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REVIEW ARTICLE (META-ANALYSIS)

# Do Thermal Agents Affect Range of Movement and Mechanical Properties in Soft Tissues? A Systematic Review

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**Abstract**

**Objectives:** To examine the effect of thermal agents on the range of movement (ROM) and mechanical properties in soft tissue and to discuss their clinical relevance.

**Data Sources:** Electronic databases (Cochrane Central Register of Controlled Trials, MEDLINE, and EMBASE) were searched from their earliest available record up to May 2011 using Medical Subjects Headings and key words. We also undertook related articles searches and read reference lists of all incoming articles.

**Study Selection:** Studies involving human participants describing the effects of thermal interventions on ROM and/or mechanical properties in soft tissue. Two reviewers independently screened studies against eligibility criteria.

**Data Extraction:** Data were extracted independently by 2 review authors using a customized form. Methodologic quality was also assessed by 2 authors independently, using the Cochrane risk of bias tool.

**Data Synthesis:** Thirty-six studies, comprising a total of 1301 healthy participants, satisfied the inclusion criteria. There was a high risk of bias across all studies. Meta-analyses were not undertaken because of clinical heterogeneity; however, effect sizes were calculated. There were conflicting data on the effect of cold on joint ROM, accessory joint movement, and passive stiffness. There was limited evidence to determine whether acute cold applications enhance the effects of stretching, and further evidence is required. There was evidence that heat increases ROM, and a combination of heat and stretching is more effective than stretching alone.

**Conclusions:** Heat is an effective adjunct to developmental and therapeutic stretching techniques and should be the treatment of choice for enhancing ROM in a clinical or sporting setting. The effects of heat or ice on other important mechanical properties (eg, passive stiffness) remain equivocal and should be the focus of future study.

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The application of thermal agents such as heat or cold is popular in clinical and rehabilitative settings. Altering tissue temperature can have a range of therapeutic effects through changes in metabolism, nerve transmission, hemodynamics, and mechanical properties.[1]

Increasing soft tissue temperature prior to exercise is an accepted practice.[2] This can involve active warm-up or local heat application using warm water immersion or hot packs. Heat is thought to alter the viscoelastic properties of muscles and other collagenous tissues in preparation for physical activity or rehabilitation.[2] Heat is also used as an adjunct to therapeutic or developmental stretching and is often employed to treat restrictions in range of movement (ROM) due to injury or prolonged immobilization.

Cryotherapy is the application of cold for therapeutic purposes. We have previously examined the evidence base for cryotherapy in acute injury management[1] and postexercise recovery.[3,4] Paradoxically, there is a growing trend of applying cold prior to exercise or rehabilitation.[5] Precooling (based on cold water immersion [CWI], ice packs, or ice vests) has gained widespread acceptance as a method of offsetting thermal strain and fatigue and increasing aerobic[6] and anaerobic capacity[7] during competitive exercise. Others advocate the application of cold prior to therapeutic rehabilitation exercises (cryokinetics)

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to induce analgesia and increase volitional muscle activation around injured joints.[8]

The benefits of using thermal interventions must outweigh any deleterious physiological effects. Recent systematic reviews advise caution with the clinical application of cryotherapy, due to short-term but adverse changes to joint proprioception,[9] muscle strength,[10] and neuromuscular performance.[11] The biomechanical properties of collagenous tissue represent an important component of function. In vitro studies[12-17] clearly show that the mechanical properties of ligament, tendon, and muscle are significantly influenced by temperature; this may suggest that heat and cold should not be used interchangeably in a rehabilitation setting. Our aim was to undertake a systematic review to examine the effect of thermal agents on the ROM and mechanical properties of soft tissue in vivo and to discuss their clinical relevance.

## Methods

### Search strategy

We searched the Cochrane Central Register of Controlled Trials, MEDLINE, and EMBASE by combining a range of Medical Subjects Headings and key words (cryotherapy; cold temperature; ice; ice pack; cold pack; ice bath; cold water immersion; cold compress; thermotherapy; hyperthermia, induced; hot temperature; hot pack; elasticity; extensibility; biomechanics; mechanical properties; stress, mechanical; viscoelastic; viscosity; range of movement, articular; stretch; flexibility; pliability). Each database was searched from its earliest available record up to May 2011. We also undertook a related articles search using PubMed (http://www.ncbi.nlm.nih.gov/pubmed) and read reference lists of all incoming articles. English language restrictions were applied.

### Inclusion criteria

Studies must have involved human participants, undertaking thermal interventions (hot or cold) to soft tissues; interventions could be used with or without concomitant stretching exercises. No restrictions were made on the mode, duration, or frequency of interventions. Studies must have reported at least 1 outcome relating to ROM or mechanical properties of soft tissue, for example, stiffness or other viscoelastic properties; these could be based on either active or passive movements. There were no restrictions made on study design or comparison group.

### Selection of studies

Two authors independently selected trials for inclusion. The titles and abstracts of publications obtained by the search strategy were screened. All trials classified as relevant by either of the authors were retrieved. On the basis of information within the full reports, we used a standardized form to select the trials eligible for inclusion in the review. If necessary, we contacted primary authors for clarification of study characteristics. Disagreement between the authors was resolved by consensus or third-party adjudication.

***List of abbreviations:***

| | |
|---|---|
| **CI** | **confidence interval** |
| **CWI** | **cold water immersion** |
| **MD** | **mean difference** |
| **ROM** | **range of movement** |
| **US** | **ultrasound** |

### Data extraction and measures of treatment effect

Data were extracted independently by 2 review authors using a customized form. For each study, mean differences (MDs) and 95% confidence intervals (CIs) were calculated for continuous outcomes using RevMan software.[a] For continuous outcomes that were pooled on different scales, standardized MDs were used. Treatment effects (MDs, standardized MDs) were based on between-group comparisons (eg, thermal vs control) and/or within-group comparisons (prethermal vs postthermal). We focused primarily on outcome data recorded before and immediately after the intervention. In the event that studies employed multiple interventions over a period of days or weeks, we also extracted outcome data recorded at the end of the entire treatment package.

### Risk of bias

For all included studies, methodologic quality was assessed by 2 authors independently, using the Cochrane risk of bias tool.[18] Each study was graded as having high, low, or unclear risk of bias for the following domains: sequence generation, allocation concealment, blinding (outcome assessor), and incomplete outcome data. Blinding of participants and caregivers was not assessed in this review on the basis of the difficulties associated with stringent blinding of a thermal intervention. For each study, the domains were described as reported in the published study report and judged by the review authors as to their risk of bias. Disagreements between authors regarding the risk of bias for domains were also resolved by consensus.

## Results

### Included studies

Figure 1 summarizes the search strategy and selection process based on included and excluded studies. There were 36 eligible studies, comprising a total of 1301 healthy participants.[19-54] The average sample size was 35.1, with the largest study based on 120 participants.[26] Participants tended to be young, and the mean ages reported in studies was between 20 and 30 years. Studies were subgrouped on the basis of primary treatment intervention. In the majority of cases, the thermal intervention was applied in isolation to muscle tissue; the remainder immersed entire body parts in water,[22,25,37,41,43] or targeted a joint region.[21,39,47,53] Further methodologic details of included studies are summarized in table 1.

