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Title: The Pectoralis Minor Muscle and Shoulder Movement-Related Impairments and Pain: Rationale, Assessment and Management

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Abstract: The adaptive shortening or tightness of the pectoralis minor muscle (PMm) is one of the potential biomechanical mechanisms associated with altered scapular alignment at rest and scapular motion during arm elevation (scapular dyskinesis) in patients with shoulder complaints. This masterclass briefly reviews the role of the PMm in shoulder movement-related impairments and provides a critical overview of the assessment of PMm tightness and the conventional approaches to increase its resting length and extensibility. A rehabilitation approach focused on PMm stretching and simultaneous optimization of the kinematic chain of arm elevation is also discussed, hoping to improve the management of shoulder movement-related impairments and pain.

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Subject: Submission of a manuscript for possible publication

Dear Editor-in-Chief of Physical Therapy in Sports

Professor Zoe Hudson

I herewith enclose the revision of a Masterclass for consideration and possible publication in Physical Therapy in Sports. We thank the editorial office and the reviewers for the time you have spent considering our paper. We have attempted to address reviewers' specific recommendations, commentaries and criticisms and would like to express gratitude for giving the opportunity to improve the quality of our paper. We found the reviews valuable and reasonable as well. Please find enclosed the revised version of the manuscript, as well as the list of amendments that have been performed. In the blinded version of the manuscript we have included the line numbers directly from the text processor, as requested by one of the reviewers, to facilitate the review process and communication between reviewers and authors. In addition, we have highlighted the most significant changes in bold.

Title: The Pectoralis Minor Muscle and Shoulder Movement-Related Impairments and Pain: Rationale, Assessment and Management

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The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the manuscript. A special thanks to the volunteers that kindly served as models for the figures illustrating the demonstration of the practice.

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Yours sincerely,
Nuno Morais

Conflict of interest statement

The authors certify that they have no affiliations with or financial involvement in any organisation or entity with a direct financial interest in the subject matter or materials discussed in the manuscript.

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Abstract

The adaptive shortening or tightness of the pectoralis minor muscle (PMm) is one of the potential biomechanical mechanisms associated with altered scapular alignment at rest and scapular motion during arm elevation (scapular dyskinesis) in patients with shoulder complaints. This masterclass briefly reviews the role of the PMm in shoulder movement-related impairments and provides a critical overview of the assessment of PMm tightness and the conventional approaches to increase its resting length and extensibility. A rehabilitation approach focused on PMm stretching and simultaneous optimization of the kinematic chain of arm elevation is also discussed, hoping to improve the management of shoulder movement-related impairments and **pain**.

Key Words: *adaptive shortening; soft tissue tightness; scapular dyskinesis*

Introduction

Pain and disability of the shoulder complex are common reasons for seeking musculoskeletal and sports physical therapists. Most often pain and disability are associated with movement; thus, correcting movement related-impairments is considered a key strategy for achieving optimal outcomes (Ludewig, Lawrence, & Braman, 2013). Abnormal scapular position and motion, commonly termed as scapular dyskinesis or scapular dysfunction, may contribute to alter the amount and the precision of shoulder movements, and be the cause or the consequence of pain and functional loss in patients with glenohumeral pathologies such as shoulder impingement, rotator cuff tendinopathy or tears, and adhesive capsulitis (Ludewig & Reynolds, 2009; Ratcliffe, Pickering, McLean, & Lewis, 2014). The adaptive shortening or tightness of the pectoralis minor muscle (PMm) has been considered as one of the potential mechanisms for altering scapular kinematics (Ludewig & Reynolds, 2009), hence addressing PMm tightness is often considered in rehabilitation programs aiming to improve shoulder function and pain. Yet, clinicians' ability to assess and treat PMm tightness has been limited by the challenges of its anatomical location and function.

The aim of this masterclass is to outline a kinesiopathologic and, therefore, a rehabilitation approach for the management of PMm tightness in shoulder movement-related impairments and pain. Firstly, the most relevant literature relating PMm tightness to shoulder pathologies with focus on scapular dyskinesis will be reviewed. Secondly, a critical overview of the existing measurement techniques to assess PMm tightness will be performed. Finally, the conventional approaches to improve PMm length and extensibility will be discussed and a more comprehensive rehabilitation approach will be provided.

Search strategy

For preparing the review components of this masterclass, an electronic literature search was performed in Pubmed database using a combination of the terms "pectoralis minor", "length", "short", "tight",

“stiff”, “stretch”, “posture”, “scapula”, “kinematic”, “pain”, “symptom” in titles and abstracts. All the relevant abstracts were screened by the first author and those not related to posture/movement-related dysfunctions (*e.g.,* pathoanatomic or neurovascular disorders) or PMm length measurement properties or conservative interventions were excluded from the pool of results. References of the remaining articles were also searched for relevant content. Additional online searches were performed in Google Scholar using the same aforementioned terms. The last search was run on 21/08/2015. Relevant articles were then read carefully and are presented in the manuscript, whenever appropriate.

Pectoralis minor muscle tightness: functional and clinical relevance

Based mainly on observations of the anatomical position and orientation of the muscle fibers, it has been hypothesized that adaptive shortening or tightness of the PMm may contribute to internally rotate, anteriorly tilt and downwardly rotate the scapula, and protract and depress the shoulder girdle (Burkhart, Morgan, & Kibler, 2003; Kendall, McCreary, Provance, Rodgers, & Romani, 2005; Kisner & Colby, 2007; Novak & Mackinnon, 1997; Sahrmann, 2002). **Several clinicians conjectured that such relatively fixed forward and downward scapular positioning may place PMm antagonist muscles (*e.g.,* lower trapezius) in an elongated and weakened position, contribute to limit the amount and precision of posterior and elevation movements of the scapula during arm elevation, and be involved in the development or perpetuation of**

abnormal stress and healing in shoulder tissues (e.g., subacromial tissues) and eventually pain (Burkhart, et al., 2003; Cools, et al., 2010; W. Benjamin Kibler, Sciascia, & Wilkes, 2012; McClain, Tucker, & Hornor, 2012; Sahrmann, 2002). Although many physical therapists guide their practice by the postural, muscle and movement imbalances model for the management of painful syndromes in the shoulder region (*e.g.,* subacromial pain syndrome) and upper body quadrant, evidence of a kinesiopathologic mechanism of shoulder injuries and pain is yet to be proven (Jeremy S Lewis, 2011). To date, there are no robust longitudinal studies that can validate the kinesiopathologic chain theorized above. Without the ability to follow human subjects prospectively, it is difficult to discern if alterations found in PMm length and scapular kinematics are compensatory or contributory to shoulder movement impairments and pain. A number of cross-sectional studies partially supports the rationale (J. D. Borstad, 2006; J. D. Borstad & Ludewig, 2005) nevertheless definitive research is required. Figure 1 summarizes the associations between PMm tightness, altered scapular position and motion, potential changes in glenohumeral arthrokinematics, abnormal stresses in tissues and painful syndromes that have been documented. Each link will be discussed next, considering also local and regional biomechanical factors that may contribute to shorten the PMm. Figure 1 also serves as a framework to guide the assessment and intervention proposed later in this manuscript.

Association between repetitive movements or maintained static postures and adaptive shortening of the PMm

The development of PMm tightness has been mostly based on the principle that adaptive changes in the muscle belly will occur over time when the muscle is chronically exposed to repetitive movements of the scapula in forward and downward directions or maintained in a static shortened position for long periods (J. D. Borstad & Ludewig, 2005 Borstad, 2006 #3833; Burkhart, et al., 2003; Kendall, et al., 2005; Novak & Mackinnon, 1997; Sahrmann, 2002). There is emerging evidence suggesting that chronic overhead throwing may lead to adaptive shortening of the PMm. In a study aimed to describe the profile of the scapulothoracic position and strength in asymptomatic elite tennis adolescent players (n = 35, 19 girls), Cools et al (2010) found a shorter PMm on the dominant arm when compared with the nondominant arm. McClain et al. (2012) compared the resting scapular position in the sagittal plane of 20 healthy overhead- and 20 nonoverhead-throwing young adult athletes in supine. The authors concluded that shortening of the PMm in the dominant shoulder of the overhead throwers (mostly tennis and baseball players) was the most likely explanation for the greater difference found between sides in the anterior position of the acromion (McClain, et al., 2012). **Kinematic studies showed that male athletes of several overhead throwing sports have a more protracted and anteriorly tilted scapular resting position in the dominant arm comparatively to their non-dominant arm (Oyama, Myers, Wassinger, Ricci, & Lephart, 2008; Ribeiro & Pascoal, 2013), or the dominant arm of non-athletes (Ribeiro & Pascoal, 2013). Although the primary goal of**

these investigations was not to study the association between soft tissue adaptations and chronic overhead throwing, the scapular pattern found has been related to a tight PMm (J. D. Borstad, 2006; J. D. Borstad & Ludewig, 2005). These researches seem to suggest the existence of resting length adaptations of the PMm in response to repetitive powerful scapular protraction movements during throwing, however, without longitudinal studies a cause-effect relationship cannot be established. Other musculoskeletal adaptations in the dominant shoulder of overhead throwers may also explain some of the findings in scapular position and orientation reported above, such as posterior shoulder tightness (Laudner, Moline, & Meister, 2010).

