Lasers in Medical Science (2004) 19: 69–80
DOI 10.1007/s10103-004-0296-8

ORIGINAL ARTICLE

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Laser acupuncture: past, present, and future

Received: 16 January 2003 / Accepted: 3 February 2004 / Published online: 3 September 2004

Abstract Laser acupuncture is defined as the stimulation of traditional acupuncture points with low-intensity, nonthermal laser irradiation. Although the therapeutic use of laser acupuncture is rapidly gaining in popularity, objective evaluation of its efficacy in published studies is difficult because treatment parameters such as wavelength, irradiance, and beam profile are seldom fully described. The depth of laser energy transmission, likely an important determinant of efficacy, is governed not only by these parameters, but also by skin properties such as thickness, age, and pigmentation—factors which have also received little consideration in laser acupuncture. Despite the frequently equivocal nature of the published laser studies, recent evidence of visual cortex activation by laser acupuncture of foot points, together with the known ability of laser irradiation to induce cellular effects at subthermal thresholds, provides impetus for further research.

Keywords Acupuncture · Collagen · Laser therapy · Skin

Introduction

In China, acupuncture's written origins date back over 2,000 years, while archeological findings are consistent with more than 3,000 years of practice [1, 2]. However, tattoos on a 5,000-year-old mummified, Stone Age body found in the Alps, on the border between Austria and Italy, suggest an even earlier origin. The tattoos' locations correspond closely with Chinese acupuncture points and furthermore correspond to points used to treat lumbar and leg-joint arthritis and abdominal disorders—conditions confirmed to be present in this individual [3]. Although an extensive narrative of thousands of years of acupuncture theory and practice is beyond the scope of this review, a brief description is necessary to provide context for the discussion of laser acupuncture.

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Acupuncture theory and practice

A central tenet of acupuncture contends that energy (Qi—pronounced CHEE), flows through the body along defined subsurface paths [1, 2]. The maintenance of good health requires that such flow be in balance. Conversely, any disturbance in this flow results in an energy imbalance, either an excess or a deficiency, which in turn results in disease. Acupuncture attempts to regulate and restore energy balance by stimulating specific points along the paths and hence treat the disease. Traditional Chinese classification identifies 361 points along 14 main paths; however, other points have been identified over time to more than double the total number of recognized points [2]. The location of these points is determined using anatomical landmarks and a system of length measurements whose units are relative to the physical proportions of the individual patient. In addition, more recently, other acupuncture practices have been developed in which all of the treatment points are located on a single appendage (principally the ear, but the hands, feet, and head have also had separate point maps constructed), which are used either alone or in combination with traditional Chinese acupuncture points [2, 4]. Although all of the points have empirically determined indications for specific illnesses or problems, in common practice only a relatively small number of the points is used regularly. Point selection to treat a complaint is typically made, not by rote formula, but rather after performing a physical assessment and taking a history from the patient. It is the practitioner's subsequent interpretation of this information that determines which points to treat. Treatments involve needle insertion at the selected point or points and ensuing needle manipulation; for example, by twirling or by an up and down motion. The nature, intensity, and duration of such manipulation are determined by the specific condition and/or the practitioner's interpretation of the means necessary to restore Qi balance. However, the inherent subjectivity, combined with the large number of potential variables present in such treatment regimes, makes rigorous scientific assessment of acupuncture a challenge.

Laser acupuncture

Despite acupuncture's long history and tradition, it is not a static discipline. This statement is supported not only by the previously mentioned frequent "discovery" of new points, but also by the progression of the technology used to stimulate acupuncture points; from stone to metal and more recently to electro-acupuncture, the application of small electric currents through the inserted needles. The most recent technologic development has been the introduction of laser acupuncture, defined as the stimulation of traditional acupuncture points with low-intensity, nonthermal laser irradiation. Evidence for laser acupuncture–mediated effects comes from recent functional magnetic resonance imaging studies that demonstrated visual cortex activation in response to laser irradiation of acupuncture point BL-67, sometimes used to treat eye pain [2], located lateral to the corner of the little toenail [5]. In contrast, no such response was found when the laser was placed in contact with the skin at the acupuncture point but was not switched on. Although similar intriguing correlations between activation of specific brain regions and needle stimulation have also been demonstrated [6], such results do not prove efficacy and hence may not appreciably counter the often negative response provoked by acupuncture in medicine [7, 8]. Therefore, acupuncture combined with the equally provocative concept of nonthermal low-intensity laser therapy significantly increases skepticism [9, 10]. My goal in this review is twofold: first, to examine the laser acupuncture literature to determine whether such skepticism is warranted and, second, to illustrate how laser parameters such as wavelength, beam profile, and power could have played a significant role in the results obtained and the conclusions drawn.

Modern history

Laser acupuncture has been clinically applied since the 1970s. Although several sources, especially Internet Web sites, credit Friedrich Plog with the first laser stimulation of acupuncture points, his experiments began in 1973–1974 [11]. These studies were pre-dated by work in the USSR, conducted between 1970 and 1972, which included reportedly successful treatment of hypertension and asthma referenced in a review [12] and alluded to in a letter to the editor [13]. However, Plog's work did prompt production of the first commercial laser acupuncture system, the Akuplas, by Messerschmidt-Bolkoew-Blohm and its subsequent clinical application [14]. Increased laser availability and reduced production costs in the late 1970s and early 1980s resulted in increased use; however, most studies were nonrandomized and uncontrolled [14–21] and were often from countries whose acupuncture trials usually produce positive results [22]. The pioneering nature of such work cannot be discounted; however, it was not until the late 1980s that increased numbers of well-designed experiments appeared.

