Exposure to Low Amounts of Ultrasound Energy Does Not Improve Soft Tissue Shoulder Pathology: A Systematic Review
PHYS THER. 2010; 90:14-25.
Originally published online November 12, 2009
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Exposure to Low Amounts of Ultrasound Energy Does Not Improve Soft Tissue Shoulder Pathology: A Systematic Review

Lisa D. Alexander, David R.D. Gilman, Derek R. Brown, Janet L. Brown, Pamela E. Houghton

Background. Although therapeutic ultrasound is commonly used to treat shoulder injuries, research to date on the ability of ultrasound to improve outcomes for shoulder pathologies is conflicting.

Objective. This study aimed to systematically and critically review available literature to ascertain whether beneficial effects of ultrasound were associated with certain shoulder pathologies or particular ultrasound treatment protocols.

Methods. Five electronic databases were searched, and the included studies, identified through pair consensus, were randomized controlled trials (RCTs) that utilized ultrasound for soft tissue shoulder injury or pain.

Study Selection and Data Extraction. Eight studies included in this review (n=586 patients, median PEDro score=8.0/10) evaluated various parameters, including the duration of patients’ symptoms (0–12 months), duty cycle (20% and 100%), intensity (0.1–2.0 W/cm²), treatment time per session (4.5–15.8 minutes), number of treatments (6–39), and total energy applied per treatment (181–8,152 J).

Data Synthesis. Inconsistent outcome measures among studies precluded meta-analysis; however, 3 RCTs showed statistically significant benefits of ultrasound, 2 of which examined calcific tendinitis. Studies that showed beneficial effects of ultrasound typically had 4 times longer total exposure times and applied much greater ultrasound energy per session (average of 4,228 J) compared with studies that showed no benefit of ultrasound (average of 2,019 J). No studies that delivered ≤720 J per session showed improvement in treatment groups.

Limitations. Current research involving ultrasound treatment protocols that delivered low levels of ultrasound energy do not adequately address whether ultrasound can improve outcomes for shoulder disorders.

Conclusion. Determining whether therapeutic ultrasound can affect soft tissue shoulder pathologies will require further research and systematic reviews that involve appropriate ultrasound treatment protocols.
Shoulder pain constitutes approximately 16% of all musculoskeletal complaints, making it the third most common musculoskeletal disorder, next only to low back and neck disorders. The annual incidence of 15 new episodes of shoulder pain per 1,000 patients seen in the primary care setting may peak during the fourth and fifth decades of life. The symptoms of new episodes of shoulder pain in the primary care setting have been shown to persist for at least 1 year in 40% to 50% of patients.

Shoulder pain with associated soft tissue pathology can be divided into several diagnostic categories, including subacromial impingement syndrome, tendinitis, tendinosis, bursitis, calcific deposits, and myofascial tears. The causes of such disorders can be multifactorial and may be associated with repetitive movements and overuse, trauma, surgical intervention, thoracic kyphosis, advancing age, acromioclavicular or glenohumeral osteophytes, decreased mobility in the cervicothoracic spine, autoimmune and inflammatory diseases, or metabolic diseases. The human shoulder complex provides a stable, yet mobile, base of support upon which coordinated movements can occur; this requirement of diametrically opposed functions also may be an underlying etiology of shoulder dysfunction.

The aims of conservative treatments for shoulder complaints are to identify and ameliorate the underlying etiology, when possible, and to control symptoms such as pain. Conservative treatments include, but are not limited to, analgesics, nonsteroidal anti-inflammatory drugs, steroid injections, and physical therapy; the last may include therapeutic exercise, joint mobilization and manipulation, education, and the application of physical modalities such as ultrasound.

Ultrasound is widely used in the management of soft tissue injuries. Seven systematic reviews and meta-analyses previously examined the effectiveness of ultrasound for musculoskeletal disorders. In 4 of these studies, investigators reported on a wide range of physical therapy interventions for the treatment of shoulder pain or disorders. The 3 remaining reviews included studies in which only the effects of ultrasound treatment were examined but in which participants exhibited a wide range of musculoskeletal disorders (eg, chronic wounds, myofascial pain, osteoarthritis) affecting several body locations (eg, perineum, ankle, low back). In a 1999 review of the treatment of shoulder disorders, van der Heijden concluded that “there was sufficient evidence that physical modalities, including ultrasound, do not contribute to pain reduction or recovery from shoulder disorders.” The Philadelphia Panel clinical practice guidelines on interventions for shoulder pain concluded that ultrasound is beneficial in the treatment of calcific tendinitis but that it has not been shown to be clinically important for nonspecific shoulder complaints, such as bursitis and tendinitis. For the most part, these conclusions are in agreement with the findings of the 2003 Cochrane review. However, the fact that these reviews included such a wide range of treatment interventions and heterogeneous patient populations could have masked any specific indication for ultrasound treatment. In addition, no published review has included newer studies (published since 1999) examining the effects of ultrasound on shoulder disorders. A more focused review specifically examining the effects of ultrasound on soft tissue disorders of the shoulder is warranted.