The few prospective studies that have examined changes in the mechanical properties of human muscles after exposure to chronic muscle actions similar to those used during throwing actions (i.e., stretch-shortening cycles), found an increased stiffness (more resistance to passive stretching) of the muscle tissue {Malisoux, 2006 #11855;Fouré, Nordez, & Cornu, 2012). Yet, the effects on muscles resting length were not studied. Further research is warranted to understand whether a change in PMm length and scapular orientation is indeed related to an excessive active tension of the muscle in shortening.

The PMm may also shorten secondary to conditions that approximate its muscular attachments or reduce the range of its operating length. In muscles immobilized in a shortened position, there is evidence that muscle length and extensibility decreases, possibly

due to a decline in the protein content and arrangement of the connective tissues in the muscle belly (Gajdosik, 2001). With this in mind, it is expected that local and regional biomechanical factors with potential to decrease scapular upward rotation, external rotation/retraction and posterior tilting relative to the thorax (e.g., strength imbalances of shoulder muscles or upper quadrant posture and mobility) may predispose the PmM to adaptive shortening. Tsai et al. (2003) observed that, after applying a fatigue protocol to the external rotators of the dominant shoulder, the scapular resting posture of 30 asymptomatic subjects have changed slightly but significantly (up to 4º) to a more anteriorly tilted, internally rotated and downwardly rotated position, a pattern that persisted during arm elevation. Even though scapulothoracic or axioscapular muscles were not assessed in this study, the authors recognized that the strength of the inferior trapezius and serratus anterior muscles may have been affected by the fatigue protocol and, in part, be responsible for the scapular kinematic changes found (Tsai, et al., 2003). This possibility gives impetus to the hypothesis that impaired strength of PMm antagonist muscles may change scapular position and motion patterns and mediate its adaptive shortening (Kendall, et al., 2005; Sahrmann, 2002). Research is needed to confirm this hypothesis.

A shortened PMm is frequently assumed to be linked with increased scapular protraction/tilting, forward head posture, and thoracic kyphosis, plus impaired mobility of the upper body quadrant. Findings from investigations conducted in asymptomatic subjects may

provide support to the existence of such regional interrelationships. Lee et al. (2015) found moderate to strong correlations between static measurements of PMm length, forward scapular posture and thoracic kyphosis (r ≥ .72, n = 18). Others observed that simulating increased, rigid thoracic kyphosis may increase up to 10° the anterior tilting and internal rotation of the scapula throughout different degrees of arm elevation (Finley & Lee, 2003; Kebaetse, McClure, & Pratt, 1999), whilst restricting full arm elevation capacity (Kebaetse, et al., 1999). Forward head posture, either simulated or acquired, has been shown to slightly but significantly restrict scapular posterior tilting (up to 3.5º) (Ludewig & Cook, 1996; Thigpen, et al., 2010), external rotation (up to 8º) (Thigpen, et al., 2010) and upward rotation (up to 5º) (Ludewig & Cook, 1996; Thigpen, et al., 2010) during arm elevation. These investigations may strengthen the idea that increased forward scapular posture, forward head posture and thoracic kyphosis could create a propitious environment to the adaptive shortening of the PMm; however, given the cross-sectional nature of the studies or the absence of PMm length measurements in data analyses, solid relationships are yet to be established.

Association between adaptive shortening of the PMm and altered scapular resting position and motion (scapular dyskinesis)

Although the relationship between PMm length and altered scapular resting position and motion has been hypothesized for a long time, the significant contributions to demonstrate its existence and magnitude were only made recently with the works of Borstad and Ludewig (2005) and Borstad (2006). These authors divided a sample of asymptomatic adults in two groups: one group with a relatively short PMm (n = 25) and the other group with a relatively long PMm (n = 25) (J. D. Borstad, 2006; J. D. Borstad & Ludewig, 2005). Then, they compared the 3-dimensional scapular kinematics of the two groups at specific angles of arm elevation in the three planes of orientation. With the subjects standing upright, significant differences were found between groups, with the shorter PMm group showing on average ~8º of more scapular internal rotation/protraction than the other group. Furthermore, scapular internal rotation at rest was significantly correlated (r = 0.39) with PMm length normalized to subjects' height (J. D. Borstad, 2006). During arm elevation, the short PMm group showed decreased external rotation/retraction (up to 10.5º) and posterior tilting (up to 10.4º) of the scapula in any plane of orientation compared with the longer PMm group (J. D. Borstad & Ludewig, 2005). **Despite the widespread belief that a shortened PmM may contribute to scapular depression or downward rotation, no association was found between PMm length and these scapular movements (J. D. Borstad, 2006) nor differences between short and long PMm subjects with regard to scapular upward/downward rotation (J. D. Borstad & Ludewig, 2005).**

Association between PMm length/scapular dyskinesis, shoulder pathomechanics, and upper quadrant pain syndromes

Studies comparing competitive overhead sports athletes with and without shoulder pain and disability found a shorter PMm in those

reporting shoulder pain (Harrington, Meisel, & Tate, 2014; Reeser, et al., 2010; Tate, et al., 2012). Given the cross-sectional nature of these investigations, it is unclear whether PMm tightness could be a contributory factor or a consequence of shoulder pain. Prospective studies investigating risk factors for the development of shoulder injuries in athletes might help clarifying this relationship, however, the literature reveals contradictory findings. While some studies identified significant contributions of scapular dyskinesis to subsequent shoulder problems (Clarsen, Bahr, Andersson, Munk, & Myklebust, 2014; Kawasaki, Yamakawa, Kaketa, Kobayashi, & Kaneko, 2012; McKenna, Straker, & Smith, 2012), others challenge these results by showing no association between scapular dyskinesis and the development of shoulder pain (Myers, Oyama, & Hibberd, 2013; F. Struyf, et al., 2014). Different methods for screening scapular (dys)function, type of sports, level of activity, instruments to evaluate symptoms and disability, or unknown representative sample size may explain part of the conflicting results. Moreover, the participation of PMm tightness in scapular position and motion in these studies was not clearly defined, except for the study of Struyf et al. (2014). Further investigations are therefore required.

A recent systematic review of research investigating the relationship between scapular orientation and kinematics in people diagnosed with subacromial impingement syndrome (SIS), concluded that although no definitive relationship could be established, a decreased scapular retraction, posterior tilting and/or upward rotation

may narrow the subacromial space and result in mechanical impingement of the tissue, thereby regarded as a contributing factor for developing or perpetuating SIS (Ratcliffe, et al., 2014). Studies included in the review have suggested a tight PMm as a possible contributing mechanism to the kinematic changes found in those subgroup of patients with SIS (Hebert, Moffet, McFadyen, & Dionne, 2002; Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999); however, the PMm length was not assessed in those studies, which limits our understanding of its presumed contribution to the condition. Further research is needed to more definitively discern the role of PMm tightness in subacromial narrowing, impingement, and sensitization of subacromial tissues.

Symptoms related to scapular dyskinesis and PMm tightness may not be restricted to the glenohumeral joint area. Parascapular and paracervical complaints may also be present. **Cleland et al. (2006) reported a prevalence of 45 % of restricted PMm length in a group of 22 patients with mechanical neck pain. Shahidi et al. (2012) found a significantly reduced PMm length bilaterally in a group of patients with chronic neck pain (n = 19) compared to healthy subjects (n = 20). Others have associated increased anterior tilting of the scapula with a tight PMm in patients with whiplash-associated disorder (n = 23) (Helgadottir, Kristjansson, Mottram, Karduna, & Jonsson, 2011). Despite these observations, the importance of PMm length to pain mechanism or disability in these patients has not been established. Axioscapular muscles have the dual role of orientating the scapula while**

simultaneously transferring forces between the upper limbs and the axial skeleton, including the cervical spine. **Given the alterations of axioscapular motor control in response to pain experience in the neck region (Christensen, Hirata, & Graven-Nielsen, 2015), it seems plausible that changes in PMm length could be a movement adaptation to pain**. Others believe that symptoms are likely related to an excessive effort of the PMm antagonist muscles (e.g., upper and lower trapezius) to minimize the impact of PMm tightness on shoulder position and motion during upper limb activities (Burkhart, et al., 2003; Sahrmann, 2002; Weon, et al., 2010). **Further research is needed to clarify the role of PMm length in patients with different types or presentation of painful neck disorders, as not all patient groups may show a presumed shorter PMm or related scapular kinematics (Helgadottir, et al., 2011; Nagai, et al., 2014).**

Brief summary

The associations between PMm tightness, altered scapular position and motion, shoulder movement dysfunction, abnormal stress in tissues and pain are not unequivocal, but the growing evidence suggests that these associations are not merely anecdotal. **There are limitations on the findings of studies that need to be addressed in the future. In particular, valid and reliable measurements of PMm length ought to be used (see discussion below), measures of PMm length and scapular and upper quadrant kinematics need to be recorded simultaneously, and the participation of PMm tightness in shoulder/neck pain mechanisms must be demonstrated experimentally.** The available research indicates that the evaluation of the PMm resting length and extensibility is important to be considered in people presenting scapular dyskinesis, particularly when showing increased scapular internal rotation/protraction and anterior tilting. The presence of shoulder and/or parascapular and paracervical pain should alert the clinician to assess PMm tightness and scapular dyskinesis, specially when those are aggravated by activities performed during or with arm elevation activities.

