MECHANICAL STIMULATION IMPROVES SURVIVAL IN RANDOM-PATTERN SKIN FLAPS IN RATS

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Abstract—This was a study on the effects of 3-MHz ultrasound at 16- and 100-Hz pulse repetition frequencies on angiogenesis and viability of random-pattern skin flaps in rats. A cranially-based dorsal skin flap was raised in 60 EPM-Wistar rats, which were randomly divided into four groups: control, sham, 16-Hz and 100-Hz groups. The mean percentage of necrosis was as follows: control, 42% ± 13%; sham, 18% ± 13%; 16-Hz group, 13% ± 10%; and 100-Hz group, 15% ± 7%, with significant differences between the control and the other groups (p < 0.001). The mean vascular density was as follows: control, 5% ± 2%; sham, 7% ± 2%; 16-Hz group, 21% ± 4%; and 100-Hz group, 24% ± 10%, with significant differences between control and ultrasound groups, and between the sham and ultrasound groups (p < 0.001). Both ultrasound treatments (16- and 100-Hz PRFs) induced angiogenesis, and sham and ultrasound treatments improved viability of random-pattern skin flaps in rats. (E-mails: pascale.tacani@hotmail.com; sandra.dcir@epm.br)

Key Words: Microcirculation, Necrosis, Physiologic neovascularization, Rats, Surgical flaps, Ultrasonic therapy, Ischemia, Skin, Plastic surgery, Physical therapy modalities.

INTRODUCTION

Skin flaps are of fundamental importance in plastic surgery, especially in reconstructive procedures, and are used as a primary resource for the repair of skin loss resulting from congenital defects, trauma or tumor resection (Duarte et al. 1998; Leite et al. 2007). However, flap necrosis is a complication difficult to overcome and may lead to the failure of the surgical procedure, prolonging the time for patients to resume normal activities. Ischemia, the major intrinsic cause of necrosis, results from an insufficient arterial flow due to the sectioning of cutaneous vessels and sympathetic nerves during flap elevation (Kerrigan 1983) and impaired venous return (Hjortdal et al. 1994; Ugland 1966). To improve blood flow in surgical flaps, experimental studies have been conducted using pharmacologic (Bezuhly et al. 2009; Duarte et al. 1998; Leite et al. 2007; Tsai et al. 2008) and physical agents, such as low-level laser therapy (Pinfildi et al. 2005, 2009; Prado et al. 2009), transcutaneous electrical nerve stimulation (TENS) (Atalay and Yilmaz 2009; Liebano et al. 2006, 2008; Russo et al. 2006), iontophoresis (Esteves Junior et al. 2004, 2009), electroacupuncture (Niina et al. 1997), shock-wave therapy (Kuo et al. 2007) and therapeutic ultrasound (Emsen 2007).

Therapeutic ultrasound is widely used in rehabilitation programs (Ebenbichler 2009) and preoperative aesthetic procedures (Roustaei et al. 2009) because of the availability of the system, ease of operation, low cost (Doan et al. 1999) and its effects on tissue repair (Dyson 1987). Depending on the parameters used, therapeutic ultrasound activates calcium influx in mast cells, neutrophils and macrophages, promotes reduction of the inflammatory phase and increases the fibroblast and endothelial cell activity, stimulating the proliferative phase of the healing process (Dyson 1987; Young and Dyson 1990a, 1990b) and angiogenesis (Doan et al. 1999; Young and Dyson 1990c). Although it has been...
demonstrated that ultrasound (US) can improve survival of skin flaps (Emsen 2007), it is important to understand the influence of the different US parameters on the mechanism of action and biologic effects of this physical agent. Several US systems, as well as other physical agents, allow the selection of pulse repetition frequencies (PRFs), which may affect the permeability of the cell membrane to various ions, including calcium (Dinno et al. 1989; Mortimer and Dyson 1988; Young et al. 1990). Calcium ions act as intracellular messengers, regulating gene expression and cell metabolism; their distribution can vary in response to modifications of the plasma membrane caused by the ultrasound (Doan et al. 1990). In an attempt to establish a window of frequencies that stimulates cellular calcium flux, in vitro studies were conducted comparing the effect of different PRFs. Blackman et al. (1979) studying 147-MHz radio-frequency carrier waves modulated at selected frequencies between 3 and 30 Hz, and Young et al. (1990) working with low-power laser irradiation at 16, 36, and 48-Hz PRFs, reported that 16 Hz was the most effective PRF in stimulating calcium flux. Other researchers obtained similar results using 1-MHz therapeutic ultrasound at 100-Hz PRF (Dinno et al. 1989; Mortimer and Dyson 1988). The fact that cellular effects are frequency-dependent over a range of frequencies may explain the high variability in treatment results, so that only treatments whose parameters are within the therapeutic window are successful (Watson 2002; Young et al. 1990). The concept of different ranges of frequencies that stimulate calcium flux, resulting in different therapeutic effects (such as acceleration of tissue repair) had distinct implications for the design of subsequent in vitro (Bauërús Koch et al. 2003; Blackman et al. 1982, 1985a, 1985b, 1988, 1991) and in vivo (Demir et al. 2004) experimental studies. Although there are studies comparing the therapeutic effects of electromagnetic waves modulated with different pulse frequencies (Bauërús Koch et al. 2003; Blackman et al. 1979, 1985a; Young et al. 1990), there is a lack of studies on the effects of therapeutic ultrasound at different PRFs (Leite et al. 2003). Considering that there is a therapeutic window (Watson 2002), PRF may be regarded as an important treatment parameter in therapeutic ultrasound, especially in the acceleration and modulation of tissue repair. Therefore, the aim of the present study was to assess the effect of therapeutic ultrasound at 16- and 100-Hz PRFs on angiogenesis and viability of random-pattern skin flaps in rats.