Furthermore, in published articles in which the clinical evidence for the ultrasound treatment of shoulder pathologies was reviewed, the appropriateness and rigor of the ultrasound treatment protocols used in the clinical trials were not considered. In a 2001 review of ultrasound effectiveness studies, Robertson and Baker were the first to calculate and compare the total amounts of ultrasound energy delivered to tissues to examine the effects of ultrasound dosages on study outcomes. However, included in that review were clinical trials involving many musculoskeletal conditions (eg, chronic wounds, carpal tunnel syndrome, osteoarthritis of the knee). Accordingly, the studies included in that review involved a wide range of ultrasound treatment protocols because many different conditions and body locations were treated with ultrasound. To calculate the ultrasound energy delivered, the authors also had to make several assumptions about transducer head size and treatment area, a fact that they suggested “was clearly a potential source of error in subsequent calculations.”

Therefore, given the heterogeneity and limitations of previous systematic reviews, there is a need to systematically review and critically evaluate existing literature to specifically examine the potential effects of ultrasound treatment of soft tissue disorders of the shoulder. The purposes of this study were to identify relevant randomized clinical trials.
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RCTs and to evaluate ultrasound treatment protocols to determine whether certain ultrasound treatment parameters were associated with improvements in soft tissue shoulder impairments or function. The specific study protocol characteristics that were evaluated in this review included the clinical characteristics of the study populations (eg, type of pathology treated, time since symptom onset) and the ultrasound parameters (eg, duty cycle, frequency, treatment time per session, total exposure, total ultrasound energy applied both per session and over the entire duration of each study).

Method

Data Sources

A search of 5 electronic databases (CINAHL, 1982–2008; Cochrane Central Register of Controlled Trials, 1947–2008; EMBASE, 1947–2008; MEDLINE, 1950–2008; and PubMed, 1950–2008) was conducted and limited by language (English), population (humans), and study type (RCT). The search included investigations published in print or electronically before April 2008. The search terms used for this process are listed in Table 1. Before the literature search was conducted, specific study inclusion and exclusion criteria were formulated (Tab. 2). To be included in the current investigation, studies had to exhibit an RCT design that involved patients who were 18 years of age or older and who exhibited soft tissue shoulder pathology or pain not attributable to hemiparesis, systemic rheumatic or autoimmune conditions, fractures, osteoarthritis, or surgical interventions. Included studies also had to report ultrasound treatment protocols in sufficient detail to enable us to calculate the power and total ultrasound energy delivered (see calculations in “Data Extraction” section below).

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Study Selection

Primary search part A: selection of relevant titles and abstracts. Initially, for identification of studies that met inclusion criteria, each database was searched independently by at least 2 authors of the present study. In part A of the search, the titles and abstracts (citations) of all studies identified in the electronic database search were assessed. For a study to be included for further assessment (part B: review of full article), a pair consensus regarding in-
clusion was reached. In instances of doubt about whether to include a study for further assessment, the full article was retrieved.

**Primary search part B: identification of full articles.** Full articles were obtained from the citations identified in part A of the electronic database search. Two copies of each article were randomly distributed among 3 researchers, who independently reviewed each article and determined whether the study met the inclusion criteria.

**Secondary search.** For further identification of potentially relevant studies, a secondary search was performed. In this stage of the investigation, the authors examined the reference lists of the relevant publications, such as reviews, meta-analyses, and case studies. Any relevant articles were retrieved and assessed for inclusion independently by 2 reviewers. These articles were selected by use of the pair consensus process described above.

**Quality Assessment (Critical Appraisal)**
For each study selected for inclusion from the primary search or the secondary search, 3 reviewers independently conducted Physiotherapy Evidence Database (PEDro) assessments. The PEDro scale was chosen for this critical appraisal process because it can allow for a reliable assessment of the RCT design quality. No study was excluded on the basis of methodological quality. The PEDro scale ranges from 0 to 10, with 10 indicating the best possible score.

**Data Extraction**
The results of included studies were extracted and analyzed. From the extracted data, the spatial average–temporal average (SATA, W/cm²), energy density per treatment (J/cm²), total energy delivered during a single treatment (J), and total exposure to ultrasound over the entire duration of the study (hours) were calculated. These parameters were determined with the following equations:

1. \[ \text{SATA (W/cm}^2\text{)} = \frac{\text{average intensity (W/cm}^2\text{)} \times \text{duty cycle (%)} } {100} \]
2. \[ \text{Energy density per treatment (J/cm}^2\text{)} = \text{SATA (W/cm}^2\text{)} \times \text{time per treatment (seconds)} \]
3. \[ \text{Total energy per treatment (J)} = \text{SATA (W/cm}^2\text{)} \times \text{transducer head size or effective radiating area (cm}^2\text{)} \times \text{time per treatment (seconds)} \]
4. \[ \text{Total exposure (hours)} = \frac{\text{number of treatments} \times \text{time per treatment (seconds)}} {3600} \]
5. \[ \text{Total energy delivered over entire study duration (J)} = \text{total energy per treatment (J)} \times \text{number of treatments} \]