### Details of thermal interventions

Heating interventions were classified as superficial agents—infrared,[28] hot packs,[27,32,35,36,50,51] hot water immersion,[22,25,37] or electric heating pads[34]—and deep heating agents—ultrasound (US)[19,20,29,47,48,54] or short wave diathermy.[24,30,31,44,49] The duration of treatments ranged between 30 seconds and 60 minutes. All but 6 studies[19,20,29,47,48,54] applied heating for at least 10

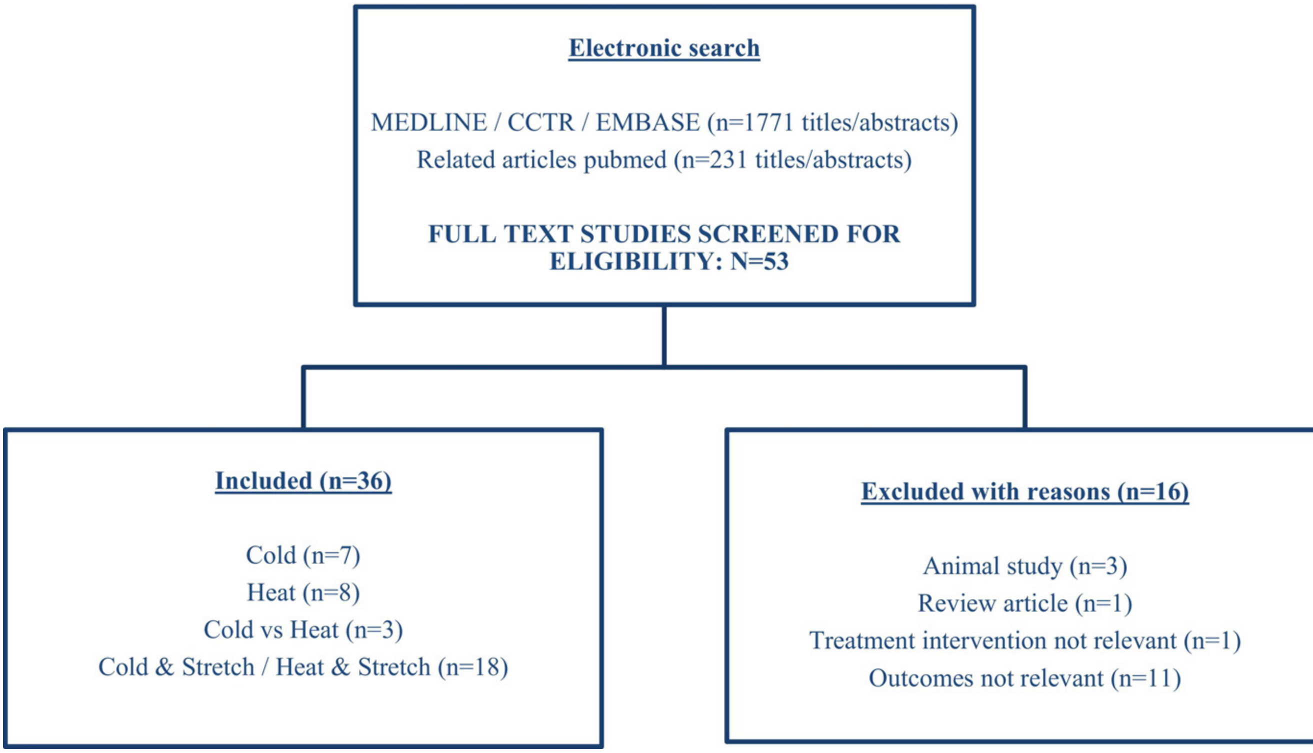


**Fig 1** Summary of search strategy and selection process based on included and excluded studies. Abbreviation: CCTR, Cochrane Central Register of Controlled Trials.

minutes. One study[51] heated until a predetermined muscle temperature increase occurred; no other study recorded tissue temperature changes associated with heat application.

Cooling was undertaken topically, with the majority using ice cubes,[26,45,46] cooling pads,[21,39,53] and CWI,[41,43] for durations between 10 and 60 minutes. A further 2 studies[33,42] employed brief applications of vapo-coolant sprays. Skin temperature reductions were reported in 4 cases; 3 studies[21,41,53] lowered the temperature to between 18°C and 23°C, with 1 study[39] cooling to 10°C. Intramuscular temperatures were reported in 1 study,[41] with reductions to 28.1°C.

## Details of outcomes

Twenty-eight studies recorded ROM; 16 studies[19,21,23,25,27-29,31,36,40,43,49-52,54] measured active ROM (hip flexion/knee extension/ankle all movement) based on goniometric/inclinometer measurements; 3 of these[29,49,50] used active, weight-bearing ankle dorsiflexion, and a single study[30] recorded trunk flexion using a sit and reach test. Eleven[20,24,32-36,38,42,44,46] measured passive ROM (hip flexion, ankle dorsiflexion, knee extension, shoulder external rotation), and in 1 study,[26] it was unclear whether the ROM tested was active or passive.

Six studies measured accessory joint movement (laxity) in response to anterior, posterior, valgus, or varus passive forces at the knee joint, using an arthrometer[21,22,47,48,53] or related device.[39] Four studies[37,41,45,53] measured passive tissue stiffness based on the relationship between joint torque and ROM. Two studies recorded passive tissue force/torque using an isokinetic dynamometer or similar device, during slow (3−5deg/s) passive movements of either the knee[41] or the ankle[37] in the saggital plane; in both cases, real-time ultrasonography was used to determine muscle fascicle length throughout the movements. Price and Lehmann[45] used a motor-driven footplate and force transducer to measure passive ankle stiffness when small-amplitude (5-deg) oscillating forces (3−12Hz) were applied, with stiffness outcomes dichotomized into elastic and viscous components.

## Follow-up

All studies recorded outcomes before and immediately after the intervention. Several undertook additional outcome assessment at 5,[51] 15,[53] 20,[21] and 30[34,43,48] minutes postintervention. As a number of studies also continued interventions over periods of 5 days[19,25,29-31,38] and 3,[20,24,44] 4,[46] or 6 weeks,[36] we also extracted outcomes reported at the end of the entire treatment package to determine potential cumulative effects of multiple treatments.

## Risk of bias

There was a high risk of bias across all studies (fig 2). Despite the majority of studies stating that some form of randomization was employed, only 3 studies[21,49,50] provided adequate details on sequence generation and no study adequately reported allocation concealment. Blinding of outcome assessor was reported in 6 studies.[27,35,36,46,49,50] There was a high risk of attrition bias across all studies; just 5 studies[20,39,43,46,47] were transparent in their reporting of dropouts, exclusions, missing data, and approach to analysis.

