Thoracic spine mobility, an essential link in upper limb kinetic chains in athletes

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INTRODUCTION

Sports-related musculoskeletal complaints involving the shoulder are common, and those that place heavy functional demands on the shoulder are complex. Reported pain or injury prevalence levels are consistently high across a number of sports: elite handball 44-75%, [1] baseball pitchers, 46-57% softball 50.2%,[2] volleyball 40%, [3] and tennis 25-47.7% [4]. Complaints are not however limited to arm dominant sports with comparable levels of 47% seen in football [5] and 54% in swimming [6]. Many studies have investigated approaches to management of sport-related shoulder injuries e.g. of the rotator cuff, acromioclavicular and glenohumeral joints; [5,7,8] with many athletes likely managed conservatively in line with current clinical guidelines [9]. Notwithstanding implementation of evidence based management many athletes go on to experience recurrent problems, with one report suggesting a 72% re-injury rate for young athletes with shoulder instability [10].

Current approaches to rehabilitation including active interventions following a shoulder injury are mainly focused to managing specific signs and symptoms of shoulder pathology, with relatively less attention given to possible disturbances within the kinetic chain and the functional interaction between the shoulder complex and trunk [11]. Functional shoulder and upper limb (UL) movement is however a product of a functional synergy of discrete body regions (e.g. shoulder, thoracic spine, and pelvis) as part of a kinetic chain. Beyond a somewhat simplistic association with static posture in the general population, and inconclusive evaluation of scapular dyskinesis in athletes presenting with shoulder pain [12,13] the kinematic relationship between the thoracic spine and the shoulder in a sporting population is currently unknown. For example, thoracic kyphosis is commonly cited at a contributor to shoulder impingement, via a proposed reduction in the subacromial space [14,15] and scapular dyskinesis exists with and without shoulder pain in athletes [13]. Whilst the thoracic spine does not feature strongly in the sporting literature for reasons including its relatively low pain prevalence and challenges with measurement [16], evidence supports the thoracic spine as playing a significant role in sporting performance; contributing to the estimated 55% of the total force and kinetic energy generated during a throw [17], around 80% of the total available range of 'trunk' axial rotation [18], and kinematically important to the UL [19,20]. With a 3 times higher elbow / shoulder injury prevalence in softball players with low trunk rotation flexibility, [2] and a beneficial effect of an UL injury prevention programme including thoracic mobility exercises on shoulder / elbow injury prevalence [1,21] a greater focus on the thoracic spine, as a discrete region within the trunk and its contribution to UL function is required. Whilst the concept of 'regional interdependence' [22] has contributed to notable growth in research investigating and supporting the use of interventions targeting an asymptomatic thoracic spine in patients with shoulder complaints [23-25]; with ostensibly a neurophysiological relationship proposed, [16,26,27] the nature of the kinematic relationship between the thoracic spine and shoulder or UL in an athletic population has not yet been fully established. Understanding the kinematics will enable the recommendation of a holistic assessment of shoulder complaints considering the thoracic spine; where trunk position, a composite of thoracic and lumbar motion have been shown to influence shoulder muscular function [12,28,29].

Aim

To synthesise the evidence of the contribution of the thoracic spine to UL movement in athletes.

METHODS AND DESIGN

This systematic review was conducted in accordance with a pre-designed unpublished protocol informed by the Cochrane Handbook for Systematic Reviews [30] and is reported in line with Preferred Reporting Systematic Reviews and Meta-Analyses (PRISMA) [31] (Appendix 1).

Eligibility criteria

Following scoping searches, eligibility criteria derived from the SPIDER [32] search concept format. Inclusion criteria comprised sample (S) athletic or general (scoping searches indicating a lack of studies specifically in an athletic population), healthy population between ages 18-40; the phenomenon of interest (PI) UL movement at the end or through range movement; observational study design (D); evaluation of thoracic spine movement (range, direction around all axes of movement) (E). The research type (R) was quantitative cross sectional observational studies. No language or geographical restrictions were applied.

Exclusion criteria: qualitative research, surgical or cadaveric studies, publications for which full text not available.

