Introduction

Chronic joint disorders represent some of the most prevalent pain conditions treated in primary care (Carmona et al 2001, Mantyselka et al 2001). They constitute several entities, with the common factor that pain is located at the articular structures.

Osteoarthritis is probably the most common entity and the prevalence of osteoarthritis is rising parallel to the increasing age of the population (Felson et al 2000). Temporomandibular joint disorders, patellofemoral pain syndrome and mechanical spine disorders are other examples of chronic joint disorders. These conditions can be associated with impaired muscular stabilisation (Cowan et al 2001, Radebold et al 2001), reduced range of motion (McNamara et al 1996, Steultjens et al 2000) and inflammation of the joint capsule (Speldewinde et al 2001, Suenaga et al 2001, Vaatainen et al 1998).

A link has been established between synovial inflammatory activity and worsening of cartilage degeneration in osteoarthritis (Chikanza and Fernandes 2000). In this context, it is interesting to investigate if an anti-inflammatory action can be induced clinically by electrophysical agents.

Controlled laboratory trials have found that LLLT can reduce inflammation through reduction of PGE₂-levels and inhibition of cyclooxygenase-2 (COX-2) in cell cultures (Campaña et al 1993, Honmura et al 1993, Sakurai et al 2000, Shimizu et al 1995). The transformation of encouraging laboratory results into clinical effectiveness has been a difficult task (Basford 1995), and clinical effectiveness of LLLT has been questioned in systematic reviews on a broad range of conditions (de Bie et al 1998, Del Mar et al 2001, Gam et al 1993). A recent Cochrane systematic review on LLLT found a minor positive effect on rheumatoid arthritis, but the material on osteoarthritis was conflicting (Brosseau et al 2000). In the following review, our hypothesis is that laser irradiation of the joint capsule can reduce pain in chronic joint disorders if the dose is adjusted to inhibit inflammatory activity in the joint capsule.

Materials and methods

A detailed review protocol was specified prior to conducting the review. This included a sequential four-step reviewing procedure involving predetermination of an optimal dose range, conduct of a sensitive literature search, application of a pre-specified inclusion/exclusion procedure, and testing of differences between trials with and without optimal dose.

The optimal dose range was derived from successful laboratory trials prior to the literature search. In the first step of the reviewing procedure, an optimal dose range was
determined at the target location and then adjusted according to energy loss estimates for each anatomical location and the size of affected peripheral, facial and spinal joints.

**Determination of possible anti-inflammatory LLLT dose at target location** In *in vitro* trials, LLLT has been reported to suppress inflammation by a reduction of PGE$_2$ in ligament cell cultures (Sakurai et al 2000, Sattayut et al 1999, Shimizu et al 1995). Low level laser therapy has also been found to reduce PGE$_2$ levels in the joint capsule of animals in *in vivo* trials (Campaña et al 1993 and 1999, Honmura et al 1993, Sakurai et al 2000). This effect was reported within a range between 0.4 and 19 J and a power density of 5-21.2 mW/cm$^2$. The lower range limits for PGE$_2$ reduction were identified because data showed no effect below this threshold. Upper range limits could not be identified, as there were no data available to show when or if this effect would level off. However, it has been shown that power densities above 20 mW/cm$^2$ temporarily inhibit fibroblast metabolism (van Breugel and Bar 1992), and numerous fibroblast cells are found in the joint capsule. We assumed doses of 0.4-19 J and power density of 5-21 mW/cm$^2$ would be capable of reducing inflammation at the target joint capsule without compromising fibroblast metabolism.