**MATERIALS AND METHODS**

All animal experiments were approved by the Animal Care and Use Committee at the Federal University of Sao Paulo, Brazil. All animals received humane care in strict compliance with the Guide for the Care and Use of Laboratory Animals (National Research Council 1996). The sample consisted of 60 adult (8-week-old) male Wistar rats, weighing 270 to 310 g. The animals were housed in individual cages, at a room temperature of 22°C, on a 12:12 hour light-dark cycle and fed standard rat chow and water ad libitum.

**Surgical procedure**

All animals were anesthetized with an intramuscular injection (right gastrocnemius muscle) of ketamine (100 mg/kg) and xylazine (50 mg/kg) and the dorsal hair (area, 12 × 6 cm) was manually removed. Following, the flap was marked on the skin using a 10 × 4 cm standardized template and a felt-tip pen (Pilot, Sao Paulo, Brazil). The skin was incised along the perimeter of the flap and detached to its full extension with a scalpel (no. 15 blade). The flap consisting of superficial fascia, panniculus carnosus and skin (Fig. 1) was raised from the deep muscular fascia to the inferior angles of the scapula and upper bones of the pelvic ring (McFarlane et al. 1965). A 10 × 4 cm plastic barrier (film F1, polyester/polyethylene) was placed between the flap and its bed (Ugland 1966). The flap was sutured to its original position with simple 4-0 monofilament nylon stitches placed 1 cm apart.

A plastic cervical collar 6 cm in external diameter, 3 cm in internal diameter and 3 cm long was placed in all animals to prevent autophagy. Fixation was performed with five simple 0-0 nylon monofilament stitches of which two stitches were placed in the posterior cervical region and three stitches were placed in the ventral cervical region. After the surgical procedure, the animals were housed individually and provided with standard rat chow and water ad libitum.

**Ultrasound equipment**

The 3-MHz ultrasound (model Sonacel Expert; Bioset Indústria de Tecnologia Eletrônica Ltda, Rio Claro,

![Fig. 1. Surgical technique. Cranially based random-pattern skin flap (10 × 4 cm).](image-url)
SP, Brazil) used in this study was previously calibrated with an ultrasonic power meter (model UPM-DT10; Bioset Indústria de Tecnologia Eletrônica Ltda) and was re-calibrated after 4 weeks, at the end of the study, to assure the accuracy and reproducibility of parameters. The ultrasound transducer had an effective radiation area (ERA) of 0.5 cm² and beam nonuniformity ratio (BNR) of 6:1.