Information sources

Informed by scoping searches (KW, TM) and subject specific and methodological expertise (NH, AR) the search employed sensitive topic-based strategies designed for each of the selected databases. Medline, The Cumulative Index to Nursing and Allied Health Literature (CINAHL) and Web of Science were searched until 30th June 2018. Additional searches involved Google Scholar, grey literature, key journals (Clinical Biomechanics, JOSPT, BJSM) alongside manual searches of literature reference lists. An example of a search of Medline search is available as a supplementary file (Appendix 2). Reference lists of included papers were also searched.

Search strategy

The search strategy included all key terms associated with of thoracic spine movement/motion and UL or shoulder movement/motion. Medical subject headings (MeSH) and keywords were used in the databases where relevant. MeSH and keywords included ‘shoulder joint’, ‘shoulder’, ‘Upper extremity’, ‘Arm’, ‘Rotator cuff’, ‘Scapula’, ‘Thoracic vertebrae’, ‘spine’, ‘Torso’, ’Range of movement/motion, Articular’, ‘Muscle, Skeletal’, ‘Movement’, ‘Motion’ and ‘Association’.

Study selection

Two independent reviewers (KW, TM) completed the searches and identified potential articles for inclusion based on eligibility criteria. One reviewer (KW) independently screened the titles and abstracts of the articles and compared these against the inclusion criteria, excluding articles where appropriate, facilitated by grading each eligibility criterion as eligible/not eligible/ might be eligible. If there was uncertainty regarding the relevance of an article against the inclusion criteria, the second reviewer (TM) reviewed the article for clarification and confirmation. Full texts were reviewed independently and included when both reviewers agreed. A third reviewer (NH) was available to resolve disagreements if agreement could not be reached following discussion. RefWorks bibliography software (RefWorks-COS, Proquest, LLC) was used to manage records and remove duplicates.

Data collection process and items

One reviewer (KW) extracted the data of interest from each included study's full text into a pre-designed and piloted data extraction form. The second and third reviewers (TM, NH) checked data extraction tables for accuracy. Study authors were not contacted for further information as this was not required.

Data items

Data extracted included study characteristics such as study design, sample size, setting, participant demographics, outcome measures, data acquisition methods and findings. Outcomes of interest were measurements of thoracic spine movement around all axes and range or description of UL /shoulder movement in all planes.

Quality assessment and evaluation

Given the limitations of existing tools such as Newcastle Ottawa Scale risk of bias and quality assessment was evaluated using AXIS tool [33]; a tool designed to enable synthesis of evidence from different disciplines e.g. research and health. A review and subsequent Delphi study informed the development of the tool which supports critical appraisal of study design and reporting quality as well as the risk of bias in cross-sectional studies. [33] The tool enables raters to evaluate key items across methods and reporting based on a binary response with 'yes' or 'no'. Agreement across raters for the current study was 100%.

Summary measures

A narrative synthesis of evidence sources combined findings for common UL movement where appropriate e.g. upper and lower thoracic spine movement. Results are presented to allow examination of movement around planes (sagittal, coronal and scapular); unilateral and bilateral movement and movement within the available range of arm elevation range where provided.

Synthesis of results

Data were tabulated and synthesised to enable review and comparison. Results for unilateral, bilateral arm elevation across planes and within the available range were possible for data synthesis. Data for unilateral flexion and abduction and, bilateral flexion and abduction are presented here along with thoracic spine extension ranges for comparison. The results were interpreted with consideration of quality and grade of recommendation for each movement. .

Quality of evidence across studies

The overall quality of the evidence for individual or combined shoulder movements was assessed using Grading of Recommendations, Assessment, Development and Evaluation working group methodology (GRADE) [34]. Using a modified version of GRADE [35] where the quality of evidence for the associations was based on the design and phase of the studies alongside 5 further factors (phase of investigation, study limitations, inconsistency, indirectness, imprecision and publication bias) quality of overall evidence was rated as very low, low, moderate or high [35].

RESULTS

From 554 studies initially retrieved (following removal of duplicates), 7 studies (n=168) met the eligibility criteria and were included. All studies were described as descriptive laboratory studies akin to cohort studies; originating from Australia (n=5), France (n=1) and Japan (n=1). The details of study selection and reasons for exclusion of studies are reported in Figure 1.