Laser acupuncture's early development was concurrent with, and influenced by, the low-intensity laser therapy research originally developed by Mester et al. [23] in Hungary to stimulate wound healing, but subsequently also used for pain relief [24–27]. This influence of, and overlap with, laser acupuncture occurs, in part, because of the existence of so-called ahshi acupuncture points ("points of pain"), which can develop anywhere on the body because of injury or disease [2]. Although these points do not have fixed locations, they nevertheless represent potential sites for acupuncture treatment. Similarly, such painful spots have been directly treated using low-intensity laser therapy [27], and, although some laser studies have combined treatment of both ahshi and fixed acupuncture points [28], I will focus on irradiation of the latter. I will also limit discussion of the extensive low-intensity laser therapy literature to instances where it might offer insight into laser acupuncture.

The skin barrier to laser transmission

Although there is no doubt that acupuncture needles can penetrate skin, a crucial question for laser acupuncture is, can laser energy do the same? To answer this question, the degree of scattering and absorption of the incident irradiance by different tissue elements should be considered. Skin's multilayered, inhomogeneous, anisotropic structure makes its optical properties complex; however, the incident irradiance generally decreases exponentially as it passes through skin in a wavelength-dependent manner because of scattering and absorption [29, 30]. In the ultraviolet and visible spectrum range from violet to orange (~400–600 nm) there is substantial absorption by hemoglobin and melanin [29], and hence limited transmission. For blue light, the depth at which incident irradiance has decreased by 99% is only ~700 μm [31]. At wavelengths above 1,400 nm, there is considerable water absorption and consequently little transmission [32]. In contrast, the red and infrared wavelengths used most often for laser acupuncture are absorbed less, and transmission is greater [29, 33]. Nevertheless, at these wavelengths, scattering by collagen still attenuates transmission [29]. Figure 1, derived from calculations based on the Kubelka-Munk theory [29], shows the approximate skin depths (in fair

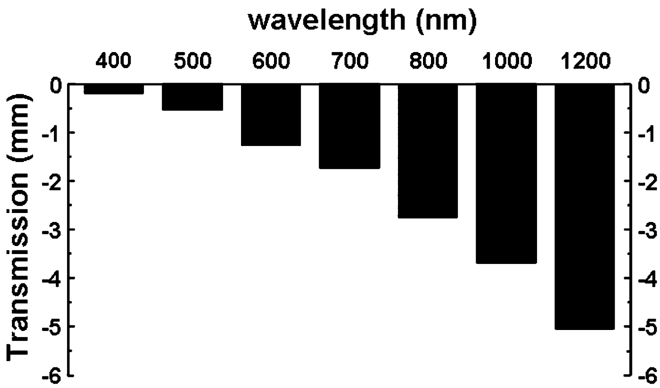

Fig. 1 Transmission in skin. Approximate skin transmission depth at which the incident radiant exposure has decreased by 90%. The transmission depth for a 99% decrease can be calculated by doubling the corresponding 90% depth. Data shown are for fair Caucasian skin. Graph drawn from data presented in [29]

Caucasian skin) at which the incident irradiance has decreased by 90% for wavelengths from 400 to 1,200 nm. Thus, at wavelengths below 800 nm, relatively little of the incident irradiance could be expected to traverse human skin, whose thickness varies from ~1–3 mm depending upon location [34]. These theoretical calculations correspond well with measurements made on ex vivo (bloodless) skin. For example, Kolárová and colleagues found that 5–10% of the incident irradiance at 632.8 nm was transmitted through 1.5–4.1-mm thick skin samples (obtained from a variety of locations in male patients, 16–40 years old, undergoing plastic surgery) versus a slightly greater transmission of 6–14% at 675 nm [35]. For a 19-mm skin sample that included subcutaneous fat, transmission was 0.3% at 632.8 nm and 2.1% at 675 nm. Similarly, Wan et al. [33] reported a 100–1,000-fold attenuation of irradiance at a wavelength of 814 nm by 15–23 mm of intercostal tissue (skin and muscle) obtained post mortem from Caucasian subjects. It is therefore clear that skin and subdermal tissue represent a significant barrier to transmission. Furthermore, there are numerous additional factors: for example, the variation of thickness with location [34, 35], age [36, 37], pigmentation [29, 38], and regional collagen fiber anisotropy [39], that will affect skin's optical properties. Nevertheless, such variables have received little or no attention in either the design or the implementation of laser acupuncture studies.