Ultrasound treatment

After the surgical procedure, the rats were randomly divided into four groups of 15 animals each as follows: (1) control group – received no ultrasound treatment; (2) sham group – received sham ultrasound treatment (ultrasound off); (3) 16-Hz group – treated with 3-MHz ultrasound, pulsed mode, 20% duty cycle, at a spatial average temporal average (SATA) intensity of 0.2 W/cm², spatial peak temporal average (SPTA) intensity of 1.2 W/cm², peak compression pressure of 0.17 MPa, peak rarefaction pressure of 0.17 MPa and PRF of 16 Hz; and (4) 100-Hz group – treated with 3-MHz ultrasound, pulsed mode, 20% duty cycle, at a SATA intensity of 0.2 W/cm², SPTA intensity of 1.2 W/cm², peak compression pressure of 0.17 MPa, peak rarefaction pressure of 0.17 MPa and PRF of 100 Hz. Ultrasound treatment was administered 60 s after surgery and on postoperative days 1 and 2, in a total of three applications of 24 min each at the cranial base of the flap. An area of 12 cm² (4 cm wide and 3 cm long) at the cranial base of the flap was selected as the site of application to improve blood flow to the distal portion of the flap through vessels that were not sectioned during flap creation. This is in agreement with other studies using physical agents, which have reported that stimulation at the cranial base led to a significant reduction in flap necrosis compared with stimulation at different portions of the flap or along its entire length (Kjartansson et al. 1988a, 1988b; Liebano et al. 2006, 2008; Prado et al. 2009). This area was longitudinally divided in half, resulting in two areas (left and right) of 6 cm² (2 × 3 cm) each. The exposure time, corresponding to 1 min of treatment per square centimeter, was calculated by: Time (T) = Area (6 cm²) / ERA (0.5 cm²) = 12 min. The application site was cleaned with 0.9% saline solution, marked with a felt-tip pen, and 2 mL of coupling gel (carboxyvinyl polymer, Carbogel, Sao Paulo, Brazil) was applied to the skin. Ultrasound was always delivered first to the right area for 12 min, after which the equipment was automatically turned off, and then to the left area for the same period of 12 min, resulting in a total exposure time of 24 min per site (Fig. 2). The transducer head was moved slowly (2 cm/s, approximately) with uniform, continuous, circular movements in the counter-clockwise direction, sliding smoothly on the application site under a pressure (244 g/cm², approximately) just sufficient to maintain a perfect coupling between the transducer head, gel and skin of the animal (Fig. 3).

Analysis of the area of necrosis

The percentage of skin flap necrosis was estimated on postoperative day 7, by two observers blinded to the treatment group, using the paper template method (Sasaki and Pang 1980). The animals were anesthetized and the boundary between viable tissue (characterized by soft, pink, warm and hair-bearing skin) and necrotic tissue (characterized by hard, dry, dark and hairless skin) areas was marked on the animals and traced on transparent paper. An individual template was made for each animal. The tracing was cut out and weighed to the nearest 0.001 g on an electronic balance (model AY220; Shimadzu, Sao Paulo, SP, Brazil). The percentage of necrotic skin was estimated using the formula (Sasaki and Pang 1980):

\[
\text{percentage (\%)} \text{ of flap necrosis} = \frac{\text{weight of paper area equivalent to the area of necrotic tissue}}{\text{total weight of the flap template}} \times 100\%
\]

Analysis of vascular density

Following the macroscopic analysis, the flap was removed and the animals were euthanized by anesthesia overdose. Transverse lines were marked every 5 mm on the skin flap. Four skin samples, corresponding to the 1st (0–5 mm), 5th (20–25 mm), 10th (45–50 mm) and...
15th (70–75 mm) segments, counting from the cranial base, were selected to be examined by light microscopy (Fig. 4). The selected samples were fixed in 10% formaldehyde, embedded in paraffin blocks and cut into 5-μm cross-sections. One section from each sample was stained with hematoxylin and eosin (H&E, Merck, Brazil, Cotia City - São Paulo, Brazil) for histologic analysis. Four photomicrographs were taken from each histologic section, in 16 images per animal, with a Sony digital camera coupled to a Zeiss light microscope (×400). A 100-point grid was placed on the micrographs and vascular density, expressed as percentage, was measured by counting the intersections between vessels and the points of the grid. The measurements were performed by the same observer who was blinded to the treatment group of the images.

Statistical analysis

Statistical analysis was carried out with the Statistical Package for the Social Sciences (SPSS) version 11.5 (SPSS Inc., Sao Paulo, Brazil), and preliminary tests to determine the normal distribution and sample size were performed with Minitab 14 Statistical software (Globaltech, Minas Gerais, Brazil). The Wilcoxon signed-rank test was used to assess interobserver agreement on the determination of the necrotic area. The Kruskal-Wallis test and post hoc Dunn’s test were used for comparisons between groups and to evaluate the differences in necrotic areas and vascular density. All tests were performed at a significance level of 5% (p < 0.05). The results are expressed as mean ± standard deviation (SD).

RESULTS

The mean percentage necrosis obtained by both observers (OB1 and OB2) and the results from the Wilcoxon signed-rank test are shown in Table 1. Since there was a high interobserver agreement, only data from observer 2 were subjected to the Kruskal-Wallis test. The mean percentage of necrosis for the different groups was as follows: control group, 42% ± 13%; sham group, 18% ± 13%; 16-Hz group, 13% ± 10%; and 100-Hz group, 15% ± 7%, with significant differences between the control and the other three groups (p < 0.001), as shown in Figure 5. The mean vascular density was as follows: control group, 5% ± 5%; sham group, 6% ± 5%; 16-Hz group, 22% ± 10%; and 100-Hz group, 25% ± 13%, with significant differences between the control and treatment groups (p < 0.001) and between the sham and treatment groups (p < 0.001), as shown in Figure 6. Figure 7 shows histologic images depicting the vascular density in the groups.