**Table 1** Summary of study characteristics

| Author (Study Type) | Subject/Inclusion Criteria | Intervention (Final Tissue Temperature Reported °C) | Outcomes Recorded (Follow-Up) | Significant Changes Within Groups | Significant Changes Between Groups |
|---|---|---|---|---|---|
| Cold vs Control | | | | | |
| Newton[42](RCT) | N=84 healthy<br>10 males, 74 females<br>Aged: Collegiate age | -Cold: Fluori-Methane spray<br>-Cold: Isopropyl alcohol<br>-Cold: Ethyl chloride. Each applied 6 times (5s each and 3s off) to the posterior aspect of the thigh<br>-Control: No intervention | Specially designed table<br>1. Passive hip flexion (immediately post-Rx) | No significant findings | No significant findings |
| Price and Lehmann[45] (single group: before/after) | N=10 healthy<br>5 males, 5 females<br>Age: 20–29y | -Cold: Ice water pack 30min (gastrocnemius) | Ankle measurement system (footplate, motor, EMG, torque/displacement transducers)<br>1. Elastic stiffness (Nm/rad)<br>2. Viscous stiffness (Nm/rad) (immediately post-Rx) | 1 and 2 increased (immediate) | NA |
| Uchio et al[53] (single group: before/after) | N=20 healthy<br>10 males, 10 females<br>Mean age: 21–28y | -Cold: Cooling pad 15min at 4°C (knee joint) (skin temperature, 21.6°C) | Knee KT 2000 Arthrometer<br>1. Total joint displacement (mm)<br>2. Terminal stiffness (N/mm) (immediately, 15min post-Rx) | 1. Decreased (immediate)<br>2. Increased (immediate) | NA |
| Melnyk et al[39] (single group: before/after) | N=15 healthy<br>Mean age: 25±3.6y | -Cold: Automatic water cooler 20min (knee joint) (skin temperature, 10.1°C±1.5°C) | Accelerated piston applying posterior to anterior force on tibia<br>1. Tibial translation distance (mm)<br>2. Tibial velocity (mm/s) (immediately post-Rx) | No significant findings | NA |
| Muraoka et al[41] (single group: before/after) | N=6 healthy males<br>Mean age: 27±4y | -Cold: CWI 60min at 5°C–8°C (lower leg) (skin temperature, 22.8°C ±2.5°C; intramuscular temperature, 28.1±–1.3°C) | Ankle dynamometer/ ultrasonography/EMG<br>1. Passive stiffness (N/mm$^2$)<br>2. Gastrocnemius muscle fasicle length (mm via US) (immediately post-Rx) | 1. Increased (immediate) | NA |
| Patterson et al[43] (single group: before/after) | N=20 healthy<br>7 males, 13 females<br>Mean age: 19.8±1.2 y | -Cold: CWI 20min at 10°C (lower leg with water turbulence) | Self-reported dominant ankle universal goniometer<br>Active ROM (deg)<br>1. D/F<br>2. P/F<br>3. Eversion<br>4. Inversion (immediately and at 5-min intervals up to 30 min) | 1. Decreased (7 and 12min post-Rx) | NA |
| Arguello[21] (Rand crossover; 1d between conditions) | N=14<br>Mean age: 24±3y | -Cold: Cooling pad 20min (knee) (skin temperature, 18.26°C±2.3°C)<br>-Control: Room temperature pad 20min (knee) | Knee handheld goniometer<br>1. Active ROM (deg)<br>KT 1000 Arthrometer<br>2. Knee joint displacement (mm) (immediately, 20min post-Rx) | 2. Decreased in cold (immediate) | 2. Cold<control |

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**Table 1** (*continued*)

| Author (Study Type) | Subject/Inclusion Criteria | Intervention (Final Tissue Temperature Reported °C) | Outcomes Recorded (Follow-Up) | Significant Changes Within Groups | Significant Changes Between Groups |
|---|---|---|---|---|---|
| Heat vs cold | | | | | |
| Minton[40] (crossover) | N=18 healthy<br>5 males, 13 females<br>Ages not stated | -Cold: Crushed ice secured with elastic wrap 20min (hamstring)<br>-Heat: Heating pads secured with elastic wrap 20min (hamstring) | Hamstring goniometer (handheld)<br>1. Active SLR (deg) (immediately post-Rx) | 1. Increased in both groups (immediate) | No significant findings |
| Benoit et al[22] (crossover; 1d between conditions) | N=15 healthy<br>8 males, 7 females<br>Mean age: 22.8±2.5y | -Cold: CWI 20min at 15°C (4in above patella)<br>-Heat: HWI 20min at 40°C (4in above patella)<br>-Control: No intervention | Knee<br>KT 1000 Arthrometer<br>1. Joint displacement with 89N (cm)<br>2. Joint displacement with maximal force (cm) (immediately post-Rx) | No significant findings | No significant findings |
| Kubo et al[37] (Rand crossover; separate days) | N=8 healthy males<br>Mean age: 26±2y | -Cold: CWI 30min at 5°C (to head of fibula)<br>-Heat: HWI 30min at 42°C (to head of fibula) | Ankle dynamometer/ ultrasonography/EMG<br>1. Passive torque (Nm)<br>2. Passive stiffness (N/mm) (immediately post-Rx) | No significant findings | No significant findings |
| Heat vs Control | | | | | |
| Reed and Ashikaga[47] (single group: before/after) | N=25 healthy<br>12 males, 13 females<br>Mean age: 23.6y | -Heat: Continuous US (1MHz, 1.5w/cm$^2$), 8min (knee) | Genucom arthrometer electrogoniometers<br>1. Anterior-posterior drawer test at 90deg of knee flexion,<br>2. Varus/valgus test at 0deg of knee flexion (full extension)<br>3. Varus/valgus at 20deg of knee flexion<br>4. The genu recurvatum test (immediately post-Rx) | 2–4. Increased (immediate) | NA |
| Funk et al[32] (Rand crossover; 7d between conditions) | N=30 healthy males<br>Age: 18–22y | -Heat: Hot moist pack 20min at 160°F (hamstring)<br>-Stretch: 3×30s hamstring | Goniometer<br>1. Passive knee extension (deg)<br>2. Subjective assessment of both treatments (questionnaire) (immediately post-Rx) | ND | 1. Heat>stretch (immediate)<br>2. Subjects believed hot pack was less beneficial |
| Sawyer et al[51] (RCT; leg randomized to treatment or control) | N=27 males<br>(3 unable to complete)<br>Mean age: 21.9±6.3y<br>(>20deg from full knee extension with the hip flexed to 90deg) | -Heat: Moist heat pad applied until muscle temperature increased by 0.4°C (hamstring) (intramuscular temperature [2.54cm below skin surface] increased by 0.4°C)<br>-Control: no intervention | Handheld goniometer<br>1. Active knee extension (deg) (immediately post, 4, 8, and 16mins Rx) | 1. Increased in both groups (immediate); increased in heat (4min post-Rx) | No significant findings |