**Location-specific dose adjustment for energy loss and anatomical size** Data on beam diameter and laser output were collected from the manufacturers’ manuals. Power density and dose were calculated according to the following formulas:

\[
\text{Power density for GaAs 904 nm pulse lasers (mW/cm}^2) = \frac{(\text{peak power pulse} \times \text{pulse duration} \times \text{pulses frequency})}{\text{spot size on skin}}.
\]

\[
\text{Power density for lasers with continuous output (mW/cm}^2) = \frac{\text{mean power}}{\text{spot size on skin}}.
\]

\[
\text{Dose (J)} = \text{mean power} \times \text{treatment time per session}.
\]

Measurement of light penetration and absorption in biological tissue is dependent on several variables. Two anatomical factors are essential to LLLT dose calculations: distance from skin to synovia and size (area) of the affected synovia. For knee (anteromedial and anterolateral part), finger, toe and temporomandibular joint, the distance from skin ranges from 1.5 to 5 mm (authors’ unpublished data; 10 persons scanned by 7.5 MHz ultrasound imaging). The distance from skin surface to the zygapophyseal joints was 8 to 20 mm for the cervical spine and 25-35 mm for the lumbar spine. Another variable that affects penetration is the wavelength of the laser. Infrared laser light has been demonstrated to have a typical penetration depth (ie the distance which reduces the incident energy to 37%) of nearly 3 mm, while red laser light has a penetration depth of 1 mm (Kolari and Airaksinen 1988). Although energy loss is exponential near the laser source, optical measurements have demonstrated that energy loss is nearly linear at greater distances (Faris et al 1991). In an experimental porcine tongue model, a 200 mW GaAlAs laser had intensity reduced to 16 mW after the first 15 mm, which is within our suggested optimal dose range (Bradley et al 1998, Gursoy and Bradley 1994). From this depth, intensities fell at a slower almost linear rate to 1.4 mW at 35 mm. In vivo trials with 904 nm pulse lasers have

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**Table 1.** Suggested range of power densities and dose for the most common joints for infrared GaAlAs and Nd:YAG (continuous) lasers with wavelength 820, 830 and 1060 nm; infrared GaAs (pulse) lasers with wavelength 904 nm; and red HeNe (continuous) lasers with wavelength 632 nm.

<table>
<thead>
<tr>
<th>Location</th>
<th>Power density (mW/cm$^2$)</th>
<th>Dose (Joules)</th>
<th>Power density (mW/cm$^2$)</th>
<th>Dose (Joules)</th>
<th>Power density (mW/cm$^2$)</th>
<th>Dose (Joules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger/toe/ temporomandibular 1 point/1 cm$^2$ Depth 2 mm</td>
<td>15 - 105</td>
<td>0.5 - 15</td>
<td>6 - 42</td>
<td>0.2 - 1.4</td>
<td>30 - 210</td>
<td>6 - 30</td>
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<td>12 - 60</td>
<td>1.2 - 84</td>
<td>90 - 500</td>
<td>9 - 2700</td>
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<td>24 - 60</td>
<td>0.8 - 56</td>
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<td>5 - 150</td>
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<tr>
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<td>48 - 480</td>
<td>30 - 210</td>
<td>15 - 105</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

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demonstrated that these lasers achieve similar effects on collagen production with far lower doses on the animals’ skin than lasers with continuous output (Enwemeka 1991, van der Veen and Lievens 2000). This effect can be attributed to the photobleaching phenomenon, where the first strong pulse bleaches the opaque barrier of tissue, letting the second pulse pass through the tissue barrier with less loss of energy (Kusnetzow et al 2001).

We postulate that energy loss due to the skin barrier for continuous HeNe (632nm) laser is 90%, for continuous GaAlAs (820nm) and NdYag IR lasers, 80% and for GaAs (904 nm) infrared pulse laser, 50%. Further energy loss is, according to the porcine penetration model, postulated to be linear at 5% per mm of tissue for infrared lasers. For red HeNe laser we postulate that further energy loss is 10% per mm of tissue.

The synovial area is rather small in finger, toe and temporomandibular joints, and we postulate that at least one single point is necessary to deliver an optimal dose of LLLT in these locations. We also postulate that a minimum of three points of the synovial membranes of the knee and the zygapophyseal joints of the spine must be irradiated to provide a sufficient dose for these locations.

Estimations of dose and power densities required for the different anatomical locations are shown in Table 1.

**Literature search** A pre-specified literature search was performed from 1980 through to November 2001 on MEDLINE, Embase, CINAHL, PEDro and the Cochrane Controlled Trials Register (Central) for randomised controlled clinical trials.

