoc tests showed a significant difference between practitioners for STTM ($p = 0.018$) but not for CVTM ($p > 0.05$).

To better reflect the overall variability, note that differences between sessions are pooled in the same Bland-Altman plots (Fig. 4). Respective bias with 95% LoA are listed by practitioner in Table 1.

Regardless the practitioner and the technique bias ranged from 2% to 7% and from 3% to 14% for preload and impulse phase, respectively (see Table 1). In general, bias and LoA were slightly lower for CVTM compared to STTM. Also, TP1 demonstrated somewhat higher bias and LoA for both techniques.
3.2. Reaction force magnitude

Descriptive outcomes are presented in Table 2 depicting preload and impulse data for all practitioners and for both STTM and CVTM. For both techniques, the z component (Fz) was much larger compared to the remaining components confirming that RF was mainly oriented in

Fig. 4. Bland-Altman (pooled differences against pooled means) plots of the manipulative task at intervertebral (STTM) and costovertebral (CVTM) joints during both and thrust (for TP1 and TP2) and preload (for all practitioners SP1, SP2, TP1 and TP2) phase. Bias and limits of agreement (LoA) are displayed for each practitioner. The bias are calculated as the mean of the pooled differences between-sessions for each practitioner and LoA correspond to bias ±1.96 standard deviation of the pooled differences.

Table 1

Results of the Bland-Altman analysis considering the pooled differences between sessions. Bias and limit of agreement are displayed in newton (N). In addition, Bias is also expressed as a percentage of the average values (Bias/mean*100) obtained for each practitioner and task are listed.

<table>
<thead>
<tr>
<th>Preload</th>
<th>STTM</th>
<th>CVTM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bias</td>
<td>LoA</td>
</tr>
<tr>
<td>SP1</td>
<td>26.2</td>
<td>[-53.1–105.5]</td>
</tr>
<tr>
<td>SP2</td>
<td>-8.7</td>
<td>[-101.2–83.9]</td>
</tr>
<tr>
<td>TP1</td>
<td>-73.2</td>
<td>[-327.7–181.4]</td>
</tr>
<tr>
<td>TP2</td>
<td>-29.4</td>
<td>[-140.0–81.2]</td>
</tr>
<tr>
<td>Thrust</td>
<td>-105.4</td>
<td>[-433.5–222.7]</td>
</tr>
<tr>
<td>TP2</td>
<td>-29.0</td>
<td>[-116.1–58.1]</td>
</tr>
</tbody>
</table>


Table 2

Descriptive outcomes of the reaction force components and magnitude during preload and impulse phases. Results are displayed for each practitioner and for both techniques, STTM and CVTM. Note that no difference (p > 0.05) was observed between the repeatability sample (n = 6) and the exploratory samples (n = 12 or n = 16).

<table>
<thead>
<tr>
<th></th>
<th>STTM</th>
<th>CVTM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fx (N)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preload</td>
<td>Preload 31.1 (16) 47.1</td>
<td>Preload 395.8 (144.2) 375.4</td>
</tr>
<tr>
<td></td>
<td>20.5 (27.0) 30.5</td>
<td>123.8 (109.2) 468.7</td>
</tr>
<tr>
<td>Thrust</td>
<td>18.8 (24.5) 10.8</td>
<td>686.0 (44.7) 287.9</td>
</tr>
<tr>
<td></td>
<td>(28.1) 30.3</td>
<td>(39.5) 287.9</td>
</tr>
<tr>
<td><strong>Fy (N)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preload</td>
<td>Preload 12.8 (16) 31.1</td>
<td>Preload 399.0 (144.2) 380.6</td>
</tr>
<tr>
<td></td>
<td>0.9 (27.2) 15.6</td>
<td>174.7 (32.3) 471.3</td>
</tr>
<tr>
<td>Thrust</td>
<td>22.8 (16.0) 41.8</td>
<td>689.4 (38.3) 290.4</td>
</tr>
<tr>
<td></td>
<td>(35.9) 15.1</td>
<td>(42.3) 290.4</td>
</tr>
<tr>
<td><strong>Fz (N)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preload</td>
<td>Preload 395.8 (144.2) 375.4</td>
<td>Preload 399.0 (144.2) 380.6</td>
</tr>
<tr>
<td></td>
<td>79.8 (104.1) 287.9</td>
<td>381.3 (104.1) 290.4</td>
</tr>
<tr>
<td>Thrust</td>
<td>654.5 (213.3) 591.5</td>
<td>689.4 (104.0) 596.3</td>
</tr>
<tr>
<td></td>
<td>(28.3) 287.9</td>
<td>(42.3) 596.3</td>
</tr>
</tbody>
</table>

Vertical direction for both preload and impulse phases. Inversely, low magnitude of Fx and Fy indicates a small involvement of shear force components during the task. Fig. 2 shows the force-time profile (including Fx, Fy and Fz components) for three consecutive preloads followed by the thrust manipulation during STTM procedure.