Clinical assessment of PMm tightness

No consensus exists about the best procedure(s) to assess PMm tightness. Tight soft tissues are characterized by a decrease in length and a greater resistance to stretching and motion. Thus, the assessment of PMm tightness has been mostly based on the measurement of its length through direct or indirect (*i.e.,* through scapular position) methodologies. Table 1 compiles the measurement properties of these clinical measures. Strengths and weaknesses of each methodology and recommendations for a better assessment of PMm tightness considering the potential relationships with the axial skeleton, its dominant effect in abnormal scapular position and motion, and pain (if it exists) are discussed below.

Direct assessment of PMm length

Direct assessment of PMm length has been investigated in studies conducted in both asymptomatic subjects and cadavers (J. D. Borstad, 2008). It can be performed by simply measuring in the standing upright position the distance between the medial-inferior angle of the coracoid process and the inferior aspect of the 4th rib, laterally to the sternocostal junction, with a caliper or a measuring tape (Table 1, Figure 2) (J. D. Borstad, 2008). For clinical purposes, direct measurement of PMm length should be normalized to a person's anthropometrics. Originally, body length was used to normalize PMm length [Pectoralis Minor Index (PMI) = PMm length (cm) / subject height (cm) x 100] (J. D. Borstad & Ludewig, 2005), but others have recently suggested to use the clavicle length instead (Tate, et al., 2012). Which body reference to normalize PMm length provides the best information for between-subject comparisons and clinical decision-making is currently unknown and deserves further investigation.

The PMI has shown good to excellent intrarater reliability in patients with SIS (symptomatic side) and good intrarater reliability in shoulders of healthy subjects (J.-h. Lee, Cynn, Yoon, Ko, et al., 2015; Filip Struyf, et al., 2014). Given the clinical belief that PMm tightness is involved in the pathogenesis or perpetuation of shoulder/neck pain syndromes, the evaluation of the clinimetric properties (e.g., **sensitivity**, specificity) of the PMI is essential to understand its value in differentiating people with these complaints. Judging by the small differences found between sides and between people with and without shoulder pain, and the relatively wide estimate of the minimal detectable change (Table 1) (Filip Struyf, et al., 2014), we anticipate difficulties in establishing a robust criterion (cut-off value) for diagnostic purposes. Still, a PMI value lower than 7.44 has been considered suggestive of a shortened PMm (J. D. Borstad, 2008), which is likely to affect the range and/or ease of retraction/external rotation and posterior tilting motions of the scapula during arm elevation (J. D. Borstad &

Ludewig, 2005). Hence, this measurement appears to be valuable for assisting in the diagnosis of scapular dyskinesis and clinical decision-making in shoulder/neck pain syndromes.

Indirect assessment of PMm length

Many clinicians prefer assessing scapular position and motion and, based on the outcome, inferring about the PMm length (W. Ben Kibler & Sciascia, 2010; W. B. Kibler, et al., 2002; Kluemper, Uhl, & Hazelrigg, 2006; McClain, et al., 2012; Roddey, Olson, & Grant, 2002). **Although this practice has a sound scientific basis (J. D. Borstad, 2006; J. D. Borstad & Ludewig, 2005),** the several clinical measurements listed in Table 1 should be used judiciously. Research has demonstrated questionable validity (J. D. Borstad, 2006; Morais, 2009) and diagnostic value (J. S. Lewis & Valentine, 2007; J. Nijs, Roussel, Vermeulen, & Souvereyns, 2005) of several of those measurements, even if acceptable reliability and agreement parameters were observed. For example, a forward shoulder/scapular posture (FSP) is frequently attributed to a tight PMm (Kendall, et al., 2005; W. Ben Kibler & Sciascia, 2010; McClain, et al., 2012; Jo Nijs, Roussel, Struyf, Mottram, & Meeusen, 2007; Sahrmann, 2002; Wong, Coleman, diPersia, Song, & Wright, 2010). Yet, Borstad (2006) showed that when FSP is measured in the supine position by the distance between the treatment table and the acromion [also known as the PMm Length Test **(J. S. Lewis & Valentine, 2007)**, see Table 1, **or the scapular anterior tilting index (J.-H. Lee, Cynn, Yoon, Choi, et al., 2015)**], its outcome is poorly correlated with a normalized PMm resting length (PMI). Hence, this measurement does not seem to guarantee a proper assessment of PMm length or tightness although frequently **used in clinical studies (Nagai, et al., 2014; Shahidi, et al., 2012; F. Struyf, et al., 2014).** A FSP may also be assessed in the upright position to account for the natural effect of gravity on the alignment of body parts. With the person standing against a wall, the examiner measures the distance between the wall and the acromion through special levelled metric rulers **(Peterson, et al., 1997) (**second indirect measurement shown in Table 1 - linear approach). **In recent studies conducted in asymptomatic populations, this measurement has shown significant associations with normalized PMm resting length (PMI) (J.-H. Lee, Cynn, Yi, et al., 2015), posterior shoulder tightness (Laudner, Moline, & Meister, 2010; J.-H. Lee, Cynn, Yi, et al., 2015) and thoracic kyphosis (J.-H. Lee, Cynn, Yi, et al., 2015). Despite these interesting findings, from a clinical decision-making perspective, this measurement may not be helpful to identify which particular biomechanical mechanism is more likely to contribute to misalignment in a certain person and tailor the intervention accordingly.**

Other indirect methods with potential to determine PMm length (Lynch, Thigpen, Mihalik, Prentice, & Padua, 2010; Roddey, et al., 2002) were originally designed to assess scapular position and displacement in the frontal plane (DiVeta, Walker, & Skibinski, 1990; Host, 1995; W. B. Kibler, 1998; Sobush, et al., 1996). We have grouped and designated them as *scapular protraction measurement* because of their similar procedures (i.e., measurement of the distance between the thoracic spine and the scapula) and theoretical framework. In general, these measurements have shown moderate to strong correlations with plane radiographs using the same reference points and a reasonable reliability (Table 1). Yet, this may not correspond to a true quantification of scapular position or orientation. Preliminary findings from a sample of healthy young adults (n =14) verified that most of these measurements were more related to anthropometrics of the upper body quadrant (e.g., thorax width or clavicle length) than to scapular protraction (Morais, 2009). The risk of misinterpretation when using them to assess scapular protraction is therefore high. One exception was found for a similar method, the scapula index (SI) (J. D. Borstad, 2006). The SI is the ratio between the distance from the sternal notch to the coracoid process and the distance from the thoracic spine to the posterolateral angle of the acromion, multiplied by 100. These measurements showed correlations with scapular internal rotation/protraction (J. D. Borstad, 2006; Morais, 2009) and PMI (J. D. Borstad, 2006) up to 0.65 (Pearson's *r*), suggesting that SI may be valuable in assessing scapular internal rotation/protraction and PMm length (Table 1). Cut-off values have not been defined yet, which limits its clinical usefulness.

The displacement of the inferior angle of the scapula from the posterior thorax (or winging) is also referred to as an altered scapular pattern associated to a tight PMm (Burkhart, et al., 2003; Lukasiewicz, et al., 1999; Jo Nijs, et al., 2007; Sahrmann, 2002; Struyf, et al., 2011). Some relatively simple measures can reliably quantify this displacement (Table 1, scapular winging or tilting measurement) (Plafcan, Turczany, Guenin, Kegerreis, & Worrell, 1997; Weon, et al., 2011); however, it is uncertain whether this displacement is actually related to PMm tightness. Impaired activity of the serratus anterior muscle can also cause scapular winging (Ludewig & Cook, 2000; Weon, et al., 2011), which emphasizes the necessity to add further data to the assessment of scapular position and motion in order to differentiate the contributing mechanisms of scapular dyskinesis **and improve clinical decision-making, as we will discuss below.**

Recommendations for the assessment of PMm tightness

Deciding whether PMm tightness exerts a dominant effect in scapular dyskinesis and/or complaints is vital to effectively correct movement impairment, reduce symptoms and obtain an optimal outcome**. In this sense, PMm tightness may be better assessed through a combination of tests. Static assessment starts with the person standing in the upright position.** Observation of a more protracted scapula in the dominant or symptomatic shoulder could be suggestive of a shortened PMm. **This rough estimation should be confirmed with a direct measurement of its resting length** (Figure 2), considering the aforementioned cut-off value. Palpation of the muscle belly could be helpful to assess potential changes in tissue compliance (e.g., tightness or stiffness); however, there is still no scientific evidence of its clinical value in the assessment of PMm.