After traversing the skin, progress is easier because of muscle's smaller scattering coefficient [38, 40]. In fact, based on results obtained from in vivo and in vitro examination of rabbit skeletal muscle, transmission through muscle at wavelengths between 600 and 800 nm is approximately fourfold greater than the corresponding skin transmission [29, 41]. Thus, minimizing or removing the skin barrier might enhance laser acupuncture. For example, perforating the skin with a hypodermic syringe needle and introducing an optic fiber through the needle into the subdermal tissue could accomplish such enhancement; however, needle insertion for evaluation of laser acupuncture is, of course, problematic. One study did use this approach, but did so only in order to combine needle and laser acupuncture [19]. A noninvasive and mechanistically cleaner ap-

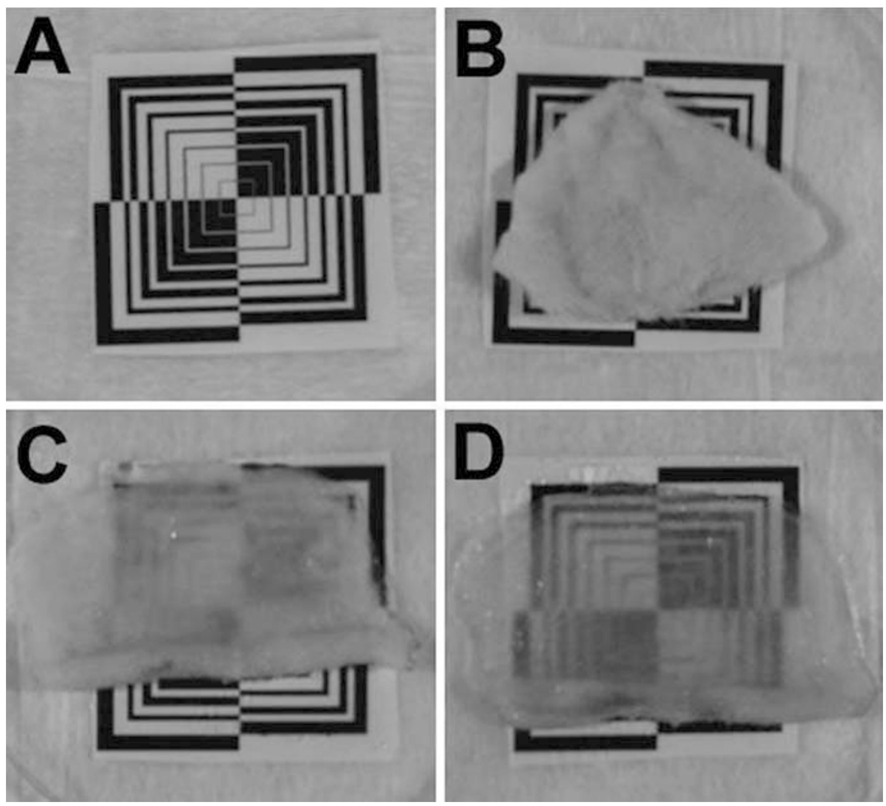

Fig. 2a–d Increased skin transmission after glycerol application. Images of a resolution target placed beneath a sample of rat skin. **a** Resolution target, **b** skin prior to glycerol application, **c** intermediate time point, portions of the target are visible, **d** end of the experiment, the target can now be seen. The skin was sandwiched between glass slides (hence the apparent shape change from **b** to **c**) to enhance glycerol absorption. The scattering caused by dermal collagen fibers is significantly decreased because the refractive index of glycerol matches that of collagen and hence light transmission is increased. In this manner, the transmission of laser treatments through skin could be enhanced (target width 3.5 cm)

proach is the topical application of glycerol (Fig. 2), which has the same refractive index, 1.46, as collagen [42] and has been shown to reduce scattering and increase transmission by ~50% in the 600–1,200-nm wavelength range [43]. However, as far as I am aware, this method has never been combined with laser acupuncture. In summary, the optical properties of skin and the underlying tissue, in combination with the amount of incident irradiance, determine the transmission of light. It seems likely that the efficacy of laser acupuncture requires some minimum level of transmission to a certain tissue depth, and therefore consideration of skin's optical properties is imperative.

Animal studies

Needle acupuncture has been examined in many animal experiments; for example, a PubMed search of "acupuncture AND (rats OR rabbits OR mice)" produced more than 1,000 references. In addition, acupuncture has a long treatment history for domestic animals in China and is used currently by some veterinarians [44]. The location of acupuncture points in animals has been derived either empirically or by transposition of human points onto animal anatomy [45]; however, the latter approach is clearly open to interpretation given the obvious anatomical differences between species.

Laser acupuncture's relatively recent origin and its clinical emphasis probably explain why there are comparatively few nonhuman studies—substitution of "laser acupuncture" in the above-mentioned PubMed search produced only eight references, all of which were published in either Russian or Chinese. Furthermore, most of the animal studies focus solely on analgesia; for example, Lundeberg and Zhou [46] irradiated isolated crayfish stretch receptors for up to 20 min with either helium-neon (632.8 nm, 1.56 mW) or gallium-arsenide (904 nm, 0.07 mW, 73 Hz) lasers. The lack of effect on action potentials led them to conclude that laser acupuncture had no direct action on nervous tissue and hence laser acupuncture–mediated pain relief was a placebo effect. The same group also investigated laser effects on pain relief in an intact animal model [47]. Rats had their tails immersed in 49°C water and the time for the well-documented tail-flick response to occur was recorded. The tests were conducted before and after either laser acupuncture (with the lasers, powers, and frequencies described above) applied on either side of the base of the tail (considered by the authors to correspond to the acupuncture point GV-1) for 1 min, or electro-acupuncture applied to needles inserted at the same location for 15 min bilaterally, or subcutaneous morphine injection. Although morphine and electro-acupuncture treatment increased the time to tail-flick versus control, lasers had no effect. However, the power used in both of these studies was low (0.07 mW). Using a similar low laser power, Kilde and Martin [48] reported that weekly 2-min treatments of several acupuncture points (specific to equine anatomy) for 11 weeks with a 904-nm laser (0.3 mW, 360 Hz) alleviated chronic back pain in 11 of 14 horses. The success rate achieved with the laser was similar to that found with both needle acupuncture and saline injection at the acupuncture points. However, this reported success was based primarily on a qualitative and subjective assessment of the horse's ability to return to normal performance (most were racehorses).