Study characteristics

The mean age of participants was 26.36 years (calculated from n=5 included studies where data provided). Assessed thoracic spine movements included extension (n=6), flexion (n=4), rotation (n=3), and lateral flexion (n=3) involving UL abduction elevation [36], right scapular elevation [37], flexion, extension and scapular elevation [38], UL flexion and abduction (45°, 60° and end range) [39], external rotation [40], functional UL flexion [41] and bilateral UL elevation [42]. Data acquisition methods included Myrin goniometer (n=2), movement analysis systems (n=5) (e.g. Fastrak), and photographic and radiographic analysis, the latter widely considered the gold standard (n=1). See Table 1.

Quality assessment and risk of bias within studies

The quality assessment and risk of bias assessment of the included studies is outlined in Table 2. Key concerns related to sample size calculation, sampling frame and sample selection with use of single sex samples,and control of confounding variables.

Quality of evidence

All included studies were catagorised as exploratory phase 1 studies seeking to identify associations and generate a hypothesis [35]. In view of this and the small sample sizes (ranging 15 to 32) the starting GRADE for quality of evidence was rated as low [35]. Across each outcome of interest (uni-, bi-lateral UL motion) inconsistency of findings is noted with few eligible studies investigating comparable outcomes, just one used an athletic population [40], imprecision with no effect sizes reported and few presenting confidence intervals and publication bias with all but one using single sex cohorts [36-38,40,41]. (Table 3)

Thoracic spine movement during maximal unilateral shoulder movement

Thoracic extension

Findings for full arm elevation through all planes indicate that movement in the thoracic spine occurred consistently into extension, ranging from 3 degrees [38] to 8 degrees (combined upper and lower thoracic spine values); [38] with flexion elevation producing the greatest movement (6.7-8 degrees) [38,39], followed by scapular elevation (4-8.9 degrees) [37,38] and then abduction elevation (3-4 degrees) [38,39]. It should be note that ranges of elevation ranged across planes from 105 to 154 degrees)

Thoracic lateral flexion

For lateral flexion, ranges were similar for flexion and abduction elevation, but differed with respect to direction of movement. For flexion elevation Crosbie et al., [38] describe differences across the upper and lower thoracic spine, with thoracic spine ipsilateral lateral flexion movement (3 degrees) occurring in the upper and contralateral movement (3 degrees) occurring in the lower thoracic spine. Meanwhile Fayad et al., [39] report a total of 7.3 degrees in a contralateral direction. For abduction elevation the pattern was the same although larger ranges of lateral flexion movement were reported [8 (1+7) -9.1 degrees); and notably Crosbie et al., [38] report more occurring in the lower thoracic spine (7 degrees). For scapular elevation, limited movement was observed in the upper thoracic spine (1-2.1 degrees), with more occurring in a contralateral direction in the lower thoracic spine (2.7-5 degrees).

Thoracic rotation

Axial rotation ranges varied considerably, with 2.1-8 degrees [38,39] during flexion elevation, 5.2-11 degrees during abduction elevation [38,39] and 9.1-11 degrees [37,38] during scapular elevation. Again differences regarding direction of movement were observed with Crosbie et al., [38] reporting ipsilateral movement for all thoracic movement whilst Fayad et al., [39] reported contralateral movement for shoulder flexion and abduction. Although not reported in detail here Stewart et al. [37] reported variability of direction within his sample. For each UL movement the level of evidence was very low, principally due to risk of bias of individual studies, precision, consistency and directness. See Table 4.

Thoracic spine movement during maximal bilateral shoulder movement

Notwithstanding the limited number of eligible studies investigating bilateral UL movement and low quality of evidence, 12-15 degrees of thoracic spine extension occurred during full flexion elevation [36,38,42], compared to 9-12.8 degrees during abduction [38,42] and 10-degrees during elevation in the scapular plane [38]. With radiographic measures [42] of flexion elevation broadly comparable with other measures (photographic [42], motion analysis systems [38,39] this offers some concurrent validity for other approaches used. Ranges of contralateral lateral flexion were small ranging from 1-degree in abduction and scapular plane movement to 2-degrees in flexion. Rotational movement occurring around a vertical axis was negligible with just one report of 1-degee of movement occurring in the upper thoracic spine during abduction. See Table 5.