**Results**
As indicated in the Figure, the electronic database search yielded 727 results, with the following number of citations for each database: CINAHL (127), Cochrane Central Register of Controlled Trials (38), EMBASE (464), MEDLINE (18), and PubMed (80). Thirty full articles were identified from the search of these citations, and 697 articles were excluded. An additional 11 articles were identified from the secondary search of references cited in book chapters, reviews, and other articles. Through a pair consensus process, 33 of the 41 selected articles were excluded on the basis of the prede-termined criteria. Eight original RCTs examining the effects of ultrasound on shoulder pathology were included in the present report. A total of 586 participants were enrolled in the 8 included studies, with 543 participants following through to completion.

In 3 of the 8 studies included in the present systematic review, Shomoto et al,23 Ebenbichler et al,24 and Downing and Weinstein27 reported that ultrasound produced outcomes significantly better than those seen in control groups. In 2 of these studies, the impact of ultrasound on calcific tendinitis was specifically examined, and both Shomoto et al23 and Ebenbichler et al24 found significant reductions in pain and calcium deposits. Ebenbichler et al24 also found significant improvements in function.

Assessment of the RCT design quality of the 8 included studies yielded a median PEDro scale score of 8.0 (range = 4–10) (Tab. 3). The following shoulder pathologies were examined in the included studies: calcific tendinitis, shoulder pain, subacromial bursitis, adhesive capsulitis, biceps tendinitis, and supraspinatus tendinitis (Tab. 4). The duration of participants’ symptoms before enrollment varied between and within the studies, ranging from 0 to greater than 12 months, with the majority of studies involving chronic shoulder disorders (ie, >6 weeks since symptom onset). There was a tendency for investigators to use multiple concurrent treatments within each study; although some used only 1 concurrent treatment,24,29 others used multiple concurrent treatments, including heat, interferential current (IFC), range-of-motion exercises, and strengthening.25,28,30 Concurrent therapies offered to participants treated with ultrasound and control participants within a study were similar; however, none of the 8
studies involved the same concurrent treatment regimens. In 2 of the studies, IFC was applied in addition to ultrasound.25,28 The results reported in 1 such study28 suggested that similar reductions in shoulder impairments occurred over time in subjects treated with ultrasound and subjects treated with IFC and that no additional benefit was observed when IFC and ultrasound were combined.

A wide array of outcome measures also were used across the studies. Several different outcome measures were used to assess quality of life, pain, and functional ability. In the 7 studies in which pain was reported as an outcome, little overlap in the measures used was observed: In 3 studies, a scale ranging from 0 to 3 was used (1 study rated pain during a specific resisted movement,26 another rated pain during rest and movement,25 and the third rated pain during daily activities27); in the remaining 4 studies, a 10-point numeric rating scale,24 a 10-point visual analog scale,30 a 7-point Likert scale,28 or a dichotomous scale was used.