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**Table 1** (*continued*)

| Author (Study Type) | Subject/Inclusion Criteria | Intervention (Final Tissue Temperature Reported °C) | Outcomes Recorded (Follow-Up) | Significant Changes Within Groups | Significant Changes Between Groups |
|---|---|---|---|---|---|
| Cosgray et al[27] (Rand crossover; 24h between conditions) | N=30 healthy males<br>Mean age: 22.3±3.1y<br>(popliteal angle measurement>10deg from vertical in the supine 90deg/90deg [hip/knee] position) | -Heat: Pneumatherm heating 20min (posterior thigh)<br>-Heat: Moist heat pack 20min (posterior thigh)<br>-Control: Dry terry cloths 20min | Fluid-filled goniometer<br>1. Active knee extension (deg) (immediately post-Rx) | 1. Increased in heat (pneumatherm) (immediate) | 1. Heat (pneumatherm)>control (immediate) |
| Robertson et al[49] (Rand crossover; 36h between conditions) | N=24 healthy<br>12 males, 12 females<br>Mean age: 21.5±2.5y | -Heat: SWD 15min (calf)<br>-Heat: Hot pack 15min (calf)<br>-Control: No intervention | Inclinometer<br>1. Weight-bearing ankle D/F (deg) (immediately post-Rx) | ND | 1. Heat (SWD)>heat (hot pack); heat (SWD)>control (immediate) |
| Demura et al[28] (Rand crossover; time between conditions not clear) | N=24 healthy<br>10 males, mean age 20.9±3.1y; 14 females<br>Mean age 21.2±1.7y | -Heat: Polarized infrared light 10min (shoulder)<br>-Placebo: Placebo heating, 10min (shoulder)<br>-Light exercise: 10min (shoulder) | Handheld goniometer<br>Active shoulder ROM (deg)<br>1. Shoulder flexion<br>2. Shoulder extension<br>3. Total ROM (immediately post-Rx) | 1–3. Increased in heat (immediate) | 1–3. Heat>placebo (immediate) |
| Sakulsriprasert et al[50] (RCT) | N=75 healthy<br>30 males, 45 females<br>Age: 18–25y | -Heat: Hot pack 15min at 45°C (calf)<br>-Heat: Hot pack 30min at 45°C (calf)<br>-Control: No intervention | Inclinometer<br>1. Weight-bearing active ankle D/F (deg) (immediately post-Rx) | ND | 1. Heat (15min)>control; heat (15min)>heat (30min) (immediate) |
| Kain et al[35] (RCT) | N=31 healthy junior/senior college students | -Heat: Hot pack 20min (shoulder)<br>-Myofascial release: 3min (shoulder) | Goniometer shoulder<br>Passive ROM (deg)<br>1. Flexion<br>2. Extension<br>3. Abduction (immediately post-Rx) | 1–3. Increased in both groups (immediate) | No significant findings |
| Ice and Stretch vs Stretch Only | | | | | |
| Halkovich et al[33] (RCT) | N=30 healthy<br>13 males, 17 females<br>Mean age: 24.5y | -Cold: Fluori-Methane spray, 6 applications, 5s on and 3s off (skin overlying the hamstring muscles when in a stretched position)<br>-Control: Held in a stretched position for 45s | Specially designed table<br>1. Passive hip flexion (side lying SLR) (deg) (immediately post-Rx) | ND | 1. Cold>control (immediate) |

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**Table 1** (*continued*)

| Author (Study Type) | Subject/Inclusion Criteria | Intervention (Final Tissue Temperature Reported °C) | Outcomes Recorded (Follow-Up) | Significant Changes Within Groups | Significant Changes Between Groups |
|---|---|---|---|---|---|
| Cornelius et al[26] (RCT) | N=120 males<br>Mean age: 21.5±2.7y | -Stretch only: PNF stretching<br>-Stretch only: Passive stretch<br>-Cold and stretch 1: PNF stretching with ice cubes 10min (posterior thigh)<br>-Cold and stretch 2: Passive stretch with ice (ice cubes) 10min (posterior thigh) | Leighton flexometer Hip flexion (deg) (immediately post-Rx) | ND | No significant findings |
| Rancour et al[46] (RCT) | N=29 healthy<br>12 males, 17 females<br>Age: 18–50y | -Cold and stretch: Ice 10min and hamstring stretch<br>-Stretch only: Hamstrings<br>Standardized Rx: Daily Rx for 4wk | Hip flexion. Double-arm goniometer<br>1. Passive SLR (supine position) (weekly during Rx and for 4wk post-Rx) | 1. Increased in both groups (immediate)<br>1. Decreased in both groups (4wk after the final Rx) | No significant findings |
| Heat/Ice and Stretch vs Stretch Only | | | | | |
| Lentell et al[38] (RCT) | N=92 US healthy males<br>Mean age: 24.3±4.1y | -Heat and stretch: Moist hot packs at ∼66°C (shoulder) during stretch<br>-Cold and stretch: Ice pack ∼0°C (shoulder), during stretch<br>-Heat and stretch and ice: Moist heat and stretch followed by ice pack<br>-Stretch only: low load prolonged stretch<br>-Control: No intervention.<br>Standardized Rx: Three 40min Rx over a 5-d period | Shoulder universal goniometer<br>1. Passive external rotation (supine position) (immediately post-Rx; 3d following final Rx) | ND | 1. Heat and stretch>stretch only (immediate; 3d after final Rx)<br>1. Heat and stretch>control (3d after final Rx) |
| Taylor et al[52] (Rand crossover; at least 7d between conditions) | N=24 US Army population<br>12 males, 12 females<br>Mean age: 25.46y | -Heat and stretch: Hot pack (77°C) 20min (posterior thigh) followed by 1min hamstring stretch<br>-Cold and stretch: Cold gel pack (−18°C) 20min (posterior thigh) followed by 1min hamstring stretch<br>-Stretch only: 1min hamstring stretch | Electronic inclinometer Lying supine with the hip of the treated thigh flexed to 90deg<br>1. Active knee extension (immediately post-Rx) | 1. Increased in all groups (immediate) | No significant findings |