One significant deficiency resulting from this dearth of preclinical laser acupuncture studies is the lack of an established animal disease or injury model that might allow not only the systematic evaluation of the laser parameters and other treatment variables, but also permit the design of experiments to investigate mechanisms.

Human studies

It is perhaps laser acupuncture's failure to follow the typical "bench-to-bedside" progression that accounts, at least partially, for the frequently confused and conflicting nature of the published clinical studies. In an attempt to provide some rational framework for discussion of the wide range of clinical applications, I will divide the studies into those involved with pain relief versus those treating other conditions.

Pain relief

Published laser acupuncture studies have concentrated mostly on musculoskeletal disorders with pain as the primary endpoint. The subsequent evaluation of these studies and also of low-intensity laser therapy trials has often employed meta-analysis [27, 49, 50]. Although the value of such approaches in evidence-based medicine is clear, there is risk in their blind application. For instance, one meta-analysis of laser treatments for musculoskeletal disorders assigned scores based on study design criteria such as randomization, therapist and patient blinding, appropriate statistical analysis, etc. [26]. However, such analysis gives no consideration to the equally important design criteria of the reporting of laser parameters, therefore potentially undermining the entire scoring system. For example, one study that found no benefit of laser acupuncture for relief of chronic myofascial pain scored poorly in design criteria; however, its ultimate laser shortcoming was a failure to report the energy used [51]. Conversely, one of the highest scoring studies (and hence considered to be superior), which reported no benefit for laser treatment of lateral humeral epicondylalgia, identified neither the irradiance nor the beam size used [52]. A similar omission occurred in another high scoring study claiming positive laser effects in myofascial pain [28]. In addition, even though there is no current compelling evidence to indicate the appropriate laser parameters necessary for success, there are nevertheless some studies that, because of the parameters selected, would appear to have little chance of success. Thus, two high scoring studies in the meta-analysis, which used very low power—one the 1.56 mW, 632.8 nm, and 0.07 mW, 904 nm lasers described in the rat tail-flick study above—found no benefit for tennis elbow treatment [53], while another used a 2-mW helium-neon laser successfully to alleviate spinal pain by treating points primarily located on the back where skin is thick and transmission limited [54]. These studies illustrate that "the quality of evidence should be assessed not by the method by which it was obtained but by its strength or weakness" [55]. Thus, otherwise well-designed studies may not merit consideration because the laser parameters were inadequately described or because the selected power, wavelength, or the site of treatment would result in limited transmission and hence may be unlikely to produce an effect.

In contrast, Zhou [21] provided more complete laser documentation, albeit in an anecdotal report, for laser-mediated anesthesia (2.8–6.0 mW, 632.8 nm) in tooth extraction and minor maxillofacial surgery. Preoperative, 1–5 min exposures were applied to one of three facial points (ST-1, ST-6, or SI-18) determined by the procedure's nature and location, and then the beam (diameter = 1.5–2.0 mm) was directed to acupuncture point LI-4 (located between the first and second metacarpals) for the duration of the surgery (10–70 min). None of the 610 patients received analgesics or sedatives, and an impressive, but undefined, success rate of $>95\%$ was reported. In an expanded report including 7,000 patients [56], Zhou also successfully used a carbon dioxide laser (100 mW), which is rather surprising because of the strong water absorption and hence very limited transmission at this wavelength (10,600 nm).

In addition to inadequate description of laser parameters, unequivocal attribution of positive results to laser acupuncture is often compromised by protocol design. For example, Ceccherelli et al. [28] irradiated both acupuncture points and tender (ahshi) points, while Naeser et al. [57] combined laser acupuncture with transcutaneous electric nerve stimulation (TENS) to treat pain associated with carpal tunnel syndrome.

Evidence to explain how laser acupuncture might reduce pain is lacking; however, low-intensity laser therapy studies provide some indication of indirect laser-mediated effects on nerve tissue. Transdermal irradiation using a continuous wave, 40 mW, 830 nm laser (radiant exposure 9.6 J cm^{-2}) demonstrated increased medial nerve conduction latency [58], which was associated with reduced skin temperature attributed to blood flow reduction [59]. Thus, the small conduction delay reported (0.2–0.4 ms) may not have been caused by a direct nerve effect. Interestingly, these changes were not observed when pulsed laser energy (9.12 and 73 Hz, 9.55 J cm^{-2}) at 820 nm was used; however, the authors acknowledged that parameters such as peak power, pulse frequency, and pulse duration could affect the response [60].