### Table 3.
Physiotherapy Evidence Database (PEDro) Scale Scores of Included Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>PEDro Scale Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shomoto et al (2002)23</td>
<td>4</td>
</tr>
<tr>
<td>Nykanen (1995)26</td>
<td>7</td>
</tr>
<tr>
<td>Downing and Weinstein (1986)27</td>
<td>10</td>
</tr>
<tr>
<td>van der Heijden et al (1999)28</td>
<td>10</td>
</tr>
<tr>
<td>Roman (1960)29</td>
<td>4</td>
</tr>
<tr>
<td>Ainsworth et al (2007)30</td>
<td>9</td>
</tr>
<tr>
<td>Median score</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Figure.
Flow diagram of search strategy and summary of excluded studies. PEDro=Physiotherapy Evidence Database, RCT=randomized controlled trial.
Table 4.
Summary of Included Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Pathologies Treated</th>
<th>Chronicity</th>
<th>Frequency (MHz)</th>
<th>Head Size or ERA (cm²)</th>
<th>Average Intensity (W/cm²)</th>
<th>Duty Cycle (%)</th>
<th>SATA (W/cm²)</th>
<th>Rx Time/Session (min)</th>
<th>Total Energy/Rx (J)</th>
<th>Average No. of Rxs</th>
<th>Total Exposure (h)</th>
<th>Total Energy Over Study Duration (J)</th>
<th>Concurrent Treatments</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shomoto et al (2002)</td>
<td>Calcific tendinitis</td>
<td>&gt;3 mo</td>
<td>3.0</td>
<td>4.3b</td>
<td>1.0–2.0</td>
<td>Continuous</td>
<td>1.0–2.0</td>
<td>15.8</td>
<td>4,076–8,152</td>
<td>28–39</td>
<td>7.4–10.3</td>
<td>114,128–317,928</td>
<td>Mobilization, exercise, stretching/strengthening</td>
<td>Yes</td>
</tr>
<tr>
<td>Ebenbichler et al (1999)</td>
<td>Calcific tendinitis</td>
<td>&gt;4 wk</td>
<td>0.89</td>
<td>5</td>
<td>2.5</td>
<td>Pulsed (20)</td>
<td>0.5</td>
<td>15.0</td>
<td>2,250</td>
<td>24</td>
<td>6.0</td>
<td>54,000</td>
<td>Analgesics</td>
<td>Yes</td>
</tr>
<tr>
<td>Downing and Weinstein (1986)</td>
<td>Supraspinatus tendinitis, adhesive capsulitis, subacromial bursitis</td>
<td>&lt;1 y</td>
<td>1.0</td>
<td>10</td>
<td>1.2</td>
<td>Continuous</td>
<td>1.2</td>
<td>6</td>
<td>4,320</td>
<td>12</td>
<td>1.2</td>
<td>51,840</td>
<td>NSAID, exercise (ROM)</td>
<td>No</td>
</tr>
<tr>
<td>Kurtis Gu¨rsel et al (2004)</td>
<td>Rotator cuff tendinitis or partial rupture, biceps tendinitis</td>
<td>NR</td>
<td>1.0</td>
<td>5b</td>
<td>1.5</td>
<td>Continuous</td>
<td>1.5</td>
<td>10</td>
<td>4,500</td>
<td>15</td>
<td>2.5</td>
<td>67,500</td>
<td>Heat, IFC, exercise (ROM, stretching/strengthening)</td>
<td>No</td>
</tr>
<tr>
<td>Roman (1960)</td>
<td>Bursitis</td>
<td>NR</td>
<td>0.87</td>
<td>2b</td>
<td>1.5</td>
<td>Continuous</td>
<td>1.5</td>
<td>5–8</td>
<td>3,150–5,040</td>
<td>8.24</td>
<td>0.6–1.1</td>
<td>25,956–41,529</td>
<td>Heat (20 min)</td>
<td>...</td>
</tr>
<tr>
<td>van der Heijden et al (1999)</td>
<td>Shoulder pain</td>
<td>0 to &gt;12 mo</td>
<td>0.8</td>
<td>4b</td>
<td>3.0</td>
<td>Pulsed (20)</td>
<td>0.6</td>
<td>5</td>
<td>720</td>
<td>12</td>
<td>1.0</td>
<td>8,640</td>
<td>NSAID, IFC, exercise (ROM, stretching/strengthening)</td>
<td>No</td>
</tr>
<tr>
<td>Nykanen (1995)</td>
<td>Supraspinatus tendinitis</td>
<td>&gt;2 mo</td>
<td>1.0</td>
<td>5</td>
<td>1.0</td>
<td>Pulsed (20)</td>
<td>0.2</td>
<td>10</td>
<td>600</td>
<td>10–12</td>
<td>1.67–2.0</td>
<td>6,000</td>
<td>Heat, massage, exercise (stretching, strengthening)</td>
<td>No</td>
</tr>
<tr>
<td>Ainsworth et al (2007)</td>
<td>Shoulder pain</td>
<td>NR</td>
<td>1 or 3</td>
<td>6.7c</td>
<td>0.5</td>
<td>Pulsed (20)</td>
<td>0.13</td>
<td>4.5</td>
<td>181</td>
<td>6</td>
<td>0.45</td>
<td>1,085</td>
<td>Advice, manual therapy, exercise (home)</td>
<td>No</td>
</tr>
</tbody>
</table>

Table is arranged in order of total ultrasound energy delivered per session. Chronicity = duration of participants’ symptoms before study enrollment, ERA = effective radiating area, SATA = spatial average–temporal average, Rx = treatment, Pain = statistically significant pain reduction compared with outcome in control group, Ca = calcium deposit reduction, ROM = improved range of motion, Fn/Dis = functional improvement or reduction in disability, ellipsis = not assessed, NSAID = nonsteroidal anti-inflammatory drug. NR = not reported, IFC = interferential current. Equations were as follows:

SATA = average intensity (W/cm²) × duty cycle

Total exposure (h) = number of treatments × treatment time

Energy per Rx (J) = SATA (W/cm²) × head size or ERA (cm²) × Rx time (s)

Total ultrasound energy delivered over study duration (J) = ultrasound energy per treatment × number of treatments

b The ERA was reported.

c Head size was estimated as the average value for the area used in the other 7 studies.
Ultrasound for Soft Tissue Shoulder Pathology