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**Table 1** (*continued*)

| Author (Study Type) | Subject/Inclusion Criteria | Intervention (Final Tissue Temperature Reported °C) | Outcomes Recorded (Follow-Up) | Significant Changes Within Groups | Significant Changes Between Groups |
|---|---|---|---|---|---|
| Brodowicz et al[23] (RCT) | N=24 healthy male athletes<br>Mean age: 20.7±1.2y | -Heat and stretch: Heat 20min (posterior thigh) during stretching<br>-Cold and stretch: Ice 20min (posterior thigh) during stretching<br>-Stretch only: 20min stretching | Hamstring Leighton flexometer<br>1. Active SLR (deg) (immediately post-Rx) | ND | 1. Cold and stretch >heat and stretch; cold and stretch>control (immediate) |
| Burke et al[25] (RCT) | N=45 healthy<br>24 males, 21 females<br>Age range: 18–25y | -Heat and stretch: HWI 10min at 44°C (up to gluteal fold) followed by PNF training<br>-Cold and stretch: CWI 10min at 8° C (up to gluteal fold) followed by PNF training<br>-Stretch only: 10min (standing) followed by PNF training.<br>Standardized Rx: PNF training to increase SLR, intervention every day for 5d | Hamstring goniometer<br>1. Active SLR (deg) (immediately post-Rx) | 1. Increased in all groups (immediate) | No significant findings |
| Heat and Stretch vs Stretch Only | | | | | |
| Henricson et al[34] (RCT) | N=30 healthy<br>15 males, 15 females<br>Mean age: 30±0.5y | -Heat and stretch: Electric heating pad 20min at 43°C followed by stretching<br>-Heat: Electric heating pad 20min at 43°C (lateral, medial, and posterior portion of the thigh)<br>-Stretch only: Stretching (SLR in supine position using a modified contract-relax technique) | Goniometer right hip. Passive ROM (deg)<br>1. Flexion<br>2. Abduction<br>3. External rotation (immediately and 30min post-Rx) | 1. Increased in stretch only (immediate); increased in heat and stretch (immediate, 30min post-Rx)<br>2. Increased in heat and stretch (immediate; 30min post-Rx)<br>3. Increased in stretch only (immediate; 30min post-Rx) | No significant findings |
| Wessling et al[54] (Rand crossover; 7d between treatment sessions) | N=30 healthy female students<br>Mean age: 20–30y | -Heat and stretch: Static stretch combined with US (1.5W/cm$^2$) 7min (triceps surae)<br>-Stretch only: Static stretch 7min<br>-Control: No Rx | Goniometer<br>1. Active ankle D/F (deg) (immediately post-Rx) | 1. Increased: Heat and stretch; stretch only (immediate) | 1. Heat and stretch>control; heat and stretch>control (immediate) |
| Draper et al[29] (RCT) | N=40 healthy college students<br>18 males, 22 females<br>Mean age: 20.4±2.5y | -Heat and stretch: US 7min (3MHz, 1.5W/cm$^2$) and stretching<br>-Stretch only. Standardized Rx: Rx twice daily (>3h apart) for 5 consecutive days | Inclinometer<br>1. Weight-bearing active ankle D/F (deg) (immediately post-Rx twice daily for 5 consecutive days) | 1. Increased in both groups (after 5d of Rx) | No significant findings |

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**Table 1** (*continued*)

| Author (Study Type) | Subject/Inclusion Criteria | Intervention (Final Tissue Temperature Reported °C) | Outcomes Recorded (Follow-Up) | Significant Changes Within Groups | Significant Changes Between Groups |
|---|---|---|---|---|---|
| Reed et al[48] (Rand crossover; 28d between conditions) | N=21 healthy women<br>Mean age: 31.5±11 | -Heat and stretch: Continuous US (3MHz, 1.25W/cm$^2$ for 2.5min) during static valgus stretch (10ft-lb)<br>-Sham heat and stretch: Sham continuous US (0W/cm$^2$ for 2.5min) and static valgus stretch (10ft-lb) | Genucom arthrometer electrogoniometers<br>1. Knee joint displacement (valgus and varus) (deg) (2.5, 17.5, and 32.5min post-Rx) | 1. Increased in both groups (17.5 and 32.5min post-Rx) | No significant findings |
| Knight et al[36] (RCT) | N=97 38 males, 59 females<br>Age: 17–50y<br>(ankle D/F<20°) | Heat and stretch: Moist hot packs 15min at 73.8°C (plantar flexors) followed by stretching (4×20s calf)<br>-Heat and stretch: US 7min (1MHz, 1.5W/cm$^2$) followed by stretching (4×20s calf)<br>-Stretch only: Stretch (4×20s calf)<br>-Exercise: Minimum of 40 heel raises<br>-Control: No intervention.<br>Standardized Rx: 3 times a week (every other day) for 6wk; only twice in week 5 | Handheld goniometer<br>1. Active ankle D/F (deg)<br>2. Passive ankle D/F (deg) (2, 4, and 6wk follow-up) | 1. Increased in all groups (weeks 2 and 4)<br>2. Increased in heat (US) and stretch (week 2)<br>3. Increased in exercise (week 4)<br>4. Increased in heat (hot pack) and stretch; stretch only (week 6) | No significant findings |
| Draper et al[30] (RCT) | N=37 college students<br>11 males, 26 females<br>Mean age: 20.46±1.74y<br>(SLR<100deg) | -Heat and stretch: PSWD 15min (hamstring) followed by stretching (3×30s hamstring)<br>-Sham and stretch: Sham PSWD 15min (hamstring) followed by stretching (3×30s hamstring)<br>-Control: No Rx. Standardized Rx: Rx once daily for 5d | Sit and reach box<br>1. Sit and reach distance (cm) (immediately after Rx for 5 consecutive days; additional follow-up 3d after final Rx) | 1. Increased in all groups (immediate; 3-d follow-up) | No significant findings |
| Peres et al[44] (RCT) | N=60 healthy (44 completed study)<br>21 males, 23 females<br>Age: 22.5±2y | -Heat and stretch: PSWD 20min (triceps surae) during stretch 10min (calf)<br>-Heat and stretch and ice: PSWD 20 mins (triceps surae) and stretch 10min (calf) and ice 5min (triceps surae)<br>-Stretch only: Stretch 10min (calf)<br>Standardized Rx: Used static stretch; 14 Rx over 3wk | Digital inclinometer<br>1. Passive ankle D/F (deg) (immediately post-Rx over consecutive 14d; additional follow-up 6d after final Rx) | 1. Increased in all groups (immediate, 6-d follow-up) | 1. No significant findings |

(*continued on next page*)