Based on TPs data, there was a significant difference of RF magnitude between preload and thrust phase for both techniques (p < 0.0001). RF magnitude was systematically lower during the preload phase, approximately 50% of the impulse peak force (see Fig. 5).

Regarding the preload phase, there was a significant main effect of the technique and the practitioner, and a significant technique * practitioner interaction on RF resultant force. For both techniques, post-hoc comparisons showed a significantly larger magnitude applied by one student (SP2) compared to the other practitioners (Bonferroni test; p < 0.0001). During STTM preloading significant difference (Bonferroni test; p < 0.01) was observed between all practitioners except between SP1 and TP2. Additionally, significant differences were demonstrated between STTM and CVTM with an exception for TP2.

Analysis of the thrust phase revealed significant main effects of practitioner (p = 0.028) and technique (p = 0.023) on RF magnitude, for which post-hoc tests indicated only significant larger magnitudes for TP1 (p = 0.002) during STTM (Fig. 5). No difference was demonstrated between practitioners during CVTM. Results also demonstrated a significant difference between STTM and CVTM (p = 0.0049) only for TP1.

3.3. Reaction force orientation

Zenithal angle data is depicted for both techniques in Table 3. Regardless of the practitioner, there was a significant effect of phase (p < 0.001) and phase*technique interaction (p = 0.049) on zenithal angle. Post-hoc tests showed that a difference was observed between STTM and CVTM during preload (p < 0.001) but not during the impulse phase (p = 0.603). Furthermore, a significant effect of the practitioner was revealed for both preload (p < 0.014) and impulse phase (p < 0.001) while practitioner*technique interaction was only demonstrated for the impulse (p = 0.003). For the latter, post-hoc tests determined a significant difference in zenithal angle between STTM and CVTM for TP2.

4. Discussion

The purpose of this study was to assess biomechanical features of supine thoracic thrust manipulation applied at two different anatomical sites (i.e. intervertebral and costovertebral joints) and to estimate reliability during both preload and thrust phase.

Biomechanical features of spinal manipulative therapy were studied during application at the cervical, thoracic and lumbar spine (Downie et al., 2010; Harms and Bader, 1997; Herzog, 2010; Herzog et al., 1993; Snodgrass et al., 2010) using various manipulative procedures. However, to our best knowledge, no previous study has investigated repeatability of supine manipulative technique neither at intervertebral nor at costovertebral joint. We recently analyzed the repeatability of reaction force magnitude and orientation during the STTM and the present study is the first investigation that compares reaction force vectors obtained during thrust techniques applied at two different anatomical sites of the same spinal level. Results showed an agreement between sessions for the thrust phase with values up to 14% and 7% for STTM and CVTM, respectively. These variations among practitioners are in line with previous variability of approximately 124N observed for chiropractic students performing a standardized thrust peak force of 600N (Starmer et al., 2016). Lower variability during CVTM may be attributed to various parameters, such as the change in regional thorax stiffness or the difference in contact surfaces and tissue interface, but such hypotheses have to be further explored.

Observing the variability between practitioners indicated larger data agreement for one practitioner, which is discussed below. One may expect that reaction force would differ (in both amplitude and orientation) when applied more laterally on the rib cage compared to a mid-sagittal plane for the zygaphyseal joints. The maximal average peak force obtained in our study for both STTM (689N) and CVTM (602N) is in line with previously published results ranging between 238N and 1044N (Downie et al., 2010). Note that the discrepancy between results obtained in the literature may be related to various experimental setups. In addition, to the author’s best knowledge, previous works related to thoracic manipulation explored prone position techniques while the present study is related to supine thoracic manipulation.

Our study demonstrated several differences between STTM and CVTM and among practitioners for preload, impulse and zenithal angle. Interestingly, data similarity was found between practitioners for CVTM procedure. These results suggest that the manipulative procedure is likely to be dependent on the practitioner ability, experience but also on other parameters such as acceleration and trunk weight of both practitioner and subject. Indeed, the present data are corrected by the weight of the subject’s trunk but acceleration during the impulse phase and trunk positioning of both participant and practitioner may still explain some variations in force magnitude and orientation as well as in task repeatability for both peak force and preload. Thus, such a parameter would be interesting to examine in further research.