Laser acupuncture is considered sufficiently established by some to use sham laser treatment as a control for needle acupuncture [61]. In contrast, Baldry stated that the term "laser acupuncture" should not even be used until lasers are shown to affect A-δ nerve fibers, a purported mechanism of needle acupuncture [62, 63]. The results of studies to examine the effect of laser irradiation on such peripheral nerve fibers are contradictory. On the one hand, Jarvis et al. [64] found no effect of 632.8-nm laser irradiation on rabbit corneal nerves. In contrast, Sing and Yang [65] demonstrated that a gallium–aluminium–arsenide laser (780 nm) decreased somatosensory-evoked potentials activated by noxious stimulation in rabbit tooth pulp in a similar manner to that found after electro-acupuncture. Although both studies appear well designed, there are differences between them. The former employed continuous irradiation of nerves in excised tissue at 5 mW (beam diameter = 4 mm) for between 20 s and 15 min, while the latter used a pulsed 5-mW beam (9,720 Hz) to irradiate acupuncture points LI-4 and ST-36 (below the knee lateral to the tibia) for 120 s each. In summary, the issue of laser acupuncture–mediated pain relief remains unresolved.

Other applications

Laser acupuncture has had numerous positive applications from intractable hiccups [66] to enuresis [67], and weight loss [68]. However, as with pain relief, there are also many negative reports ranging from treatments for migraine [69] and bronchial asthma [70] to smoking cessation [71] and alcohol withdrawal [72]. Although these studies are often equivocal, they frequently illustrate important issues. For example, two studies reported no protection against exercise-induced asthma either in children [73] or in adult female patients [74]. Interestingly, only one acupuncture point out of the combined total of 11 selected in these studies was common to both protocols even though selection was based on points "usually used to treat asthma or respiratory problems." Thus, point selection adds yet another potentially confounding variable.

One needle acupuncture application for which there are many positive studies is the treatment of postoperative nausea and vomiting (PONV) [75]. It is therefore surprising that there has been only one laser PONV trial. Furthermore, the study was done in children, the one patient group for which other acupuncture methods have been ineffective [76]. A 670-nm laser (10 mW) was used to irradiate the acupuncture point P-6 (located above the midpoint of the transverse crease of the wrist) bilaterally for 30 s in 20 children 15 min before anesthesia induction and again 15 min after completion of strabismus surgery, which is associated with a high incidence of PONV [77]. A sham treatment group underwent the same protocol; however, the laser was not switched on. Laser acupuncture reduced the incidence of vomiting from 85% (sham group) to 25% ($P=0.0001$). The use of acupuncture for PONV has two features that make it of interest in terms of potential scientific insight. First, given the considerable evidence supporting needle acupuncture's success as an antiemetic (reviewed by Mayer [78]), comparative studies could be designed to address wavelength and dosage issues for laser acupuncture. Secondly, because treatment involves irradiation of a single point, the number of variables is reduced.

Placebo effects

In the absence of an accepted mechanism of action, some people attribute positive results in any acupuncture study to a placebo effect. Although placebo effects in general [79] and also the potential influence on efficacy of patients' attitudes toward alternative and complementary medicine [80] are becoming topics of scientific investigation, an in-depth discussion of these issues is beyond the scope of this review. Nevertheless, there are a couple of studies that indicate the potential placebo effect of laser acupuncture. For example, Wilder-Smith [81] treated a single (unidentified) acupuncture point in patients who experienced nausea during dental procedures. Treatment efficacy was assessed by documenting changes in the patient's response to a subsequent procedure and by measurement of how deeply a dental mirror could be inserted on the palate. All 20 subjects received laser acupuncture; however, half were told that the treatment would lessen nausea, while the rest did not know the laser's purpose. In the knowledgeable group, six were able to undergo procedures that had, before treatment, induced nausea and there was an average 1-cm increase in the tolerated depth of mirror insertion. In contrast, none of the patients unaware of the laser acupuncture's intent had increased tolerance. In the study combining laser acupuncture with TENS for carpal tunnel syndrome pain, there was a placebo effect (defined as $>50\%$ pain reduction after sham treatment) in 27% of the patients [57].

Thus, it is possible that the allure of acupuncture's "Eastern mysticism" combined with the appeal of "space-age technology" lasers produces a "super-placebo." It is therefore necessary, especially in pain treatments [82], to have appropriate control groups. In needle acupuncture, some studies use needle insertion at locations distant from acupuncture points as a control; however, this approach could also result in an effect, and so is not without critics. A placebo needle that, although blunt, produces a sensation simulating skin puncture and appears to penetrate the skin by retreating into the handle has been developed [83]. In contrast, laser acupuncture placebo treatment is straightforward; the laser can simply not be switched on (most convenient for nonvisible infrared wavelengths) or, for visible wavelengths, the light can be shielded.

Laser dose

The unlikelihood of injury and acupuncture's traditionally empirical nature appear to have allowed laser application to by-pass the animal and clinical testing usually needed to establish dosage parameters. In addition, dose determination cannot be rigorously evaluated when the mechanism of action is unknown. Thus, most studies have used only a single dose, the selection of which often appears arbitrary and is seldom discussed. The first Soviet studies used helium-neon lasers with output powers (12–25 mW) considerably higher than those typically used in current practice (<10 mW). Little energy will reach deeper than 1 cm when low power (1–5 mW) lasers in the 600-800 nm range are used (Fig. 1), a fact sometimes cited to dismiss the effect of low-intensity laser therapy [84]. However, what has apparently been unappreciated in laser acupuncture is that backscattering within skin and internal reflection of light at the skin-air interface allows the fluence near the surface to exceed the incident radiant exposure significantly [30, 85], albeit only in the epidermal and upper dermal layers. Thus, shallow acupuncture points may receive a larger than expected laser "dose" even when low-power lasers are used.