**Table 1** (*continued*)

| Author (Study Type) | Subject/Inclusion Criteria | Intervention (Final Tissue Temperature Reported °C) | Outcomes Recorded (Follow-Up) | Significant Changes Within Groups | Significant Changes Between Groups |
|---|---|---|---|---|---|
| Draper et al[31] (RCT) | N=30 healthy<br>19 males, 11 females<br>Mean age: 21.5y<br>(<160deg of knee extension with the hip at 90deg of flexion) | -Heat and stretch: PSWD 15min (distal hamstrings) during stretch 10min (hamstrings)<br>-Sham heat and stretch: Sham heating 15min (distal hamstrings) during stretch 10min (hamstrings)<br>-Control: No Rx Standardized Rx: Daily Rx for 5d | Handheld goniometer<br>1. Active knee extension (deg) (immediately post-Rx for 5 consecutive days; additional follow-up 3d after final Rx) | 1. Increased in heat and stretch; sham heat and stretch (mean daily increase over 5d) | 1. Heat and stretch>sham heat and stretch (after 3, 4, and 5d of Rx; 3d after final Rx) |
| Brucker et al[24] (RCT) | N=23 healthy college-age<br>8 males, 15 females<br>Mean age: 22.7±2.1y<br>5 subjects dropped out: 3 were unavailable, and 2 subjects did not report for the study | -Heat and stretch: PSWD 20min during stretch<br>-Stretch only: Stretch (low-load, prolonged, long-duration calf)<br>Standardized Rx: 14 Rx over 3wk | Digital inclinometer<br>1. Passive ankle D/F (deg) (immediately post-Rx over 3wk; additional follow-up at 3 and 17d after final Rx) | 1. Increased in both groups (day 19, 24, and 39) | No significant findings |
| Akbari et al[20] (RCT) | N=50 inactive boys<br>Age: 12–14y<br>(SLR<70deg) | -Heat and stretch: US 5min followed by stretch (4×15s hamstring)<br>-Heat and stretch: US for 5min followed by stretch (2×30s hamstring)<br>-Heat: US 5min (hamstring)<br>-Stretch only: 4×15s hamstring<br>-Stretch only: 2×30s hamstring<br>Standardized Rx: Rx 10 times (every other day) for 3wk | Goniometer<br>1. SLR (passive knee extension) (deg) (after 3wk of Rx) | 1. Increased in all groups (after 3wk of Rx) | No significant differences |
| Aijaz et al[19] (RCT) | N=30 healthy males<br>Mean age: 24.13y<br>(ankle D/F<20deg) | -Heat and stretch: Static stretch (calf) and US (1MHz) applied to the plantar flexors for first 7min of 10-min stretch protocol<br>-Stretch only: Static stretch (calf) for 10min Standardized Rx: Rx once daily for 5 consecutive days | Handheld goniometer<br>1. Active ankle D/F (deg) (immediately after Rx for 5 consecutive days; additional follow-up 3d after final Rx) | 1. Increased in both groups (immediately after 5d of Rx; 3d after final Rx) | 1. Heat and stretch>stretch only (immediately after 5d of Rx; 3d after final Rx) |

Abbreviations: D/F, dorsiflexion; EMG, electromyography; HWI, hot water immersion; NA, not applicable; ND, no data; P/F, plantar flexion; PNF, proprioceptive neuromuscular facilitation; PSWD, pulsed short wave diathermy; RCT, randomized controlled trial; Rx, treatment; SLR, straight leg raise; SWD, short wave diathermy.

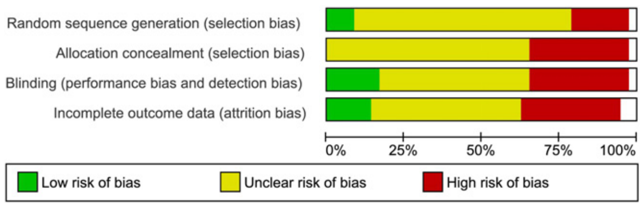


**Fig 2** Included studies: Risk of bias summary.

## Study heterogeneity

Meta-analyses were not undertaken because of clinical heterogeneity. This related to clinical diversity in terms of a number of key study characteristics: treatment intervention, dosage, outcome measure, and body part. Post hoc subgroup analyses were considered as a means of investigating study heterogeneity further; however, there were an insubstantial number of studies for each characteristic.[55] Individual effect sizes were calculated and presented on forest plots to provide a graphic overview of the results based on treatment comparison (figs 3−5).

## Effect of cold

### Hip flexion ROM

Three studies[21,40,42] examined the immediate effect of topical cooling on hip ROM. One study[21] found that 20 minutes of cooling over the hamstring muscle had little effect on active knee extension in supine position (90-deg hip flexion). In contrast, large increases in hip flexion straight leg raise were recorded immediately after a 20-minute ice pack application (MD, 11.78 deg [95% CI, 8.82−14.73] vs baseline)[40] and brief (5s×6) sprays of vapocoolant (mean increase from baseline, 8.78±4.97deg).[42]

### Ankle ROM

Patterson et al[43] measured ankle ROM before and after a 20-minute CWI of the lower limb, with follow-ups recorded every 5 minutes, for 30 minutes after treatment. The only significant findings were decreases in ankle dorsiflexion at 7 and 12 minutes versus baseline; there were insufficient data for effect size calculation.

### Passive accessory ROM: knee

This was assessed by 4 studies,[21,22,39,53] but there were few significant findings. Two found that anterior-posterior tibial displacement was reduced (MD from baseline) by .92 millimeter (95% CI, .34−1.50)[21] and 1.00 millimeter (95% CI, −.59 to 2.59)[53] immediately after cooling. Others found small but statistically insignificant effects in the opposite direction, with increased knee joint displacement immediately after cooling (MD, .30mm [95% CI, −.42 to 1.02] vs baseline)[39] (MD, .80mm [95% CI, −1.40 to 3.00 vs control]).[22]

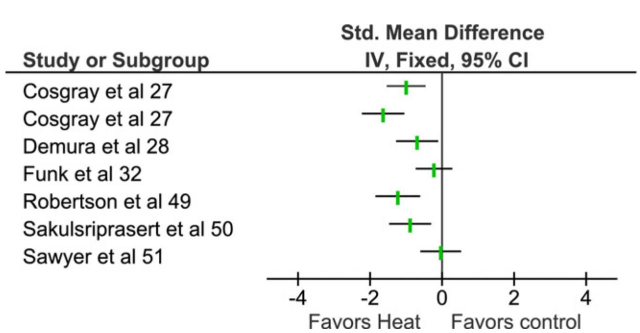


**Fig 3** Forest plot of between-group comparisons (heat vs control). Abbreviation: Std., standard.

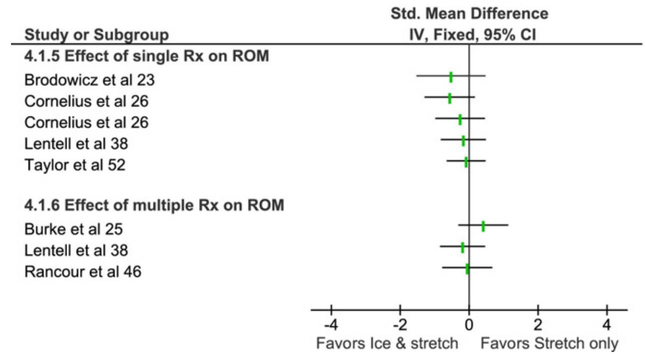


**Fig 4** Forest plot of between-group comparisons (ice and stretch vs stretch only). Abbreviations: Rx, treatment; Std., standard.