Concerning the preload, regardless of the practitioner experience,
our data for STTM (range: 290–471 N) and CVTM (range: 285–434 N) are comparable to the force magnitude of grade IV mobilization applied on thoracic spine (range: 231–499 N) that is considered as the grade level prior to the thrust achievement defined as the grade V (Snodgrass et al., 2006). The LoA were larger for TP1 than other practitioner, showing some variations between practitioners whatever the level of experience that may reflect the difficulty of performing a preload without specific standards. However, values of bias obtained for all practitioners are relatively low considering the absence of preload recommendations and direct feedback in performing the task. The present work adds potential basis for further standardization of preload and thrust phase during supine thoracic thrust manipulation applied to the intervertebral and costovertebral regions.

In addition, our results support the expectation that during impulse larger force magnitude is applied relative to preload. The peak force/preload force ratio obtained in the present study for STTM (range: 1.8–2.1) and CVTM (range: 1.9–2.1) are similar suggesting a very comparable manipulative procedure whether it is located on vertebra or costotransverse joint. Moreover, these peak force/preload ratios are close to the one of 2.5 reported during prone thoracic spine manipulation (Herzog et al., 2001).

Concerning injury risk, it is unlikely that thoracic spine manipulation induces sufficient chest compression to cause injuries (Stemper et al., 2011). According to previously published injury risk curves (Kent et al., 2005), 10% risk of a rib fracture required 20% chest compression corresponding to approximately 4810 N (Stemper et al., 2011) whereas the maximal peak force obtained in the present work occurred during STTM and reached 1167 N. However, this observation does not dispense practitioner to take into account that the higher is the force transmitted, the higher is the risk of traumatic injury. This is essential especially when considering individual patient characteristics including age, degeneration, and sex that may increase injury risk due to change in overall thorax compliance (Forman and Kent, 2014; Kent et al., 2005).

As mentioned in previous publication (Dugailly et al., 2020), the trunk weight of the practitioners (TP1 = 440 N; TP2 = 220 N approximately) may influence RF magnitude as well as velocity and acceleration or inertia provided during the HLVA procedure (Downie et al., 2010; Herzog, 2010) but these parameters have not been analyzed in the present work.

### 4.1. Limitations

Although the present investigation provides innovative outcomes, several limitations should be taken into account. First, due to ethical restrictions, students were not allowed to performed thrust manipulation on asymptomatic volunteers and therefore comparison between SP and TP was limited to the preload phase. This analysis would have been interesting to examine the kinetic characteristics of 5th grade students when performing thrust manipulation in an exploration of the teaching-learning process. In addition, the sample dedicated to the repeatability analysis included 6 subjects randomly chosen. A larger sample associated to a larger number of practitioners with various level of experiences may improve the interpretation of repeatability results and add substantial information concerning the potential effect of level of experience on the manipulative skills.

Second, the procedure was performed the subjects lying on the
ground and not on a medical table as usually applied during clinical practice. Further research should use an instrumented table to better reflect the reality of the manipulative procedure. However, we trust that data obtained are of interest since the STTM procedure was performed according to rigorous technical steps that should not critically influence the reliability analysis.

5. Conclusion

The present study is the first to explore biomechanical parameters for supine thoracic thrust manipulation at two different anatomical sites. Task repeatability was assessed by examining reaction vector force for preload, peak force and zenithal angle. Repeatability results defined agreements among practitioners for supine manipulative techniques at both intervertebral and costotransverse joint. For trained practitioners, regardless of the anatomical site of the same spinal level, the preload was approximately 50% of the peak force, and zenithal angle indicated a mostly vertical orientation of the reaction force during the impulse phase, and therefore in an anteroposterior direction relative to the subject's thorax. The present results are of interest for further pedagogical applications on learning manipulative skills in order to improve safety and standardization related to STTM procedures. Further research will explore dynamic parameters (i.e. velocity and acceleration) combined with potential clinical and neurophysiological effects of such manipulative technique.

Ethical approval

Ethical approval was provided by the ethical board of the academic hospital (P2015/553; B406001526691). All participants gave their written informed consent before taking part in the study.

Funding

Not applicable.

Declaration of competing interest

All authors declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsmbsp.2020.102217.

References