Static assessment of the PMm length should be complemented with the assessment of scapular mobility. Performing manual retraction and posterior tilting of the scapula may help estimate PMm extensibility, inform the therapist about its passive resistance to scapular motion and highlight the compensatory movements occurring in the axial skeleton (e.g., elevation of the ribs or thoracic extension when the PMm is excessively tight - Figure 3).

Assessment of scapular position and motion during arm elevation is also important to be evaluated to verify if a scapular pattern consistent with a shortened PMm exists (J. D. Borstad & Ludewig, 2005). However, differentiating between PMm tightness and impaired function of its antagonist muscles in the mechanism of increased scapular protraction and anterior tilting and/or pain during arm elevation is challenging without proper instrumentation, such as electromyograms or motion tracking devices (Uhl, Kibler, Gecewich, & Tripp, 2009). **Furthermore, both muscle mechanisms might be associated**. The current alternative for clinical practice consists of performing active retraction of the scapulae (J. Nijs, et al., 2005) and manual muscle testing of the serratus anterior and the lower portion of the trapezius (P. McClure, Greenberg, & Kareha, 2012) to check for impairments in muscle strength, and manual redirection of the scapula to test for changes in symptoms (Rabin, Irrgang, Fitzgerald, & Eubanks, 2006). Given that the latter procedure is not specifically designed to test the influence of PMm tightness but rather the general contribution of the scapula in the pathogenesis of the pain, a strong resistance felt during manual correction of anterior tilting, retraction and upward rotation of the scapula may suggest PMm tightness. **Studies are needed to determine the relationship between PMm length and pain during movement in pain provocative positions**.

As early discussed, increased forward head posture and thoracic kyphosis may also alter scapular posture and restrict motion in a similar pattern to that of a shortened PMm. Hence, the examination of posture and mobility of the head, cervical and thoracic spines should be conducted along with scapular evaluation to improve clinical decision. This can be verified by simply repositioning the axial skeleton to the midline, in the upright standing position, and then assess changes in scapular position and motion and in symptoms, and vice-versa (Figures 3).

Treatment approaches to increase PMm length

Stretching techniques are a common approach to improve muscles length and extensibility (Gajdosik, 2001). To lengthen the PMm, the muscular insertion in the coracoid process should be moved away from the attachments in the thorax (3rd, 4th and 5th ribs). A wide variety of stretching techniques and positions have been proposed, taking into account several clinical factors, such as the rehabilitation stage, the presence or absence of pain, the importance of PMm tightness in movement dysfunction, or the need for a simple technique to be performed by the patient (self-stretching) (Bang & Deyle, 2000; John D. Borstad & Ludewig, 2006; Kendall, et al., 2005; Kisner & Colby, 2007; Lawson, Hung, Ko, & Laframboise, 2011; T. S. Lee, et al., 2007; Lynch, et al., 2010; Wang, McClure, Pratt, & Nobilini, 1999; Wong, et al., 2010). A short synthesis of the available stretching techniques is provided as supplementary material. Small variations have also been proposed (Burkhart, et al.; Caldwell, Sahrmann, & Van Dillen, 2007; Kluemper, et al., 2006; P. W. McClure, Bialker, Neff, Williams, & Karduna, 2004; Roddey, et al., 2002; Sahrmann, 2002). The corner or doorway stretch (passive horizontal abduction with the shoulder at 90º of abduction and external rotation) is one of the most frequently used exercises to stretch the PMm in preventive and rehabilitation programs

(Bang & Deyle, 2000; W. Ben Kibler, et al., 2013; Ludewig & Borstad, 2003; P. W. McClure, et al., 2004; Wang, et al., 1999). It has the advantage of being self-administered and offering great potential to lengthen the PMm (John D. Borstad & Ludewig, 2006). However, patients with shoulder complaints, particularly those with subacromial pain syndrome, may experience pain intensification in this position (Figure 1). **Moreover, increasing glenohumeral horizontal abduction may furthermore strain the anteroinferior capsoligamentous complex of the glenohumeral joint and aggravate functional imbalances between the anterior and posterior sides of the shoulder, a known contributing factor for developing or worsening shoulder pain and disability in overhead throwing athletes (Borsa, Laudner, & Sauers, 2008). In such cases, PMm stretch can be attained by the application of a posterior force to the coracoid process into retraction within a pain-free or tolerable glenohumeral range of motion (John D. Borstad & Ludewig, 2006; Burkhart, et al., 2003; Caldwell, et al., 2007; Kisner & Colby, 2007; Kluemper, et al., 2006; Sahrmann, 2002). Studies conducted in asymptomatic subjects (John D. Borstad & Ludewig, 2006) and cadavers (Muraki, et al., 2009) showed that this manual action indeed lengthens the PMm significantly, nevertheless its magnitude may be limited if not combined with arm elevation (John D. Borstad & Ludewig, 2006; Muraki, et al., 2009). Thus, when deemed appropriated, glenohumeral motion should be encouraged. During passive elevation of the arm, the scapula naturally undergoes upward rotation, posterior tilting and external rotation/retraction (Ebaugh, McClure, & Karduna,** 2005), which moves the PMm insertion on the coracoid process posteriorly and superiorly relative to the thorax. Up to 150° of passive arm elevation lengthens the PMm gradually, resulting in a mean change of 50% compared with its resting length (Muraki, et al., 2009). This value, however, was observed in a cadaveric model, which cannot be extrapolated to living subjects. The activity of the serratus anterior and lower trapezius increases the magnitude of scapular motions during arm elevation (Ebaugh, et al., 2005), hence, complementing PMm stretching with the activity of these muscles seems essential to magnify its lengthening. This hypothesis has gained support recently. Lee et al.(2015) demonstrated that combining PMm stretching with a posterior tilting exercise increased PMm resting length (PMI) and improved upward rotation and anterior/posterior tilting alignment of the scapula in a group of asymptomatic subjects with a short PMm (n = 15).

Soft tissue mobilization (Williams, Laudner, & McLoda, 2013; Wong, et al., 2010), corrective braces (J.-h. Lee, Cynn, Yoon, Ko, et al., 2015), and scapular kinesiology taping (Han, Lee, & Yoon, 2015) have been suggested as adjuvant or alternative techniques to stretching in the management of PMm tightness and forward shoulder posture. Albeit previous studies have shown that manual soft tissue mobilizations may influence the biomechanical properties of muscle tissues (Eriksson Crommert, Lacourpaille, Heales, Tucker, & Hug, 2015), only the latter appear to be beneficial at increasing PMm length and improve scapulothoracic alignment (Han, et al., 2015; J.-h. Lee, Cynn, Yoon, Ko, et al., 2015). Further studies are necessary to evaluate

the potential advantages of combining treatment modalities in the management of postural and movement impairments of the shoulder and upper body quadrant related to muscle tightness.

PMm stretching in a rehabilitation approach to optimize the kinematic chain of arm elevation

Interventions aiming to improve PMm length and extensibility at rest and during arm elevation should also consider the influence of the position and motion of the head, cervical and thoracic spines and rib cage. Good postural alignment and mobility of the axial skeleton may facilitate a normal scapular position and motion during arm elevation (Finley & Lee, 2003; Kebaetse, et al., 1999; Ludewig & Cook, 1996; Thigpen, et al., 2010; Weon, et al., 2010) and, possibly, PMm stretching. Given this, some authors have included thoracic spine extension in PMm stretching, but few have accounted for head posture or arm position (John D. Borstad & Ludewig, 2006; Burkhart, et al., 2003; Kluemper, et al., 2006; Lynch, et al., 2010). Others have suggested moving both points of attachment of the PMm in the opposed direction through arm and trunk dissociation (Bang & Deyle, 2000; Lawson, et al., 2011; Wong, et al., 2010) or through the assistance of thoracic movement and breathing patterns (John D. Borstad & Ludewig, 2006; Kisner & Colby, 2007). However, none of the techniques combines all these components together.