Key words were: Low level laser therapy, low intensity laser therapy, low energy laser therapy, HeNe laser, IR laser, GaAlAs, GaAs, diode laser, osteoarthritis, chronic joint disorder, temporomandibular joint, hip, knee, thumb, spine. Hand searching was also performed on national physiotherapy and medical journals from Norway, Denmark, Sweden, The Netherlands, Germany, Switzerland, England, USA, Canada and Australia.

Additional information on randomised controlled trials was gathered from researchers in the field. The literature search was concluded by the end of November 2001.

**Methods**

**Inclusion criteria** The trials were subjected to six inclusion criteria: joint disorder of more than six months duration or osteoarthritis verified by x-ray, random allocation of patients to groups, control group received identical placebo treatment, blind patients and outcome assessors, laser exposure of skin overlying inflammatory joint capsule, and outcome measure of pain and change in health status.

**Assessment of methodological quality** A criteria list of 10 methodological criteria developed for the PEDro database of physiotherapy trials at The University of Sydney, Australia, was used (Moseley et al 2002). Assessments of methodology were made by an assessor who was blinded to the trial results. No specific cut-off limit for method scores was pre-planned as a criterion for exclusion.

**Outcome measures** We selected pain on a visual analogue scale (VAS) as the first of two main outcome measures. In trials where several aspects of pain were measured, measures of pain during physical activity were preferred. Variance was calculated from post-treatment data and given as 95% confidence intervals (95% CI) in millimetres on VAS. Results were presented as weighted mean differences (WMD), ie a pooled estimate of the difference in mean change of the treatment and the placebo groups weighted by the inverse of the variance using a random effects model. Variance was calculated from the standard deviation (SD) of post-treatment data and given as 95% CIs. If variance data were reported as interquartiles, then the average SD from the other included trials was used for the statistical pooling.

The second main outcome measure was categorical data of change in global health status. Improved global health status was defined as any one of the following categories: “improved”, “good”, “better”, “much improved”, “pain-
free”, “excellent”. If sufficient data from the trial reports were provided, then the proportions of “improved” and “not improved” patients were pooled and expressed as a relative risk. A random effects model was used for statistical pooling.

### Results

#### Included studies


### Dose assessment

The results of the dose assessment revealed that three trials (Basford et al 1987, Jensen et al 1987 and Klein and Eek 1990) did not use doses inside our dose suggested range. These trials are indicated in Italics in Table 3. The remaining 11 trials, which included 565 patients, adhered to the suggested dose range.

### Method scoring

Method scores for trials that used the suggested dose range satisfied on average 6.9 out of 10 possible criteria on the PEDro scale, while the remaining three trials satisfied six out of all 10 criteria on the PEDro scale. Seven trials had previously been assessed by PEDro reviewers. For one trial, our assessment differed from the PEDro database scores (Jensen et al 1987). Missing concealed allocation to groups and intention to treat analysis were the most frequent shortcomings in the included trials. The results of the method scoring is summarised in Table 4.

### Pain reduction on VAS

Nine trials provided data of pain on VAS (Table 5). Two trials used a dose outside our suggested dose range and both reported a non-significant difference in pain reduction (Conti 1997, Klein and Eek 1990). Of the remaining eight trials with LLLT dose inside our suggested dose range, one trial reported variance data as interquartiles (Bulow et al 1994). These variance data were substituted by the average SD of the other six trials in the statistical pooling. By using a random effects model, WMD in change of pain on a 100 mm VAS was calculated to 29.8 mm (95% CI 18.9 to 40.7) in favour of active laser (Figure 1).

### Table 4. Method scores (PEDro scale).

<table>
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<tr>
<th>First author</th>
<th>Randomisation performed</th>
<th>Concealed allocation to groups</th>
<th>Baseline similarity</th>
<th>Patient blinded</th>
<th>Therapist blinded</th>
<th>Observer blinded</th>
<th>Withdrawals/ dropouts &lt; 15%</th>
<th>Intention-to-treat analysis</th>
<th>Between-groups difference tested statistically</th>
<th>Mean and variability data</th>
<th>Total score</th>
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</table>

Trials shown in Italics gave treatment outside suggested dose range. * Indicates that the same method scores have been given by PEDro reviewers. (*) Indicates method score by PEDro reviewers where disagreement with our assessment existed.