An additional point made to counter arguments that low-intensity irradiation is insufficient to stimulate anything is the ability of even single photons to initiate light perception in the retina [86]. Although it seems unlikely that the general tissue response to laser acupuncture would be as sensitive as a tissue whose prime function is photon detection, without dose-response studies the possibility cannot be discounted. Another unappreciated fact in laser acupuncture is that beam diameter and profile affect energy delivery [87, 88]. For example, calculations made using Monte Carlo methods for light propagation in arterial tissue revealed that a flat profile 4-mm diameter incident beam resulted in a higher subsurface fluence rate and greater penetration than a 1-mm beam of equal irradiance [87]. The same phenomena occur in skin because of scattering-induced lateral diffusion [88]. Thus, beam profile can significantly influence the delivered laser "dose."

Acupuncture points are considered to be located at certain specific depths, and hence the necessary depth of needle insertion for each point is specified in acupuncture texts [2]. Nevertheless, few laser studies have altered laser treatment parameters to take point depth into account. Naeser et al. [89] treated shallow hand and facial points for 20 s (20 mW, 780 nm) versus 40 s for deeper points located on the arms and legs; however, increased exposure does not increase transmission. A more recent study from that group applied 632.8-nm treatment to shallow points and 904-nm to deeper ones [57], which is a more reasonable approach (Fig. 1).

Finally, although I have used the term laser acupuncture throughout this article, there is no evidence that lasers might be the only effective electro-magnetic radiation source. Laser beam coherence is soon lost in skin and noncoherent light sources have been reported to be effective in low-intensity laser therapy [90]. Thus, photonic acupuncture has been suggested as a more appropriate term; however, I am unaware of published acupuncture studies using noncoherent light sources.

Study comparisons

Comparisons have already been made between some of the studies; however, there is also value in looking at an overall comparison between the 15 positive (Table 1) and the 15 negative (Table 2) laser acupuncture studies discussed in this review. Interestingly, although there is a widely held belief that, for any given topic, published positive studies will outnumber negative ones because negative studies are less likely to be written up and subsequently accepted for publication, the equal distribution illustrated in the tables indicates that this does not appear to be the case for laser acupuncture. Perhaps the most striking feature of both tables is how much information is missing with respect to the laser parameters employed. Unfortunately, the failure to include beam diameter is not uncommon in laser studies in other fields; however, the failure to report the wavelength and/or power in ~30% of the acupuncture studies obviously makes their evaluation difficult. Another striking feature is the considerable variation in treatment parameters, especially so when irradiation time and acupuncture point selection are included and thus inter-study comparison is further compromised. In addition, the potential influence of multiple studies conducted by the same groups of investigators for both positive and negative studies should be noted. Nevertheless, a couple of general comments can be made. The majority of the negative studies used appropriate sham laser treatment groups and/or appropriate subject and investigator blinding (11/15). In contrast, such design criteria were less frequently found in positive studies (5/15). Although this difference was not statistically significant ($P = 0.07$; Fisher's exact test), it may indicate a placebo-related bias toward positive outcomes. Conversely, the majority of the positive studies used wavelengths with greater skin transmission and a higher incident power than the negative studies. One additional factor that further complicates comparison is that there is no basis to assume that laser acupuncture would be effective in all of the listed procedures and diseases. In summary, the tables illustrate the confusion in the current laser acupuncture literature and highlight the need for more complete documentation of treatment parameters in future laser acupuncture studies.

Lasers versus needles

There are practical differences between laser and needle acupuncture. One laser disadvantage is that treatment protocols often involve multiple point stimulation. This requirement is easily met with needles; however, piecemeal treatment is obviously required with a single laser and optic fiber. The relative safety of the two methods is also a potential issue. Although needle acupuncture's incidence of adverse events is small [97], especially given the large number of treatments, complications such as hepatitis transmission and pneumothorax have occurred

Table 1 Positive laser acupuncture studies (arranged in order of increasing wavelength); – information not provided, *cw* continuous wave laser irradiation, *X* multiple treatments

Reference no.	Subject	Laser parameters					Acupuncture points, number	Blinded treatment	Sham group
		Wavelength (nm)	Power (mW)	Frequency (Hz)	Beam diameter (mm)	Treatment time (s)			
[54]	Pain	632.8	2	100	1–2	30	5–6 included ear points	Yes	No
[19]	Smoking cessation	632.8	3	cw	0.015	10 X	4 ear points via needle insertion	No	No
[21]	Dental analgesia	632.8	2.8–6.0	cw	1.5–2.0	300	2–4	No	No
[57]	Carpal tunnel syndrome	632.8904	15Variable	cw73–3,500	25	67–462 X60 X	> 11	Yes	Yes
[66]	Hiccups	670	10	cw[a]	–	60 X	4 Korean hand points	No	No
[77]	PONV	670	10	cw[a]	–	30	1	Yes	Yes
[67]	Enuresis	670	10	cw	–	30 X	7	No	No
[65]	Pain—rabbits	780	5	9,720	–	120	2	No	No
[89]	Stroke-related paralysis	780	20	cw	–	20–40 X	14–19	No	No
[91]	Dry eye	780	4	–	–	20 X	> 9	Yes	Yes
[48]	Pain—horses	904	0.3	360	–	120 X	~3–5	–	No
[28]	Pain	904	5	1,000	–	20 X	5 + ahshi points	Yes	Yes
[56]	Dental analgesia	10,600	20–30	cw	–	300	2–4	No	No
[92]	Pain—rabbits	10,600	–	cw	–	2–3	1	–	–
[68]	Weight loss	–	24	900	–	10–15 X	8 included ear points	No	No