To efficiently act on the kinesiopathologic chain provided in Figure 1, optimize PMm lengthening and facilitate the restoration of a normal or further adaptable scapular motion, the progressive alignment of the axial skeleton with PMm stretching seems mandatory. This progressive alignment is better controlled with the person in supine, starting with arms alongside the trunk. **The sagittal alignment of the axial skeleton and forward head through head retraction and lengthening of the cervical and thoracic spines tensions the scaleni muscles and extends the thoracic spine. This elevates the upper ribs (Figures 3 and 4), which may reduce the lengthening capacity of the PMm**. Thus, deep progressive expirations should be encouraged to move away the thoracic insertions of the PMm from that of the coracoid process while keeping spinal alignment (Figures 4 and 5). A light overpressure can be applied on the ribs at the end of expiration to facilitate this movement. Since PMm assists in inspiration (Kendall, et al., 2005; Palastanga, Field, & Soames, 2002), upper thoracic inspiration should be avoided to actively limit shortening of its muscle fibers. The diaphragmatic breathing should be encouraged instead (Figure 4). The manual contact of the clinician must be different in male and female patients to account for the difference in their physiognomy (specifically in breast sizes). In female patients, the proximal hand of the clinician should address the thoracic insertions of the PMm indirectly, either through the sternum or the lower adjacent ribs (Figure 4, frame 3; and Figure 5, frames 2 and 4). The other hand should apply a posterior and superior force to the coracoid process to further stretch the PMm (Figures 4 and 5). These actions offer a more balanced stretching between PMm attachments, a more comfortable feeling to patients, and a safer procedure to be performed in the early stages of rehabilitation after a shoulder injury.

The addition of the shoulder abduction component should be slow and gradual (Figure 5). The starting range and increment rate of shoulder abduction depend on the previous clinical assessment (e.g., pain elicited at a specific range of motion). A progressive increment of 10º is usually safe and allows an efficient management of the compensatory movements that may occur during shoulder abduction, such as the scapula moving into protraction (or less retraction) or elevation of the ribs. The patient must keep the scapula attached to the surface of the table using PMm antagonist muscles (e.g., lower trapezius), thereby facilitating external rotation, posterior tilting and upward rotation (Ebaugh, et al., 2005). If difficult, the clinician can further perform the contract–relax technique of the PMm to facilitate its lengthening and the activity of its antagonist muscles. As the arm is being abducted, particularly after the 90º, the trunk will naturally follow contralateral **side flexion, ipsilateral axial rotation,** and extension (Fayad, et al., 2008)**. The tighter the PMm is, the sooner the thorax is expected to follow arm movement.** To obtain a full distance between PMm attachments (full stretching), these thoracic movements should be stabilized. This can be performed by either applying an external force on the rib cage, as previously described, or actively controlling these movements using the contraction of **the core muscles of the trunk** (Figures 4 and 5). **To ensure a proper alignment of the thoracic spine with the cervical spine and the rib cage throughout the stretching maneuver, a manual correction should periodically complement the visual inspection (Figure 6). The therapist places his or her hand between the table and the mid-thoracic spine,**

with the spinous processes between the 3rd and 4th fingers. With the patient's body in a restfully position on the therapist's hand and arm (wrist in the neutral position), the therapist uses the spinous processes as fulcrum and through wrist movements performs contralateral gliding and rotation and ipsilateral side-flexion of the vertebrae to the midline. Then, the therapist slides his or her hand up to the occiput using a posterior movement of his/her body, manually lengthening the spine. The other hand can control rib cage movements and perform lateral alignment of the cervical spine to the midline and head retraction as the lower hand reaches the occiput.

This rehabilitation approach has the advantage of stretching the PMm through passive (gravity and/or the manual action of the therapist) and active (PMm antagonist muscles) forces throughout the range of motion of arm elevation while considering regional interrelationships with the axial skeleton. Muscle activity and motor control are encouraged, possibly influencing scapular orientation and motion in a greater extent than stretching alone (J.-H. Lee, Cynn, Yoon, Choi, et al., 2015; J.-h. Lee, Cynn, Yoon, Ko, et al., 2015; Wang, et al., 1999; Williams, et al., 2013), likely reducing the rehabilitation period. Research is needed to document the efficacy of this approach.

Dosage

The efficacy of stretching techniques depends on the force and duration (dosage) being applied. However, the best dosage for an effective stretch has not been determined yet (Weppler & Magnusson, 2010). A shorter stretching duration may reduce the perception of pain or increase tolerance of the connective tissue to lengthening so the muscle can stretch further (Weppler & Magnusson, 2010). Sometimes this might be sufficient to facilitate the achievement of other rehabilitation purposes deemed more important in a particular case (e.g., strengthening shoulder external rotator muscles). However, if limitations of the shoulder function are closely related to a tight PMm, a longer stretching duration is required. A total duration of 1 to 10 minutes of PMm stretching has been suggested (Bang & Deyle, 2000; Kluemper, et al., 2006; Ludewig & Borstad, 2003; Lynch, et al., 2010; P. W. McClure, et al., 2004; Roddey, et al., 2002; Wang, et al., 1999; Wong, et al., 2010). Nevertheless, a minimum of 10 minutes per session appears to be necessary to achieve a higher improvement in muscle flexibility and passive stiffness over time, probably due to a more permanent deformation of the connective tissue (Guissard & Duchateau, 2004). To perform the stretching technique throughout arm elevation, as described above, approximately 15–20 minutes are required.

The lengthening capacity of a muscle also depends greatly on the force being applied (Weppler & Magnusson, 2010). Nevertheless, this has been poorly controlled in studies investigating the effects of stretching techniques in PMm length (John D. Borstad & Ludewig, 2006; J.-H. Lee, Cynn, Yoon, Choi, et al., 2015; J.-h. Lee, Cynn, Yoon, Ko, et al., 2015; Muraki, et al., 2009) and in scapular position and motion (J.-H. Lee, Cynn, Yoon, Choi, et al., 2015; J.-h. Lee, Cynn, Yoon, Ko, et al., 2015; Williams, et al., 2013). In order to understand which technique(s) might stretch the PMm in a greater extent, this parameter should also be considered in future research.

Summary

The PMm may adaptively tighten when chronically exposed to maintained postures and repetitive movements involving scapular protraction and anterior tilting. **Such tightness has been associated with altered scapular position and motion (scapular dyskinesis) and be the cause or the consequence of shoulder and/or neck pain syndromes.** Clinical assessment of PMm tightness is mostly based on the measurement of PMm length through direct or indirect methodologies. However, given the possible interaction between PMm tightness and other biomechanical mechanisms and components of the upper body quadrant, PMm length should be assessed along with the examination of scapular mobility, muscle strength of its antagonist muscles, and posture and mobility of the head, cervical and thoracic spines. Several stretching techniques have been proposed to improve PMm length and extensibility; however, most of them do not account for the influence of posture and mobility of the upper body quadrant on PMm lengthening capacity. Further research is necessary to confirm the value of a comprehensive assessment of PMm tightness, as presented in this manuscript, and to identify which stretching technique(s) is/are more likely to induce greater changes in PMm length and in scapular position and motion over time.

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Captions to figures

Figure 1. **Proposed** associations between pectoralis minor muscle (PMm) tightness, altered scapular position and motion and shoulder/neck pain syndromes. Pectoralis minor muscle tightness can be a primary or secondary

mechanism of shoulder movement impairments **and pain** (two-way arrow). GH, Glenohumeral

Figure 2. Direct measurement of the pectoralis minor muscle length in the standing upright position. The therapist palpates and measures the length between the medial-inferior angle of the coracoid process and the inferior aspect of the 4th rib near its junction with the sternum.

Figure 3. Scapular and upper quadrant mobility assessment. The extensibility of the pectoralis minor muscle is estimated by moving the scapula from rest to full retraction and posterior tilting (first two frames). Postural mobility of the head, cervical and thoracic spines (green arrows) and compensatory movements (red arrows) are shown in the last two frames. Blue arrow represents the schematic line of action of the pectoralis minor muscle and the direction of tension.

Figure 4. Complementary assessment of the relationships between pectoralis minor length and the axial skeleton. Retraction and posterior tilting of the scapulae leads to an elevation of the upper thorax, which limits the pectoralis minor muscle full lengthening capacity (first two frames). Deep progressive expirations are encouraged to descend the upper thorax while keeping the scapulae close to the treatment table (last two frames). Green arrows indicate the actions of the patient, therapist or both. Red arrows represent the compensatory movements of the upper thorax or scapulae to the actions of the patient, therapist or both. Blue arrow represents the

schematic line of action of the pectoralis minor muscle and the direction of tension.

Figure 5. Technique to stretch the pectoralis minor muscle throughout shoulder abduction. The therapist presses the coracoid process superiorly and posteriorly to stretch the muscle, stabilizes the thorax preventing misalignments and assists in the depression of the 3rd, 4th and 5th ribs. The patient performs deep progressive expirations to descend the upper thorax while keeping the scapulae close to the treatment table. A contract-relax technique (forward movement of the scapula) can be performed whenever points of tightness are felt (last frame). Green arrows indicate actions of the patient, therapist or both. Blue arrow represents the schematic line of action of the pectoralis minor muscle and the direction of tension.