Table 5.
Comparison of Studies in Which Ultrasound Was Reported to Be Beneficial and Studies in Which No Statistical Difference Was Found Between Treatment and Control Groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ultrasound Found Beneficial</th>
<th>Ultrasound Found Equivalent to Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of studies</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Total no. of participants</td>
<td>121</td>
<td>465</td>
</tr>
<tr>
<td>Energy density, J/cm², (\bar{X}) (range)</td>
<td>768 (432–1,422)</td>
<td>413 (27–900)</td>
</tr>
<tr>
<td>Total energy per session, J, (\bar{X}) (range)</td>
<td>4,228 (2,250–6,114)</td>
<td>2,019 (181–4,095)</td>
</tr>
<tr>
<td>Total exposure, h, (\bar{X}) (range)</td>
<td>5.3 (1.2–10.3)</td>
<td>1.3 (0.5–2.5)</td>
</tr>
<tr>
<td>Total energy over study duration, J, (\bar{X}) (range)</td>
<td>107,289 (51,840–216,028)</td>
<td>20,394 (1,085–67,500)</td>
</tr>
</tbody>
</table>

* Values for studies in which a benefit of ultrasound was seen or in which no benefit was seen in the ultrasound group compared with the control group. Studies were considered “beneficial” when a statistically significant improvement in 1 or more of the chosen outcome measures was reported. Equations were as follows:

\[
\text{Energy density} = \text{spatial average} \times \text{temporal average} \times \text{treatment time}
\]
\[
\text{Total energy per session} = \text{spatial average} \times \text{temporal average} \times \text{transducer head size} \times \text{treatment time}
\]
\[
\text{Total exposure} = \text{treatment time per session} \times \text{number of sessions}
\]
\[
\text{Total energy over study duration} = \text{total energy per session} \times \text{number of sessions}
\]
The treatment area sizes were considered to be the same for all of the studies because only the shoulder area was included in these studies.

(“yes” or “no”) was used. Quantitative outcome measures used included x-ray imaging for calcific deposits and goniometric measures of shoulder range of motion. Because of the wide range of outcome measures and the variety of treatment parameters used in the studies, pooling results for a meta-analysis was not possible in the present investigation.

The intensity of ultrasound used varied greatly among the studies, as Sata values ranged from 0.1 to 2.0 W/cm². In 4 of the 8 studies included in the present review, pulsed ultrasound was used (20% duty cycle), and in the other 4 studies, continuous ultrasound waves were used. The mean application time per treatment session and the number of treatment sessions were also variable, ranging from 4.5 to 15.8 minutes per treatment session and from 6 to 39 treatment sessions. The transducer head size or effective radiating area was reported in all but 1 study (Ainsworth et al.), and in most studies, similar head sizes were used (4–5 cm²). The ultrasound machine used in the study by Downing and Weinstein was larger (10 cm²). The total energy delivered per session was calculated to be greater than 2,250 J in most of the studies, but it was much lower in the studies of Nykanen, van der Heijden et al., and Ainsworth et al.

The total exposure times varied greatly among the studies, ranging from 0.45 to 10.3 hours. Calculations of the total ultrasound energy delivered over the entire duration of each study (total energy \( \times \) number of treatment sessions) demonstrated the dramatic differences in the amounts of ultrasound energy to which subjects in the different studies were exposed (Tab. 4). In particular, in the recently published study of Ainsworth et al., the total energy delivered per session was 181 J. This low level of ultrasound energy, combined with the relatively small number of treatments administered (6 treatments), resulted in a total exposure over the study duration (1,085.4 J) that was about 1/100 of the average for the studies that were included in the present review and that noted a benefit of ultrasound (107,289 J) (Tab. 5).

Calculations performed to compare and contrast the intensity and duration of ultrasound exposure in the 3 studies in which a benefit of ultrasound treatment was reported with those in studies in which no significant difference between participants receiving ultrasound treatment and control participants was reported are provided in Table 5. Average values for the ultrasound energy density, the total ultrasound energy delivered per session, and the amount of time ultrasound was applied over the entire study duration were all at least 2 times higher in studies that detected a significant improvement in subjects treated with ultrasound versus control subjects than in studies that failed to find a difference between those groups of subjects. Participants in studies in which ultrasound was not found to be beneficial received an average level of ultrasound energy for the study duration that was one fifth of that in studies in which ultrasound was found to be beneficial (Tab. 5). Unfortunately, there were fewer studies with fewer participants in which effective ultrasound treatment protocols were used.

Discussion
The present systematic review of the available research on ultrasound as it relates to the treatment of soft tissue shoulder disorders and pain resulted in a total of 8 RCTs that met the inclusion criteria. Three of the 8 trials revealed statistically significant improvements in outcomes for treated participants compared with control participants. Studies that de-
tected statistically significant improvements in patients treated with ultrasound generally involved higher levels of total ultrasound energy per treatment and provided longer exposure times than studies that failed to detect a difference between patients treated with ultrasound and control patients. Studies in which a benefit of ultrasound (relative to placebo ultrasound) was reported tended to include subjects from a well-defined patient population (such as those with calcific tendinitis).