[a]Not stated, but deduced from information provided in the paper

Table 2 Negative laser acupuncture studies; *cw* continuous wave laser irradiation, *X* multiple treatments

Reference no.	Subject	Laser parameters					Acupuncture points, number	Blinded treatment	Sham group
		Wavelength (nm)	Power (mw)	Frequency (Hz)	Beam diameter (mm)	Treatment time (s)			
[70]	Asthma	632.8	5.6	cw	1.13[a]	10–20	> 8 included ear points	Yes	Yes
[93]	Whiplash pain	632.8	5	cw	–	15	11 included ear points	No	No
[94]	Analgesia	632.8	10	Pulsed	–	60	4	Yes	Yes
[71]	Smoking cessation	632.8	2.5–3.0	cw	1	60	4 ear points	Yes	Yes
[81][b]	Nausea in dental surgery	632.8	6	cw	–	180	1	–	No
[95]	Sinusitis	632.8[a]	2	–	–	–	5	No	No
[96]	Gastric secretion	632.8[a]	2[a]	20	–	1,800	3	No	Yes
[51]	Pain	632.8[a]	–	–	–	15 X	12	Yes	Yes
[47]	Pain—rats	632.8904	1.560.07	cw73	–	60	2	–	–
[53]	Pain	632.8904	1.560.07	cw73	–	60 X	10	Yes	Yes
[73]	Asthma	830	22.5	cw	1	60 X	6	Yes	Yes
[72]	Alcohol withdrawal	830	–	–	–	60	2–10 ear points	Yes	Yes
[52]	Epicondylagia	904	12	70	–	30 X	5	Yes	Yes
[69]	Migrane	904	–	Pulsed	–	40 X	4	Yes	Yes
[74]	Asthma	–	1.5	–	–	20	5	Yes	Yes

[a]Not stated, but deduced from information provided in the paper
[b]Results from one component of a multifaceted study

[98, 99]. Such problems, coupled with many people's aversion for needles, make laser therapy attractive.

Efficacy is the crucial comparison issue; however, most comparative studies have employed shallow-penetrating red wavelengths and hence may not provide the optimal basis for comparison. The first report used the Akuplas 2 mW, 632.8 nm system and concluded, based primarily on subjective symptom improvement in nonrandomized treatment of numerous ailments, that needle acupuncture was superior [100]. Pothman and Yeh [95] also reported needle superiority for chronic sinusitis treatment (72% of patients improved vs 37% for both laser and antibiotic therapy). However, the study was not blinded, the symptomatic improvement endpoint was not clearly defined, no sham-treatment groups were included, and the duration and number of laser exposures was not described [95]. Furthermore, the wavelength was not stated and the power was low (2 mW). Two higher power, 632.8-nm treatments did not provide as much pain relief (5 mW) as needles after whiplash injury [93] or failed (10 mW), in contrast to needle acupuncture, to increase pain threshold in volunteers subjected to heat stimuli [94].

In an infrared laser study of conjunctivitis sicca (dry eye), patients were randomized to control (artificial tears), needle, laser (4 mW, 780 nm), or sham-laser (nonfunctioning laser) acupuncture [91]. At least nine points associated with eye and head pain were treated weekly for 20 s each with the laser and sham laser and for 30 min with needles for 10 weeks. Both acupuncture groups showed similar improvement in objective tests versus sham and control groups. It may be important that the acupuncture points selected for this study are treated with shallow, transverse needle insertion and so could be accessible to low-intensity laser irradiation.

Some comparative studies of needle versus laser have assessed physiologic effects. Litscher et al. [101] found that although needle acupuncture of vision-related points in healthy volunteers increased blood flow velocity in the posterior cerebral artery, laser irradiation of the same points (19 mW, 685 nm) had no effect on flow. However, both methods increased the amplitude of 40-Hz oscillations in the brain, which have been reported to be generated during cognitive tasks. In another study, several vision-related points were subjected to needle insertion or laser irradiation (30–40 mW, 685 nm delivered simultaneously to each point using multiple laser diodes coupled into 500-µm-diameter fibers) for an average of 10 min [102]. Needle acupuncture again increased flow, as did laser acupuncture, although to a lesser extent. The delay between activation and the peak in velocity were similar in both groups. Therefore, the authors concluded that the signal activation and transmission mechanisms were the same for both treatments. Although the latter conclusion appears speculative, data from these studies are consistent with needles being more effective. Another Akuplas laser study failed to inhibit gastric acid secretion stimulated by sham feeding—chewing but no swallowing [96]. Although needle acupuncture also had no effect, electro-acupuncture and TENS did inhibit secretion, which was attributed to increased stimulation intensity by the latter methods. Nevertheless, as with other aspects of laser acupuncture, definitive data required to address laser-needle comparisons are lacking.