Figure 6. Maneuvers of the therapist to improve the alignment and mobility of the thoracic spine. Green arrows represent the direction of the maneuvers directed to improve the alignment and the mobility (rotations and translations) of the thoracic spine. These maneuvers can be applied at different ranges of motion of shoulder abduction, whenever maintenance of the alignment and mobility of the spine and thorax throughout the stretching is difficult (see text for details).

Acknowledgments

None

Table 1

TABLE 1. Measurement properties of the clinical methods used to assess the pectoralis minor muscle length

Measure	Reference	Measurement properties*				
		Reliability (ICC)		Agreement (SEM, MDC)		Validity
		Intrarater	Interrater	Intrarater	Interrater	
Direct						
PMm resting length	Borstad (2008)					ICC 0.82–0.87 (MTD vs. caliper vs. tape measurements)
	Rondeau et al. (2012)	0.98–0.99		0.29–0.32 cm		0.694 < r < 0.838 (MTD vs. special caliper measurements)
	Struyf et al. (2014) (PMI)	0.76–0.93	0.47–0.72	0.19–0.32 %, 0.54–0.89 %	0.38–0.61 %, 1.07–1.61 %	
	Lee et al. (2015)	0.94 (95%CI 0.81–0.98)		0.32 cm, 0.89 cm; CV = 10.60%		

Indirect						
PMm length test	Nijs et al. (2005)		0.88–0.94	0.23–0.46 cm		
	Borstad (2006)					$0.10 < r < 0.16$ with PMI
	Lewis & Valentine (2007)	0.90–0.97		0.34–0.45 cm		
	Wong et al.(2010)	0.80 (0.68–0.88)		0.12 cm		
Forward shoulder posture	Linear measurement					
	Peterson et al. (1997)	0.89–0.99		SEE ~1.1 cm		r^2 0.30–0.59 with radiographic measurements
	Struyf et al.(2009)		0.72		1.7 cm, 4.71 cm	
	Laudner et al.(2010)					$r^2 = 0.50$ with posterior shoulder tightness
	Lee et al. (2015)					$r = 0.89$ and $r^2_{adj} = 0.78$ with PMI $r = 0.72$ with posterior shoulder tightness $r = 0.72$ with thoracic kyphosis

	Angular measurement					
	Lewis et al. (2005)	0.99 (0.99–1.0)	0.93 (0.78–0.99)	0.5°	1.4º	
	Gibson et al. (1995)	0.88–0.95	0.18–0.92	0.44–0.79 cm	0.65–1.65 cm	
	Sobush et al. (1996)	0.84–0.96	0.76–0.92			0.76 < r < 0.82 with radiographic measurements Scoliometer vs. radiographic measurements mean differences 0.03–0.56 cm
Scapular protraction measurement	Kibler (1998)	0.84–0.88	0.77–0.85			r = 0.91 with radiographic measurements
	McKenna et al. (2004)	0.85–0.94	0.20–0.87		0.53–1.19 cm, 1.46–3.32 cm	
	Morais (2009)					r > 0.75 with anthropometrics of the upper quadrant (Morais, 2009) r < 0.50 with 3D scapular position (MTD)

Scapula index (SI)	Borstad (2006)					SI $r = 0.30$ with scapular internal rotation (MTD) SN to CP $r = 0.48$ with PMI (J. D. Borstad, 2006)
	Morais (2009)			SN to CP 0.5 cm, 1.4 cm ThS to PLA 0.6 cm, 1.8 cm		SI $0.60 < r < 0.65$ with scapular internal rotation (MTD)
Scapular winging or tilting	Linear measurement					
	Weon et al. (2011)	0.97 (0.87–0.99)		0.1 cm		
	Angular measurement					
	Plafcan et al. (1997)	0.97–0.99	0.92–0.97	0.6–1.1º	1.1º–1.7º	

Abbreviations: 3D, three-dimensional; 95% CI, 95% confidence intervals; CP, coracoid process; CV, coefficient of variation; MTD, motion tracking device; ICC, intraclass correlation coefficient; MDC, minimal detectable change; PLA, posterolateral angle of the acromion; PMI, pectoralis minor index; PMm, pectoralis minor muscle; r, correlation coefficient; r^2, coefficient of determination; SEE, standard estimate of error; SEM, standard error of the measurement; SN, sternal notch; ThS, thoracic spine.

* Reliability has been assessed with the Intraclass Correlation Coefficient (ICC) and agreement with the standard error of measurement (SEM) and minimal detectable change (MDC), in centimeters, unless otherwise stated.

Stretching techniques used to increase the pectoralis minor muscle length

Reference	Position	Technique
Self-stretching		
Bang & Deyle (2000)	Standing, with shoulders abducted at 90º, elbows flexed at 90° and the palm of the hands and forearms placed on a flat surface (adjacent walls or a doorframe); known as the bilateral corner stretch.	The patient leans the body forward into adjacent walls of a corner or a doorframe.
Lawson et al. (2011)	Sitting on a chair, with the hands resting on the armrests.	The patient lifts his/her upper body with the full extension of the elbows to detach the upper body from the seat. The lengthening of the PMm is obtained by dropping the body weight until maximum shrug of the shoulders is reached.
Lee et al. (2007)	Supine	The arm is positioned at 135° of shoulder abduction and held externally rotated with a 2 kg weight.
Lynch et al.	Supine, with a towel or foam roll along the	The patient starts with both shoulders and elbows flexed

(2010)	spine.	at 90°, so that the forearms and palms are touching. Patient then horizontally abducts the shoulders and retracts the scapulas whilst flattening the spine against the roll.
Wang et al. (1999)	Standing, with shoulder abducted at 90º, elbow flexed at 90° and the palm of the hand and forearm placed on a flat surface (wall or doorframe); known as the unilateral corner stretch.	The patient rotates the trunk away from the elevated arm without moving the feet, thus increasing the horizontal abduction of the shoulder.
Wong et al. (2010)	Supine, with knees bent and legs rotated to the floor, in the opposite direction of the arm to be stretched.	The patient slowly brings the arm in a circular motion overhead pausing at points of tightness, maintaining close contact to the mat.
Manual stretching		
Borstad & Ludewig (2006)	Supine, with a towel or foam roll along the spine.	The therapist positions patient's shoulder at 90° of abduction and external rotation and the elbow at 90° flexion while applying a posterior force to CP.
Kendall et al.	Supine, with the knees bent and arms at side.	The therapist applies a diagonal force to CP in the

(2005)	A towel or foam roll can be placed along the spine.	opposite direction of the PMm fibers (posterior, lateral and superior direction). To avoid any rotation of patient's trunk, the force is applied on both shoulders.
Kisner & Colby (2007)	Upright sitting position without back support and arms at side.	The patient inhales deeply and holds the breath while the therapist stretches the PMm by applying a posterior force to CP and stabilizing the inferior angle of the scapula. The patient then exhales while the therapist holds the position.