Along with identifying study protocol characteristics that have been associated with more beneficial results for ultrasound in the management of shoulder injuries, this investigation also sought to identify attributes in currently available RCTs that may have obfuscated previous assessments of the effectiveness of ultrasound in treating shoulder complaints. These issues are outlined below.

**Classification of Shoulder Pathology**

All of the studies included in the present review focused on soft tissue musculoskeletal disorders of the shoulder. Specific inclusion and exclusion criteria were applied consistently, and potential subjects were excluded if their shoulder disorders involved neurological or systemic inflammatory conditions. In 6 of the 8 included studies, subjects underwent a screening evaluation performed by an independent assessor, and diagnostic imaging was used to confirm the diagnosis in 3 of the studies. In 2 of the 8 included studies, subjects had a wide range of conditions, such as rotator cuff tendinitis and tendinosis, biceps tendinitis, subacromial bursitis, and adhesive capsulitis, in the same study populations. These disorders have been shown to vary greatly with respect to the underlying cellular processes and pathologies at work, thereby reducing the likelihood of achieving a valid conclusion concerning the effectiveness of ultrasound. Likewise, in 2 of the 8 studies, subjects had shoulder disorders broadly categorized as causing “shoulder pain.” As indicated by Burbank et al., who outlined standardized diagnostic criteria for numerous categories of shoulder disorders, the diagnosis of shoulder pain falls well short of the mark for the degree of diagnostic precision that clinicians can achieve by obtaining a focused medical history and performing a careful physical examination. By categorizing study participants in this nonspecific manner, investigators risk obtaining a highly heterogeneous study population for which it could be difficult to avoid type 2 errors. Furthermore, by broadly categorizing study participants as experiencing shoulder pain, investigators risk including people who are experiencing referred pain from the cervical spine or other regions of the body and who, in fact, do not have true shoulder pathology.

It is clear that in future studies of the effectiveness of ultrasound, every effort should be made to assemble a highly homogeneous study population. This goal can be greatly facilitated with the aid of diagnostic imaging. Several imaging modalities, such as radiography, ultrasonography, and magnetic resonance imaging, can be of substantial diagnostic value for conditions such as osteoarthritis, rotator cuff pathology (e.g., tendinopathy, full- or partial-thickness tears), and calcific tendinitis. The benefit of using imaging modalities to help define a focused study population may be evident in the studies (described in the present investigation) that included only participants with calcific tendinitis. In both of these trials, ultrasound (relative to placebo ultrasound) was reported to result in significant improvements.

**Staging or Chronicity of Shoulder Disorders**

Previous RCTs examining the effects of therapeutic ultrasound on shoulder disorders also may have had a limited ability to detect changes because they included participants with a broad range of symptom durations (chronicity of the condition). Three of the 8 investigations included in the present study did not explicitly report the chronicity of participants’ conditions. In the remaining 5 studies, patients’ pre-enrollment symptom durations ranged from 0 to greater than 12 months. Combining acute, possibly first-occurrence shoulder disorders with chronic, possibly recurrent disorders in a study population may be especially problematic given that the duration of patients’ symptoms has been shown to dictate the pathological state of affected tissues. For example, histopathological studies have revealed striking differences among the 3 well-documented stages of adhesive capsulitis and between acute and chronic tendinopathy (tendinitis versus tendinosis). Because acute tendinopathy has been characterized by the presence of inflammatory mediators, whereas chronic tendinopathy involves a disorganized collagen structure and changes consistent with hypoxia, it is unlikely that these disparate pathologies would respond in similar ways to a uniform set of ultrasound parameters. In fact, it is more likely that, given the differences in the proposed effects of nonthermal ultrasound and thermal ultrasound, a pulsed duty cycle and a continuous duty cycle would be most beneficial for acute and chronic injuries, respectively.

Thus, the broad range in chronicity exhibited by participants within many studies, combined with the facts that all participants within a given study received the same treatment protocols and that acute and...
chronic injuries were not necessarily treated with the potentially most appropriate duty cycle, may account partly for the relatively small amount of evidence supporting the utility of therapeutic ultrasound for soft tissue shoulder pathology. Future investigations need to account for the fact that the same ultrasound protocols cannot be used to treat conditions with vastly different underlying pathophysiological processes.