**Figure 1.** Effect of low level laser therapy on pain (mm on a 100 mm VAS).
Six trials measured change in health status, and provided data that made it possible to calculate the number of patients that improved their health status in active LLLT groups and placebo laser groups (Table 5). In one trial that used a lower dose than our suggested dose range, no significant difference was registered between groups (44% versus 47% with improved status; Basford et al 1987). The remaining six trials used doses within our suggested dose range. In one of them (Basford et al 1999), the data showed a significant effect in favour of active laser but the presentation of the data did not allow for identification of the number of patients who experienced improvement. Five trials reported improved health status for a total of 110 patients in the active LLLT groups versus 53 in the placebo groups. Health status remained unchanged for 50 patients in the active LLLT-groups and 97 patients in the placebo groups. The pooled estimate of the change of health status was significantly in favour of active LLLT with a relative risk of 0.52 (95% CI 0.36 to 0.76) when calculated by a random effects model. The results for health status are summarised in Figure 2.

### Health status

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<th>First author</th>
<th>No. of patients</th>
<th>Condition</th>
<th>Mean pain (mm) before treatment</th>
<th>Mean pain (mm) after treatment</th>
<th>Mean change in pain (mm)</th>
<th>Proportions of patients improved</th>
<th>Author’s test of significance</th>
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</tbody>
</table>

Randomised placebo-controlled trials where LLLT has been used for CJD. Outcome data are extracted from trial reports. Trials shown in Italics gave treatment outside suggested dose range. *Visual estimates of data from graphs in trial report. Blank boxes indicate missing data in trial report. N.S. = not statistically significant.

### Health status

Six trials measured change in health status, and provided data that made it possible to calculate the number of patients that improved their health status in active LLLT groups and placebo laser groups (Table 5). In one trial that used a lower dose than our suggested dose range, no significant difference was registered between groups (44% versus 47% with improved status; Basford et al 1987). The remaining six trials used doses within our suggested dose range. In one of them (Basford et al 1999), the data showed a significant effect in favour of active laser but the presentation of the data did not allow for identification of the number of patients who experienced improvement. Five trials reported improved health status for a total of 110 patients in the active LLLT groups versus 53 in the placebo groups. Health status remained unchanged for 50 patients in the active LLLT-groups and 97 patients in the placebo groups. The pooled estimate of the change of health status was significantly in favour of active LLLT with a relative risk of 0.52 (95% CI 0.36 to 0.76) when calculated by a random effects model. The results for health status are summarised in Figure 2.

### Duration of pain relief

Six trials with assumed optimal treatment employed follow-up measurement of at least three weeks. Four of these trials reported pain relief under blinded conditions (Basford et al 1999, Götte et al 1995, Gray et al 1994, Nivbrant and Friberg 1992). Two trials with intensive, daily treatment regimens (Soriano and Rios 1998, Stelian et al 1992) reported pain reduction from LLLT for four to six months, but evaluation in the follow-up period was unblinded.

### Side effects and adverse reactions

In terms of side effects, six of the LLLT trials with optimal dose (Basford et al...
The differences in numbers and frequencies of the LLLT is achieved through an anti-inflammatory action. This adds support for our hypothesis that pain reduction from those which did not allow for this co-intervention. This explicitly allowed anti-inflammatory drugs was poorer than anti-inflammatory drugs. The overall effect in trials that results is that only some trials prohibited co-intervention by other trials, baseline pain was above 48 mm on the VAS. Perhaps the weakest point of this review is the heterogeneity in treatment procedures and within the patient sample. The latter is reflected by mean baseline pain scores that ranged from 35 mm to 82 mm on VAS (Table 5). In two trials it was explicitly stated that patients were excluded if they experienced an acute episode of exacerbation (Basford et al 1999, Klein and Eek 1990). For the other trials, baseline pain was above 48 mm on the VAS.