Thoracic spine movement during unilateral through range shoulder movement

Few studies have investigated thoracic spine movement in positions other than end range elevation. Fayad et al., [39] explored unilateral arm movement at 45 degrees, 60 degrees and maximum flexion and abduction. No more than 1.5 degrees of movement were reported to occur in any direction in positions less than 60 degrees [39], with as reported above greater ranges occurring at maximum flexion elevation and abduction elevation of 4.0-6.7 extension, 7.3-9.1 degrees lateral flexion and 2.1-5.2 degrees axial rotation reported [39]. During mid-range flexion elevation (80 degrees) Crosbie et al., [38] reported approximately 11 degrees of thoracic extension and during unilateral maximum external range of shoulder movement, Miyashita et al., [40] reported 8.9 degrees of thoracic extension. With few studies, all at risk of bias this amounts to a very low level of evidence for thoracic spine movement ranges during early and mid-ranges of arm elevation. See Table 6.

Synthesis of results for thoracic extension and flexion elevation

For unilateral UL movements (100.0-154.4 degrees) thoracic spine extension was 6.7-8.0 degrees and 3.0-4.0 degrees for flexion elevation and abduction elevation respectively. For bilateral movements (103.0-172.0) thoracic spine extension ranged 9.0-15.0 degrees with more during flexion elevation and at greater range of UL movement. See Table 7.

DISCUSSION

This is the first systematic review, conducted with a rigorous methodology, to report thoracic spine movement at the end of UL elevation in 3 planes and within range for some movements. Findings provide evidence of thoracic spine movement contributing to UL functional movement, specifically for activities involving mid to end range arm positions in the sagittal plane. Notwithstanding the quality of the overall body of evidence, findings from this evidence synthesis can be used to support further targeted high quality research in a sporting population and lends weight to earlier research [36-38,42] where examination of thoracic spine movement is recommended in UL functional movement impairment.

Unilateral shoulder movement

Findings from 3 studies (n=82, n=68 females) report 4 to 8 degrees thoracic extension occurring during arm elevation [37-39] with studies reporting variable ranges and degrees of other thoracic movement. Findings are relevant to athletes engaged in overhead sporting activities [1,3] where deficiencies in thoracic extension may place more stress on other components of the kinetic chain resulting in pain, altered performance and impact on an athlete's ability to train and compete. [1] Whilst a recent review found inconclusive evidence of a relationship between static thoracic posture and shoulder complaints [15], functional kinetic chains are dynamic; requiring a variable mix of movement, motor control, and strength across the component parts, including the thoracic spine to enable performance of skilled functional movement. Despite a paucity of evidence exploring kinetic chain rehabilitation an injury prevention programme for handball players which included thoracic mobility exercises resulted in a 24% reduction in UL injuries, including 12% reduction of serious injuries [1].

Bilateral shoulder movement

Findings from 3 studies (n=83, n=62 female) report 9-15 degrees of thoracic extension occurring during flexion elevation [36,38,42], and then 9-10.5 degrees and 10 degrees for abduction and scapular elevation respectively in one study [38]. As data is derived from predominantly female populations, caution should be taken regarding generalisability to male athletes. Findings are particularly relevant to sports such as netball which utilises repetitive overhead bilateral arm elevation for throwing and catching. With a high prevalence and reoccurrence rates of low back and shoulder injuries further research is required to fully understand the functional kinematics of this fast paced demanding sport with a particular focus to the thoracic spine mobility and motor control [43].