Multiple Concurrent Treatments

Unfortunately, of the 8 studies identified in the present analysis, none included a similar treatment program in the control arm of the study. Thus, it appears that there is little agreement about the standard treatment approach for soft tissue disorders of the shoulder. In 6 of the 8 studies, exercise was part of the treatment intervention; however, the type and intensity of these programs were not provided in any detail to allow an assessment for similarities. Ebenbichler et al used the fewest cointerventions, allowing occasional use of analgesics (but not anti-inflammatory medications) as required in both study groups. In contrast, Kurtai Gürsel et al provided up to 6 concurrent treatments. Although it may be a common clinical practice to combine different types of therapies, such as exercise, medications, and modalities, to address shoulder pathologies, it is not clear why the authors elected to administer several similar concurrent modalities (such as heat, ultrasound, and IFC). This approach seems to be unjustified and very likely may have masked any potential effect of the ultrasound treatment protocol because the proposed physiological effects of ultrasound may be similar to those induced by the concurrent treatments. Although the authors did ensure that the cointerventions were similar between the comparison groups, we strongly recommend that future clinical trials testing the therapeutic benefits of ultrasound avoid the use of concurrent modalities or treatments with effects that are similar to or counterproductive to the suggested physiological effects of ultrasound.

Study Design and Size of Study Population

Assessment with the PEDro scale suggested that, on average, the included studies had most of the desirable methodological attributes (such as internal validity and statistical rigor) that are evaluated with this scale. The average PEDro scale score assigned by our 3 independent evaluators was 8.0, which was in keeping with the scores assigned to these clinical trials by the Centre for Evidence Based Physiotherapy (average score=6.75). We did not elect to remove any study on the basis of the PEDro scale score, partly because of contention regarding whether investigators are actually able to use effective masking strategies for ultrasound.

A common feature of more recent RCTs is the use of prestudy calculations to establish the sample size required to detect the desired or presumed effect size of treatment. When effect sizes are thought to be relatively small, larger sample sizes are required to detect the differences between 2 groups. It is worth noting that only 1 of the 8 studies included in the present analysis conducted such calculations to ensure that an adequate sample size was used. Ainsworth et al suggested that a sample size of at least 200 patients was required to detect a meaningful change in their primary outcome measure (the Shoulder Disability Questionnaire). A much smaller sample size requirement of 26 participants for ultrasound studies was suggested in a review by Robertson and Baker. Four of the studies included in the present review failed to meet this (n=26) suggested sample size. Therefore, it is possible that studies involving very small numbers of subjects may not have detected differences between groups because of reduced statistical power. Similarly, small sample sizes may partly explain the positive findings reported by Downing and Weinstein and Shomoto et al. Notably, the 2 studies involving the largest sample sizes did not find a significant difference in outcome measures between subjects treated with ultrasound and control subjects, suggesting that the inability to find a difference between the groups was not necessarily attributable to inadequate sample sizes.

Future studies of therapeutic ultrasound for shoulder injuries should include sample size calculations and demonstrate that a sufficient number of participants were included to detect differences between study groups. Given the inherent difficulties with recruiting a large homogeneous population of subjects into any particular study, problems with inadequate sample size may be addressed more easily by combining results from several studies with a meta-analysis; however, this method would require a more consistent use of valid outcome measures that are known to be able to accurately assess shoulder impairments and upper-extremity function.

Ultrasound Stimulus Parameters and Treatment Protocols

Experimental human research studies have demonstrated that the physiological responses to ultrasound depend on ultrasound intensity and frequency. Draper and colleagues showed that the average rates of temperature increase per minute with continuous ultrasound administered at a frequency of 1 MHz were 0.04°C at 0.5 W/cm², 0.16°C at 1.0 W/cm², 0.33°C at 1.5 W/cm², and 0.38°C at 2.0 W/cm². Also, the rates of temperature in-
crease per minute with ultrasound at a higher frequency (3 MHz) were 0.3°C at 0.5 W/cm², 0.58°C at 1.0 W/cm², 0.8°C at 1.5 W/cm², and 1.4°C at 2.0 W/cm². Although changes in tissue temperatures (thermal responses) are only part of the biological responses produced by the mechanical waves of ultrasound, these measurable changes strongly support the assertion that the amount of ultrasound energy delivered to tissues depends on the ultrasound parameters selected. Given the barely detectable temperature change occurring when low-frequency (1-MHz) ultrasound was delivered at an intensity of 0.5 W/cm², it is very unlikely that the ultrasound treatment used by Ainsworth et al.30 would have achieved sufficient levels of the desired physiological responses to induce changes in their primary outcome measures of pain and range of motion. The low ultrasound intensity used in that study was confounded by the use of the pulsed ultrasound mode (20% duty cycle), the application of short treatments (4.5 minutes), and the limited number of treatment sessions. Collectively, these factors made the total amount of ultrasound energy delivered in that study one fifth of the average amount used in the other included studies. These arguably suboptimal ultrasound treatment parameters must be considered a key determinant that may explain the lack of effect observed in the study of Ainsworth et al.30