Another issue that can partly explain heterogeneity in results is that only some trials prohibited co-intervention by anti-inflammatory drugs. The overall effect in trials that explicitly allowed anti-inflammatory drugs was poorer than those which did not allow for this co-intervention. This adds support for our hypothesis that pain reduction from LLLT is achieved through an anti-inflammatory action. The differences in numbers and frequencies of the treatment sessions may also increase heterogeneity in results. However, the majority of trials involved treatment for two to four weeks, and only one trial (Toya et al 1994) treated once and measured the immediate effect of LLLT. We were in doubt whether this trial should be removed from the calculations of improved health status.

The structures which contribute to neck pain or low back pain are disputed, but both muscular and articular structures seem to be involved. The majority of patients with chronic spinal pain in our review had an x-ray confirmed diagnosis of osteoarthritis (Basford et al 1999, Oxdemir et al 2001, Soriano and Rios 1998). The presence of inflammation, however variable in activity, is a cardinal sign in osteoarthritis (Pelletier and Martel-Pelletier 2002). For this reason, we decided to include these trials as chronic joint disorders trials.

We think that the inclusion of pain from the temporomandibular joint is fairly uncontroversial. It is a common condition and, like other chronic joint disorders, is characterised by pain, synovial inflammation and decreased range of motion (Rauhala et al 2000).

Assessing scientific evidence from clinical trials is always a complex matter. We do agree that the methodological quality of trials is important, and have assessed the trials according to a widely accepted standard (the PEDro scale). Fortunately, the included trials were all of acceptable methodological quality, which made it unnecessary to exclude any of them from our conclusion. Six of the trials have been assessed by PEDro reviewers and confirm our method scores. For one trial we found that partial blinding was performed, which contradicts the PEDro review. In addition, two other trials (Bertolucci and Grey 1995, Stelian et al 1992) have previously been assessed by other reviewers who found that they fulfilled more than half of the quality criteria on the Jadad and Maastricht lists, respectively. There is, however, genuine disagreement between our method score and the score of a Swedish trial (Nivbrant et al 1992) in another review (de Bie et al 1998). This may be attributed to linguistic difficulties, or the fact that two reports have been published from this trial.

There is some evidence that LLLT may inhibit fibroblast activity (Loevschall and Arenholt-Bindslev 1994) when dose exceeds 4 J. As the joint capsule is populated by fibroblasts, future research is needed to clarify the matter of optimal balance between biological effects such as COX-2 inhibition and fibroblast activity.

Laser dosage is a complex topic, and missing parameters can give a misleading picture if they are not fully reported. We have retrieved the missing laser parameters by getting specifications from the manufacturers of all the lasers used in the included trials and we have recalculated all power densities, dose per treatment sessions and weekly doses. However, it is a weakness that testing and calibration of laser output was only performed in two of the clinical trials (Basford et al 1999, Bulow et al 1994).
In five of six LLLT trials with follow-up, pain reduction remained significant for three weeks, and unblinded follow-up suggested significant pain reduction for up to six months (Stelian et al 1992).

The literature on LLLT is full of conflicting reports, and we believe that much of this is caused by the lack of dosage consensus. One large, well-designed trial found no effect from LLLT on ankle sprains (de Bie et al 1998). In our opinion, the poor results may have been caused by insufficient irradiation, because only a single 1 cm² point of the swollen joint capsule was treated by LLLT. In a recent review on LLLT effectiveness (Brosseau et al 2000), results for osteoarthritis were conflicting. This review lacked procedural assessment of the laser exposure technique, and dose analysis was not used to adjust for differences in energy loss for each anatomical location. In addition, our literature search is more recent and extensive and includes two more trials on osteoarthritis of the knee (Götte et al 1995, Nivbrant and Friberg 1992), in addition to trials with spinal and temporomandibular joint disorders.

Conclusion

Although the heterogeneity of the trial results calls for caution in interpretation, LLLT seemed to be effective in reducing pain from chronic joint disorders. The hypothesis that LLLT acts through a dose-specific anti-inflammatory effect in the irradiated joint capsule is a potential explanation of the positive results. This hypothesis needs to be verified or refuted in studies where outcome measures of inflammatory activity are used. More and larger trials are needed to precisely determine optimal treatment procedures for LLLT and possible interaction with other therapies for chronic joint disorders.

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