General comments

Finding suggest for uni- and bilateral UL movement across all planes a relatively greater contribution of thoracic spine extension from the lower rather than upper thoracic spine [37,38]. It is also noteworthy that one study [38] reported no lumbar spine motion during end range movement, perhaps attributable to studies being controlled laboratory-based studies. Considerable variability was noted across other movements although a trend for more thoracic rotation in the upper spine and lateral flexion in the lower during uni-lateral UL movement was noted [37,38]; differentiation the upper and lower thoracic spine regions is an important consideration to support targeted rehabilitation and precision in exercise prescription. Where much attention has been paid to scapular dyskinesis in athletes [12,13] current findings may usefully stimulate further investigation of the kinematic interaction between the scapula and the thoracic spine during functional UL movement; a notable gap in the current evidence base, yet essential for force transfer, movement and motor control between the UL and thorax.

Methodological considerations

Where the majority of included studies used movement sensors or goniometers to quantify thoracic movement these approaches do not mitigate soft tissue artefact, an unavoidable source of measurement error [44]; reported to be 14-16 mm using skin sensors during thoracic rotation [45]. That said, one study used the gold standard of radiographic and photographic images to determine thoracic extension during bilateral arm elevation [42]. With comparable ranges of thoracic spine extension reported across studies [36,39] this provides some evidence for concurrent validity of other measures and the reported 12-15 degrees thoracic extension during UL flexion elevation in standing. Moreover with the radiographic images resulting in 2+ degrees more movement than photographs it is conceivable that current evidence from skin based motion analysis systems underestimates the contribution of the thoracic spine to functional UL movement. With advances in ultrasound technologies and the ability to combine motion analysis with ultrasound imaging [46 45] to ensure bone visualisation further research may be possible to better understand the 'true' relationship of thoracic mobility and UL functional motion. These developments offer a relatively inexpensive and safe approach to future motion analysis studies in the thoracic spine.

Strengths and limitations

This was a methodologically rigorous review synthesising evidence to support clinical practice recommendations in assessing shoulder and functional movement impairment in athletes and guide and inform further high quality research. The main limitations to inform conclusions of this systematic review include a lack of research into the population of interest with only one study assessing an athletic population [40] and lack of reporting guidelines specific for exploratory laboratory based studies (case controlled and cohort). Additional methodological limitations of this review include lack of a published protocol and full text review being completed by one reviewer.

Perspective and future directions

Generalisability of our findings to all athletic populations should however be done with caution with many sports involving 'sitting' *e.g.* rowing or Para sport. That said shoulder complaints feature highly in some such sports e.g. wheelchair basketball, rugby *etc.*[47] and is perhaps attributable to thoracic spine mobility being significantly lower in those who sit for prolonged periods [48] or restricted by external constraints such as wheelchair belts or supports. Also where extracted data from Crosbie et al., [38] reports only results from dominant arm movements and other studies failing to report or control for arm dominance this may impact transferability to some athletic populations. Findings from this review do however lend further support for examination of, and within the thoracic spine in athletes with shoulder impairments and disruption within UL kinetic chains. Valid approaches to measure thoracic spine mobility in practice (iPhone and inclinometers) now exist [49] and can be used to investigate effectiveness of exercise prescription on thoracic spine mobility in the future. Review findings, combined with preliminary evidence of the benefit of thoracic mobility exercises in handball players [1] also supports a focus on thoracic spine in rehabilitation and injury prevention for athletes involved in sports with a high functional demands involving unilateral and bilateral arm elevation. Further research is now needed to assess this within different athletic populations, to identify whether sport specific adaptations including repetitive movement of the shoulder affects these established relationships. Moreover, a further review needs to be conducted including the studies with participants over the age of 40 [19,50], as these could strengthen the relationship of findings within the general population or allow recommendations to be made for the growing population of older athletes. Finally, research needs to assess thoracic spine movement in mid-range and multi-planed functional shoulder movement to better reflect the performance requirements of athletes within and across a number of sports.

CONCLUSION

Thoracic mobility UL functional motion

For individuals less than 40 years of age who reflect the age of an athletic population this review provides evidence, albeit of very low quality of thoracic spine mobility during mid and end range UL movements into elevation across all movement planes in standing. Targeted high quality research is now needed to further explore this in an athletic population, including movement involving different planes, ranges and conditions. Practitioners working with athletes where functional UL movement involves the kinetic chain should further incorporate dynamic assessment of thoracic spine mobility.

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