### Passive stiffness

Uchio et al[53] found a cold-induced increase in terminal stiffness during anterior to posterior tibial displacement at the knee joint (MD, 22.10Nm/mm [95% CI, 4.90−39.30] vs baseline). Price and Lehmann[45] also found that both elastic (MD, .52 Nm/rad [95% CI, −.38 to 1.41]) and viscous tissue stiffness (MD, 1.04 Nm/rad [0.1−1.99]) around the ankle increased from baseline levels. There were conflicting results when passive tissue stiffness was measured during slow, lengthening physiological movements. Muraoka et al[41] found that cooling increased stiffness in the triceps surae muscle and tendon unit (MD, 2.00Nm/mm [95% CI, −7.05 to 11.05] vs baseline), whereas Kubo et al[37] found a small reduction in stiffness (MD, .80N/mm [95% CI, −11.06 to 12.66] vs baseline); however, neither change was statistically significant.

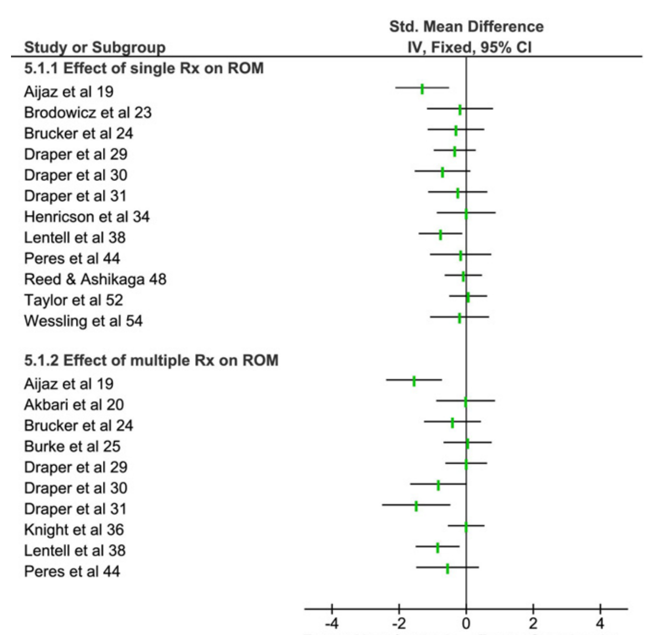


**Fig 5** Forest plot of between-group comparisons (heat and stretch vs stretch only). Abbreviations: Rx, treatment; Std., standard.

## Effect of heat

### Hip flexion ROM

Four studies found that hamstring heating increased knee extension[27,32,51] or standard leg raise ROM.[40] The largest increase from baseline was an MD of 8.8 degrees (95% CI, 4.77−12.83).[27] This study[27] also reported significant increases in ROM compared with an untreated control (MD, 7.8deg [95% CI, 5.42−10.18]). Others found small but statistically insignificant effects in favor of heating when compared with icing [MD, 2.3deg [95% CI, −8.65 to 13.25],[40] stretching (MD, 2.6deg [95% CI, −3.12 to 8.12]),[32] or untreated controls (MD, .36deg [95% CI, −4.87 to 5.59]).[51]

### Ankle dorsiflexion ROM

In 2 studies,[49,50] calf heating increased weight-bearing dorsiflexion ROM significantly more than untreated controls; heating was based on 15 minutes of short wave diathermy (MD, 1.9deg [95% CI, 1.04−2.76])[49] or hot pack application (MD, 2.68deg [95% CI, 1.03−4.33]).[50]

### Shoulder ROM

Infrared heating at the shoulder resulted in statistically significant increases in ROM compared with placebo (MD, 11.5deg [95% CI, 2.28−20.72]).[28] Although Kain et al[35] found greater ROM after myofascial release compared with a 20-minute hot pack, between-group differences were small and statistically insignificant.

### Passive accessory ROM: knee

Using a single group (before/after) design, Reed and Ashikaga[47] found that 8 minutes of knee joint heating with US increased passive knee joint displacement from baseline. The largest change from baseline was an increased varus/valgus displacement (at 20deg of knee flexion) of 1.3 millimeter (95% CI, −0.9 to 3.5). In a randomized controlled trial, Benoit et al[22] compared passive knee joint displacement, before and after either hot water immersion or control; there was a small trend that heating decreased displacement (MD, 0.2mm [95% CI, −1.73 to 2.13] vs control) but no significant within- or between-group differences.

### Passive stiffness

Kubo et al[37] found that heating resulted in small statistically insignificant reductions to tendon stiffness during slow, passive lengthening physiological movements (MD, 0.4N/mm [95% CI, −11.73 to 12.53] vs baseline).

## Effect of heat or cold used in combination with stretching

A large number of studies compared the effects of stretching only, to stretching combined with either cold[23,25,26,33,38,46,52] or heat interventions,[19,20,23-25,29-31,34,36,38,44,48,52,54] with all studies reporting ROM.

### Cold and stretching versus stretching only (single intervention)

Five studies[23,26,33,38,52] found effects in favor of cold and stretching over stretching alone based on a single intervention. Brodowicz et al[23] recorded the largest increase in ROM (MD, 22.6deg; [95% CI, −17.1 to 62.3]), with others finding MDs of 6.1 degrees (95% CI, −1.43 to 13.63)[26] and 3.9 degrees (CIs not available).[33] Effect sizes in the remaining studies were small and statistically insignificant.[38,52]

### Cold and stretching versus stretching only (multiple interventions)

Three studies used multiple interventions over periods of 5 days[25,38] or 4 weeks.[46] There were no significant differences in ROM at the end of each study; the largest between-group differences were in favor of stretching only (MD, 2.4deg [95% CI, −1.7 to 6.5]).[25]

### Heat and stretching versus stretching only (single intervention)

Eleven out of the 12 studies[19,23,24,29-31,34,38,44,48,52,54] reported larger increases in ROM after a single intervention of heating and stretching compared with stretching alone. Only 2 effects in favor of heat and stretching reached statistical significance (MD, 2.9deg [95% CI, 1.36−4.44])[19] (MD, 5deg [95% CI, 1.12−8.88]).[38]

### Heat and stretching versus stretching only (multiple interventions)

Ten studies[19,20,24,25,29,30,31,36,38,44] examined the effects of multiple interventions undertaken over periods of up to 5 weeks. Four studies[20,25,29,36] found little differences in ROM between groups, at the end of the intervention package. The remaining 6 studies[19,24,30,31,38,44] found effects in favor of stretching and heat, with 4 studies[19,30,31,38] reaching statistical significance. The largest effect in favor of heating and stretching was reported by Draper et al[31] based on an MD of 10.9 degrees (95% CI, 4.76−17.04 vs stretching alone).

## Heating dose

Few studies compared different modes of thermal interventions. Two studies found significantly greater increases in ROM based on a pulsed, dry heating device (pneumatherm) (MD, 6.6deg [95% CI, 2.32−10.88])[27] and short wave diathermy (MD, 1.1deg [95% CI, .13−2.07])[49] compared with a moist heat pack. Interestingly, Sakulsriprasert et al[50] found that heating for 15 minutes resulted in larger increases in ankle ROM than did a 30-minute treatment duration (MD, 2.52deg [95% CI, .27−4.77]). One study[36] compared combinations of hot pack and stretching with US and stretching; despite recording active and passive ankle ROM after 2, 4, and 6 weeks of treatment, there were no significant differences between groups.