Abbreviations: CP, coracoid process; PMm, pectoralis minor muscle

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Figure 1

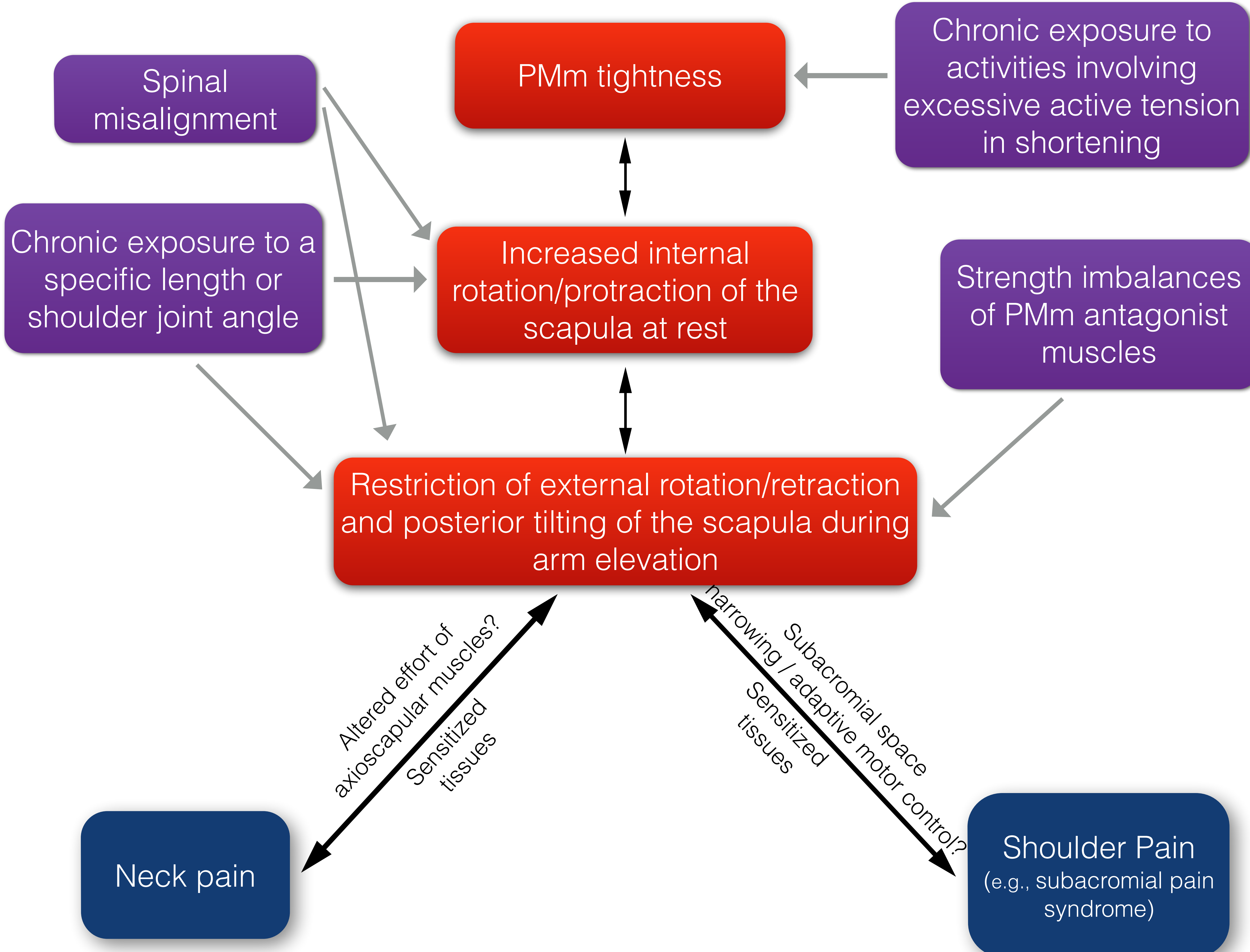
Spinal misalignment
PMm tightness
Chronic exposure to activities involving excessive active tension in shortening
Chronic exposure to a specific length or shoulder joint angle
Increased internal rotation/protraction of the scapula at rest
Strength imbalances of PMm antagonist muscles
Restriction of external rotation/retraction and posterior tilting of the scapula during arm elevation
Altered effort of axioscapular muscles?
Sensitized tissues
Subacromial space narrowing / adaptive motor control?
Sensitized tissues
Neck pain
Shoulder Pain
(e.g., subacromial pain syndrome)