Of concern is the fact that the study of Ainsworth et al.30 is the most recent report in the literature that has examined the effectiveness of ultrasound for soft tissue shoulder disorders. That study was a multisite investigation performed in 9 centers in the United Kingdom with 221 study participants. The ultrasound treatment regimen was not defined by the study protocol but rather by the average ultrasound treatment parameters selected by the 28 physical therapists applying the treatments. The average ultrasound intensity was 0.5 W/cm² (range=0.1–1.0 W/cm²) applied for 4.5 minutes (range=3–7 minutes), with 46% and 39% of therapists selecting 1 MHz and 3 MHz, respectively. These results suggest that common practice in this region of the United Kingdom is to apply ultrasound treatments that deliver extremely little sound energy to the target tissues. Of greater concern is that the practice of applying relatively low intensities of pulsed ultrasound for relatively short periods of time (5 minutes or less) is apparently being adopted more broadly across the profession of physical therapy. Although current evidence to support the use of ultrasound in the treatment of shoulder pathologies is limited, there is good evidence to suggest that the application of suboptimal ultrasound parameters like those used by Ainsworth et al.30 is extremely unlikely to provide additional benefits to patients with soft tissue shoulder disorders.

Calculations of total ultrasound energy revealed 2- to 5-fold larger amounts of ultrasound energy per treatment and longer exposure times (treatment time × number of treatments) in studies in which a benefit of ultrasound was reported. Furthermore, none of the studies in which ≤720 J per session was applied reported an additional benefit of ultrasound. We feel that studies delivering such low doses of ultrasound energy are in effect delivering sham ultrasound and could not reasonably be expected to produce treatment effects.

Conclusions
The findings of the present study reveal that favorable patient outcomes in RCTs of therapeutic ultrasound for shoulder pain and injury have been noted when ultrasound energy of at least 2,250 J per treatment session was applied. Furthermore, when insufficient ultrasound energy (ie, ≤720 J per session) was provided, positive outcomes rarely occurred. Our results suggest that the effectiveness of ultrasound on soft tissue pathologies has not yet been evaluated using optimal treatment parameters, and, therefore, it is premature to conclude through systematic review of existing literature that this treatment dose “is not effective.”6,13,18 However, systematic reviews conducted to date6,13,18 have focused their evaluation of study quality on generic aspects of study design such as studies’ randomization processes, blinding, and statistical analyses. Our findings echo the general concerns reported by Robertson and Baker17 and agree with the criticisms of others43–45 that the prohibitive conclusions of previous systematic reviews in this realm are based on weak evidence.

More recent trials28,30 that used improved RCT designs with larger sample sizes have used ultrasound treatment protocols that resulted in the delivery of 1/5 to 1/20 of the average ultrasound energy per session that was used in ultrasound studies that produced beneficial results. Should these RCTs that used suboptimal ultrasound treatment protocols be included in future systematic reviews, the question of the effectiveness of ultrasound treatment for these common musculoskeletal disorders will remain an uncertainty for many years to come.

Future Directions
Future primary studies must focus on selecting optimal ultrasound treatment parameters that deliver more than 720 J of ultrasound energy per session (perhaps closer to an average of 4,228 J per session) and treatment schedules that expose tissues to ultrasound for a sufficient period of time (ie, average total exposure time
of >5 hours). Providing sufficient detail in future reports, such as including descriptions of the transducer head size and treatment area, is required if ultrasound treatment protocols are to be critically evaluated. Such studies must also create more homogeneous treatment groups with respect to the diagnosis and chronicity of the disorder. Future investigators should be cognizant of the histopathological state of affected target tissues before selecting the ultrasound parameters that will be used in an investigation to determine whether the thermal or non-thermal effects of ultrasound will likely be of most benefit (see Xu and Murrell, Sharma and Maffulli, and Khan et al for excellent reviews of tendinopathy histopathology). Although there may be ethical reasons why all concurrent therapies cannot be withheld, eliminating the application of similar modalities during a clinical trial may help to unmask some of the benefits of adding ultrasound to the treatment of patients with shoulder pathology. Standardizing the outcome measures used between studies and maintaining consistent characteristics of application are needed if studies with relatively small sample sizes are to be combined by use of meta-analytical techniques. In addition, it is critically important to this area of practice that researchers involved in future systematic reviews or meta-analyses strongly consider the appropriateness of ultrasound treatment parameters when selecting articles to be included in a review.

In a recent article, Norman et al referred to the lessons of Cronbach and proposed that instead of examining the main effects of treatments, investigators should focus on identifying the characteristics of people that make them more or less responsive to particular treatments. Although this direction of research may not be the most scientifically rigorous, it does account for the facts that practitioners treat patients, not pathologies, and that patients may respond to their efforts in different ways. Thus, study designs other than RCTs, such as carefully designed case studies, may prove to be critical for determining which ultrasound parameters should be used for treating individual patients.

All authors provided concept/idea/research design and writing. Ms Alexander, Mr Gilman, and Mr Brown provided data collection. Ms Alexander, Mr Gilman, Mr Brown, and Ms Brown provided data analysis. Dr Houghton provided project management. Ms Brown and Dr Houghton provided consultation (including review of manuscript before submission).

This article was received September 4, 2008, and was accepted August 13, 2009.


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