## Duration of effects

A small number of studies reported outcomes beyond the immediate stages after treatment. Despite reporting an immediate effect on knee stiffness, 2 studies found no significant differences at 15[53] and 20 minutes[21] after icing. Reed et al[48] and Henricson et al[34] found that heating and stretching combined, and stretching alone, both significantly increased knee joint ROM for up to 30 minutes after treatment, but there were no between-group differences.

# Discussion

## Summary of findings

To the best of our knowledge, this is the first review to systematically examine the in vivo effects of thermal interventions on

ROM and biomechanical properties of soft tissues. There was a consistently high risk of bias across included studies, and we were unable to meaningfully subgroup studies into high and low quality. Few studies reported adequate sequence generation or allocation concealment. Equally, few studies undertook blinding of outcome assessors or adequately described missing outcomes or how these were managed. Overall, the poor quality of evidence, and the small number of participants within many included studies, means that findings should be interpreted with some degree of caution.

The majority of studies assessed ROM using goniometers or inclinometers; both devices have been shown to have high intra- and interrater reliability.[56-58] There were conflicting data on the effect of cold on ROM. There was clearer evidence that heat increases ROM, with a number of studies showing statistically and clinically significant effects. Heat also seems to be an effective adjunct to stretching. A small number of studies assessed the effect of thermal interventions on other mechanical properties (eg, accessory joint movement or passive stiffness); however, the results were equivocal.

## Therapeutic heating

Increasing soft tissue temperature prior to exercise is a popular practice. Heat is thought to alter the viscoelastic properties of collagenous tissues in preparation for physical activity. In accordance with current practice, we found clear trends that heating immediately increases ROM at a variety of joints. There was further evidence that heat improves the therapeutic effects of stretching; this was evident after a single treatment intervention in 11 out of the 12 studies, with 2 studies[19,38] reporting significant effects over stretching alone. Furthermore, cumulative increases in ROM were reported when heat and stretching were repeated over a period of days or months.

There may be a number of mechanisms underpinning the heat-induced increases in ROM reported. In vitro research into the effects of temperature on tissue mechanics shows explicit patterns, with human supraspinatus,[13] canine patellar tendon,[16] and porcine hamstring tendon[17] all showing reduced stiffness and greater viscous mechanical behavior at higher temperatures. In contrast, cooling is associated with an increased force response in ligaments[12] and increased muscle stiffness.[14,15] Notwithstanding this, it is unlikely that the included human studies could replicate the large temperature changes induced within in vitro models. We also found conflicting evidence on the effect of temperature on related mechanical properties such as accessory joint movement and passive stiffness. A more likely mechanism is that heat increased patients' stretch tolerance based on sensory stimulation and analgesia. Although this mechanism cannot be substantiated on the basis of current evidence, it does align with the theory that increased muscle extensibility after stretching is primarily due to the modification of sensation rather than acute changes in tissue mechanics.[59-61]

## Thermal dose

The fundamental principle for thermal interventions is to transfer or extract heat energy from the body. The magnitude of energy transfer and the resultant temperature fluctuation is a key determinant of therapeutic effect. Studies in this review employed a range of thermal interventions, of which many were topical agents such as ice packs, hot packs, or water immersion. Large temperature changes may be difficult to achieve with topical agents, due to the insulating effect of adiposity.[62] In the current review, only 2 studies[41,51] considered intramuscular temperature change, with the largest increase reported to be just 0.4°C.[51] Previous studies confirm that deep thermal modalities such as US can rapidly increase deep (3cm) tissue temperature by >4°C,[63,64] perhaps suggesting a superior therapeutic effect. Direct comparison between deep and superficial heating agents was limited to 2 studies,[27,49] with both finding larger increases in ROM with deep heating agents. Another interesting observation was that studies undertaking stretching and heating simultaneously[19,24,31,38,44] generally reported larger effects (over stretching alone) than did those that initiated stretching shortly after heating.[20,25,36] Tissue temperature has been shown to drop rapidly after the removal of a heating agent,[63] and potentially, applying heat and stretching simultaneously can maximize its therapeutic effects.

## Cryotherapy

Cold agents are often applied prior to sports or other physical activities. For example, athletes often apply short periods of cooling at the sideline or during half time, before returning to sporting competition. A growing trend is the use of precooling before exercising in the heat. Recent systematic reviews advise caution when undertaking physical activity immediately after cryotherapy; this is due to short-term but adverse changes to joint proprioception[9] and muscle strength.[10] A related concern is often that cooling reduces tissue compliance and ROM; however, this cannot be fully substantiated from the current evidence base. The effects of local cooling (without therapeutic stretching) on joint ROM were conflicting. There was also limited evidence to determine whether acute cold applications enhance the effects of stretching. ROM, tissue stiffness, and compliance are important factors determining performance and injury risk,[65] and the in vivo effect of cold temperature on these parameters is an important area for future study.

## Study limitations and future study

The majority of studies in the current review applied thermal agents to muscle. Tendons and ligaments have unique mechanical properties and may respond differently to changes in temperature. This is an important area for future research as tendon mechanics have an important role in sporting performance. Indeed, different sports need different levels of musculoskeletal compliance. Sports involving jumping or bounding carry a high volume of stretch-shortening demands and therefore favor a more elastic, compliant tendon, whereas less compliant tendons are suited to sports where isometric or concentric activity predominates.[66] An interesting concept may be the judicious use of thermal agents to optimize tendon mechanics and force transmission prior to sports.

Our primary focus was on the effects of thermal interventions, and potential differences in stretching techniques were not addressed. In studies comparing heat and stretch, or ice and stretch versus stretch alone, the stretching dose was standardized across groups, in terms of its mode, duration, and frequency. Subsequent research should consider whether heating or cooling complements certain stretching techniques or dosages.

Perhaps the most significant limitation is the high risk of bias across included studies. Future studies should incorporate a randomized controlled design with adequate sequence generation and allocation concealment and ensure effective and explicit blinding of outcome.

## Conclusions

Thermal agents are commonly used in a variety of capacities throughout sports and rehabilitation, and we must have strong rationale for their use. An inherent limitation in the current evidence base is the high risk of bias. The majority of studies have focused on effects of thermal agents on ROM. Although the effects of cold are conflicting, there was clearer evidence that heat increases ROM. This seems to provide a therapeutic window that ameliorates the effects of stretching interventions on ROM, and there was clear evidence that combined heat and stretching is more effective than stretching alone. These findings seem to support the use of heat as an adjunct to developmental and therapeutic stretching techniques. The effects of heat or ice on key mechanical properties such as passive stiffness remain equivocal and should be the focus of future study.

## Supplier

a. The Cochrane Collaboration, UK Cochrane Centre, Oxfordshire OX2 7LG.

## Keywords

Cold temperature; Hot temperature; Joint range of motion; Muscle stretching exercises; Rehabilitation

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