Figure 2

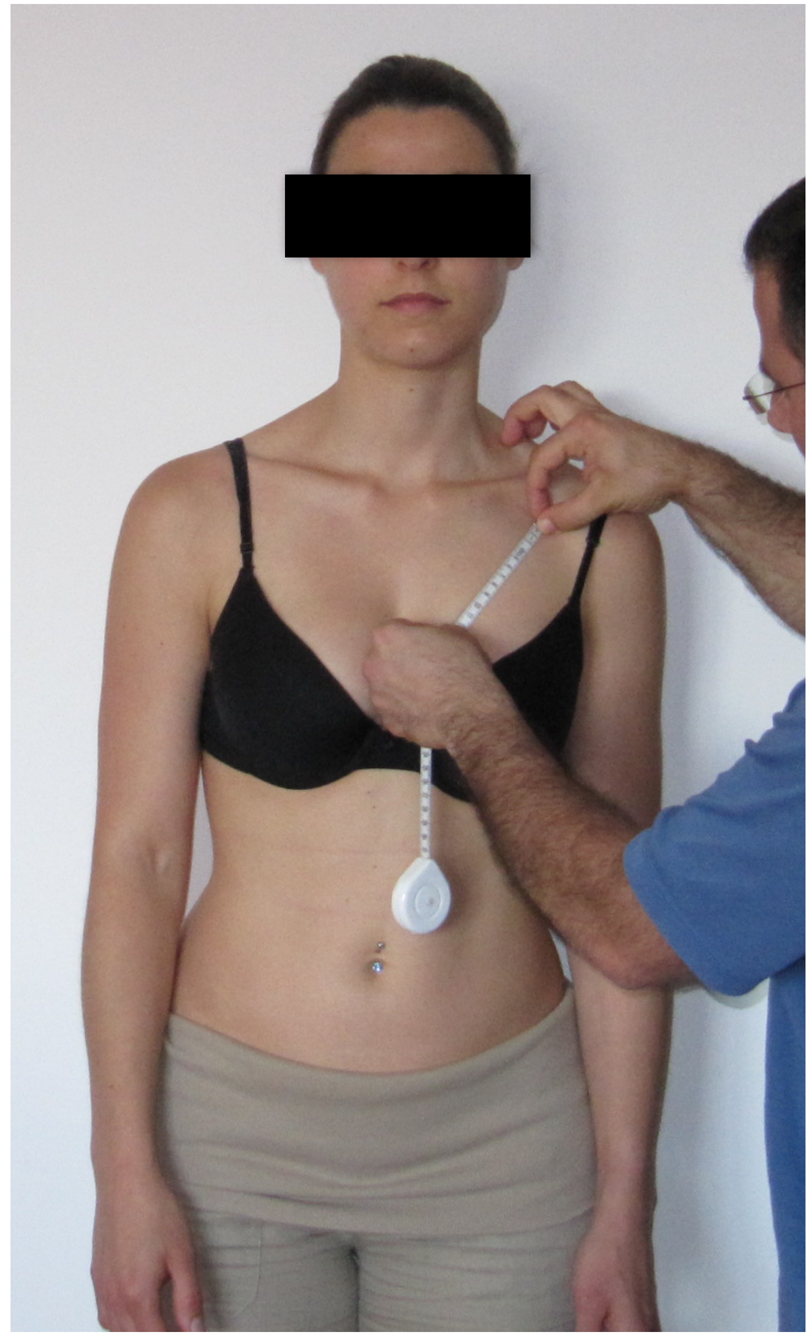

Figure 3

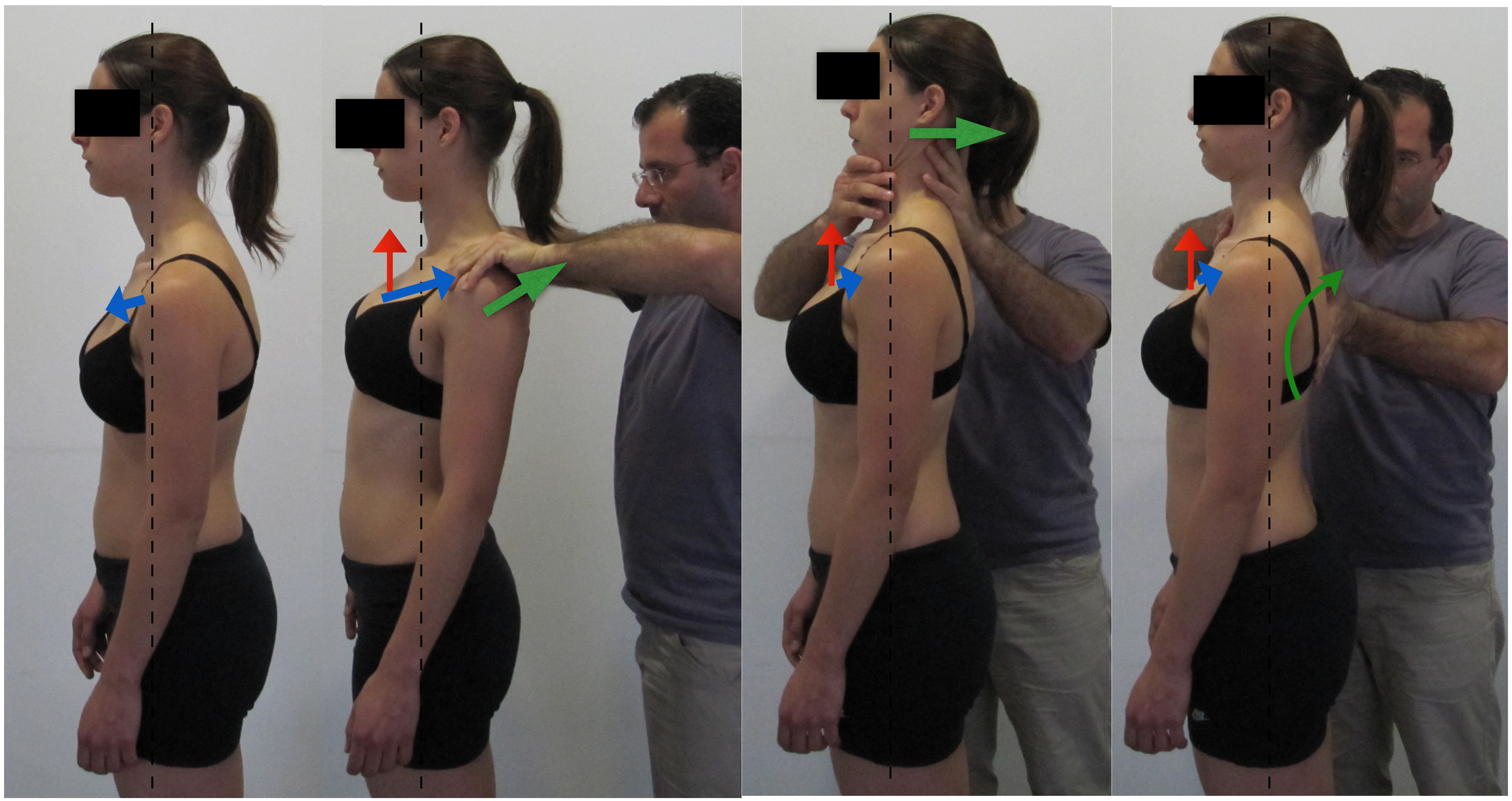

Figure 4

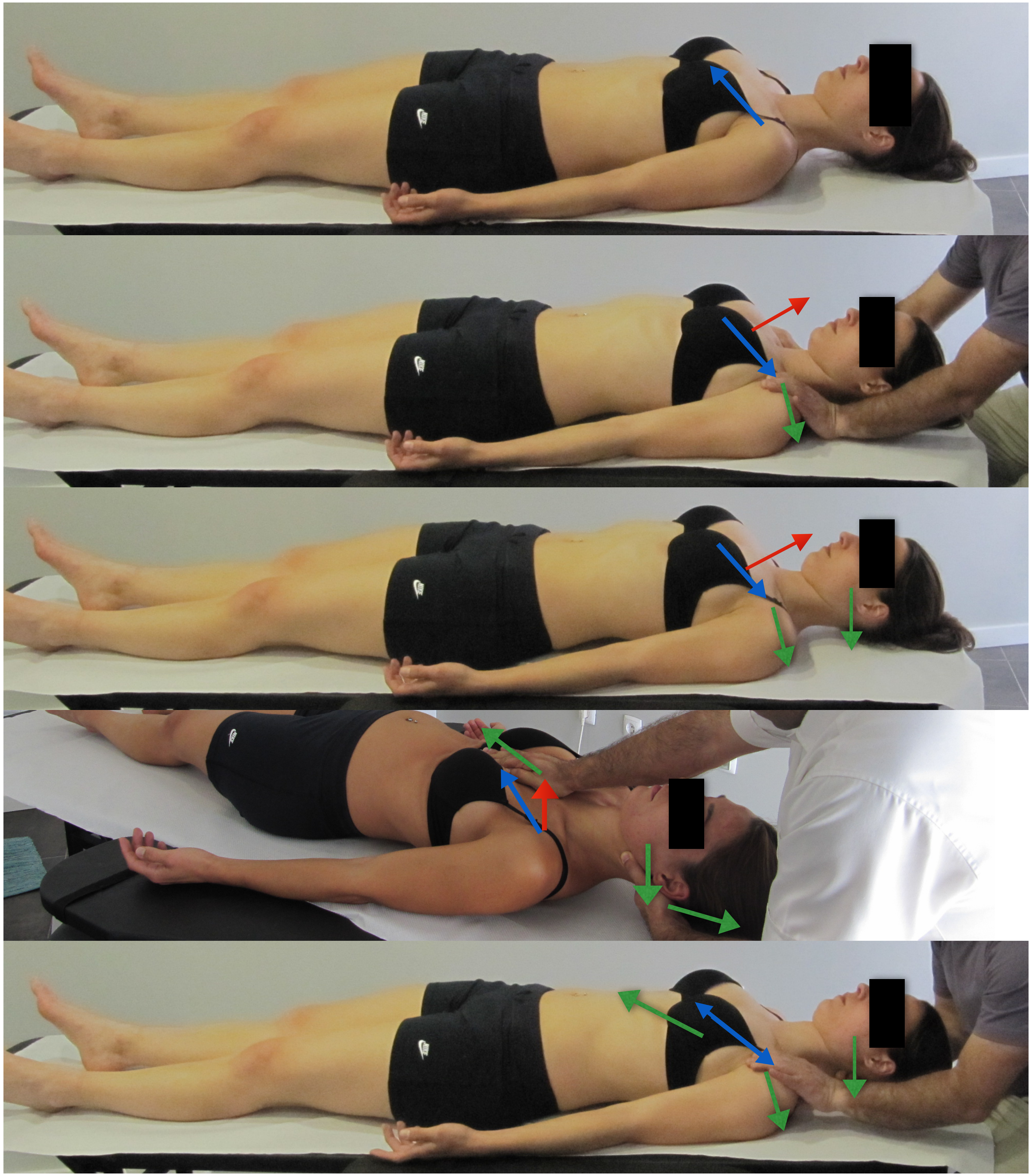

Figure 5

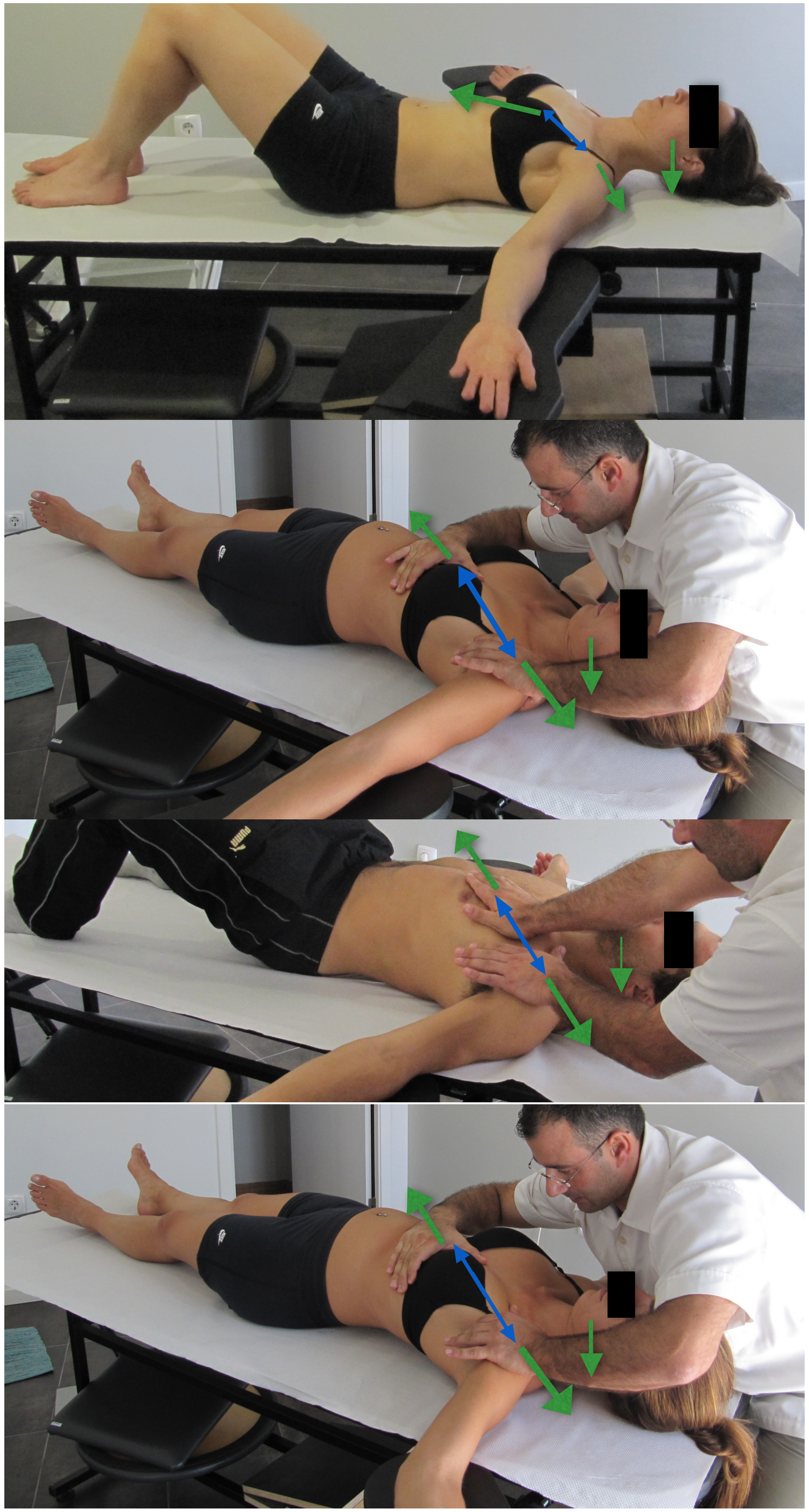

Figure 6