Mechanism of action

An implicit assumption in positive laser acupuncture studies is that benefits derive via the same mechanism as needle acupuncture. Nevertheless, physical differences between the methods suggest that common mechanisms are unlikely. Langevin et al. [103–105] proposed that mechanical activation of signal transduction pathways initiated by needle-mediated collagen fiber reorganization is important. Low-intensity laser irradiation cannot produce such mechanical effects; however, cross-talk between transduction pathways could allow photon-mediated effects at a different point on the same pathway. For example, calcium, important in many signal transduction pathways including those governing visual photoreceptors [106], can be affected by irradiation. For instance, in vitro mitochondrial calcium transport increased with 632.8-nm irradiation at low radiant exposure (0.1–0.2 J) and decreased at higher radiant exposure (0.6–7.2 J) [107]. Moreover, mitochondrial cytochromes, which absorb in the red and near-infrared [108, 109], have been implicated in low-intensity laser therapy's beneficial effects [110].

Circumstantial evidence supporting opioid-mediated mechanisms for acupuncture pain relief comes from increased cerebrospinal fluid opiate levels after electro-acupuncture [111, 112] and blockade of needle acupuncture–mediated effects by the opiate antagonist naloxone in some, but not all, studies [113, 114]. Inhibition of laser acupuncture by naloxone has also had mixed results. Pretreatment with both low and high doses of naloxone (2 and 20 mg kg^{-1}) failed to block the increased latency produced by laser irradiation (4 Hz, 0.95 mW, 632.8 nm) of acupuncture point GV-1 in rat tail-flick experiments [115]. The low dose was considered sufficient to antagonize the analgesic effect of endogenous opioids, while the high dose was thought to also antagonize the analgesic effect of nonopioids. In contrast, the high dose did partially inhibit laser-induced increases in time to nociceptive response for rats placed on a 55°C hotplate and led the investigators to conclude that mechanisms other than endogenous opioid release were involved and, because only the hotplate response was blocked by the high naloxone dose, that the mechanism was supraspinal in origin [115]. In contrast, 0.8 mg kg^{-1} intravenous naloxone partially blocked the analgesic effect of laser acupuncture (applied to point GV-26 in rabbits—one third the distance from the bottom of the nose to the top of the lip) in experiments using potassium iontophoresis challenge with the electrode placed on an ear [92]. Furthermore, partial blockade was also achieved using *p*-chloroamphetamine, a 5-hydroxotryptamine depletive agent, implicating serotonin as a mediator. However, this study used the shallow-penetrating carbon dioxide laser. As mentioned, naloxone is not specific to opioid antagonism, and it should be noted that it can also antagonize the antinociceptive effects of nonopiates such as acetylcholine and substance P and can affect calcium [116]. Thus, despite some interesting findings, the mechanism of action is unresolved.

Conclusions

Thirty years of investigation have produced a steady stream of laser acupuncture studies; however, objective evaluation of the results obtained is difficult, if not impossible, because of many confounding factors. The scope of these problems extend from the wide range of unrelated medical problems examined (often in poorly designed trials) and the frequently inadequate documentation of the treatment variables employed, to the possibility that many studies have used lasers with insufficient power to reach the targeted acupuncture points. Such major deficiencies indicate that it is possible to make a good argument for the statement that laser acupuncture has yet to be adequately evaluated. Therefore, it appears reasonable to conclude that skepticism regarding the efficacy of laser acupuncture remains warranted. Nevertheless, laser use has found a niche in clinical acupuncture practice, which will likely grow alongside the increased acceptance of complementary and alternative medicine [117]. Will future use be based on empiricism or scientific theory? Although each method can exist without the other, the best approach may be to reconcile the two. Hence, we should recognise that laser acupuncture is more complicated than simply pointing a laser beam at an acupuncture point. This caveat applies not only to the acupuncturist who must appreciate the significance and role of wavelength and beam profile, but also to the laser scientist who should appreciate that traditionally successful acupuncture treatments combine judicious point selection with consideration of concepts not readily quantified in terms of Western scientific thought processes. Even though we should retain a large degree of skepticism, there is perhaps sufficient circumstantial evidence to suggest that the cliché "further investigation is necessary" may, for once, be valid. Specifically, the association between laser acupuncture and visual cortex activation coupled with the established fact that laser-tissue interactions do occur at subthermal thresholds to produce cellular effects could provide a rational basis for such investigation. It is therefore possible that integration of modern technology and science with Stone Age empiricism may yet provide the basis for cogent therapeutic strategy.

Acknowledgements A review of such diverse literature, sometimes in non-English-language publications, would not have been possible without assistance. Therefore, I would like to thank the following for their help in locating or translating references: Dr Petra Camborova, Dr Jochen Müller-Ehmsen, Dr Karin Przyklenk, and Dr Katarina Skalova. In addition, I would like to thank the authors who responded to e-mail requests for information and reprints, the reviewers for their thorough and thoughtful critique, and Michelle Maynard for her assistance with Fig. 2. This work was done during P.W.'s tenure as an Established Investigator of the

American Heart Association. Supported in part by a grant from the Worcester Foundation for Biomedical Research.

Appendix

Acupuncture points specified in the text are abbreviated according to the following channel classification: BL = bladder, GV = governing, LI = large intestine, P = pericardium, SI = small intestine, and ST = stomach.

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