DISCUSSION

In the present study, random-pattern skin flaps treated with 3-MHz ultrasound at PRFs of 16 Hz and 100 Hz were evaluated. Both ultrasound treatments (16- and 100-Hz PRF) resulted in significantly higher vascular density compared with those found in the control and sham groups. However, it is very interesting to note that there were no significant differences in percentage necrosis between the sham and treatment groups. This may indicate that the mechanical stimulation caused by the movement of the transducer head on the skin increased the viability of random-pattern skin flaps in rats. These results are in agreement with the findings of Robinson and Buono (1995) who investigated the effect of a 5-min ultrasound treatment session on blood flow in the skin and muscle of the forearm of healthy individuals. These authors observed a significant increase in blood flow in both the treatment and sham groups, with no significant differences between them. Fabrizzio et al. (1996) investigated the effect of a 15-min ultrasound treatment session on blood flow velocity in the human popliteal artery in a control, sham and intervention groups. These authors found significant differences in
blood flow velocity between the control and intervention groups and between the control and sham groups. The two aforementioned studies suggested that the increase in blood flow observed in the sham group could be attributed to a massage-mediated thermal effect caused by the movement of the transducer head (Fabrizio et al. 1996; Robinson and Buono 1995). More recently, Noble et al. (2007) conducted a study on the effects of a 6-min treatment, using 3-MHz ultrasound in both the continuous and pulsed modes (50% duty cycle), on the blood flow in human forearm skin in a control, sham and intervention groups. These authors reported a significant increase in blood flow in the sham and intervention groups compared with the control group but they found no significant differences in blood flow rates between the sham and intervention groups. They suggested that the increase in blood flow in the sham group could be attributed to a massage effect produced by the movements of the transducer head.

In this study, the transducer head was moved slowly and gently on the skin surface with no additional pressure other than that exerted by the weight of the transducer (244 g/cm², approximately) during both the ultrasound treatment and sham stimulation. Probably, the mechanical stimulation of the skin by the transducer head increased blood flow, as suggested by Fabrizio et al. (1996) and Noble et al. (2007). According to Fabrizio et al. (1996), this massage effect may trigger autonomic stimuli, resulting in an increase in skin temperature; Noble et al. (2007) argued that vasodilation may occur as a consequence of the release of chemical mediators, such as histamine, as well as an increase in skin temperature, improving flap viability both in the sham and treatment groups. In a study conducted by Morhenn (2000), the cheek of eight volunteers was firmly stroked, resulting in a significant increase in skin temperature and erythema formation. However, the increase in temperature and erythema formation did not occur due to histamine release, since the volunteers received oral antihistamines before the experiment. According to the author, increases in temperature and erythema formation were related to the stimulation of nociceptors that release substance P, which stimulates the production of nitric oxide in the dermal microcirculation. Both the substance P and nitric oxide are vasodilators. However, it is important to note that in our study, the ultrasound transducer head was placed gently against the skin and almost no

Table 1. Mean percentage necrosis obtained by both observers (OB1 and OB2) according to the different groups and results from the Wilcoxon signed-ranks test

<table>
<thead>
<tr>
<th>Groups</th>
<th>Control</th>
<th>Sham</th>
<th>16-Hz</th>
<th>100-Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>OB 1</td>
<td>41.69 ± 13.4</td>
<td>42.18 ± 13.5</td>
<td>18.44 ± 12.8</td>
<td>18.58 ± 13.1</td>
</tr>
</tbody>
</table>

Wilcoxon test: p = 0.851 (Control vs. Sham), p = 0.700 (Sham vs. 16-Hz), p = 0.600 (Sham vs. 100-Hz), p = 0.826 (16-Hz vs. 100-Hz).

SD = standard deviation.
pressure was applied to it; the motion of the transducer could be compared with a gentle and superficial stroking rather than a firm stroking. With regard to nociceptive stimuli, the activation of low-threshold mechanoreceptors connected to afferent Aβ fibers by mechanical stimulation may induce an increase in blood flow in alldynic areas, such as skin flaps, but not in normal pain-free skin (Cervero and Laird 1996; Garcia-Nicas et al. 2001). The increase in blood flow occurs because there is a release of vasoactive neuropeptides, such as calcitonin gene-related peptide (CGRP) and substance P, in the area under stimulation and corresponding dermatome (Garcia-Nicas et al. 2001).

The reduction in flap necrosis might be related to the mechanical stimulation if the movements of the transducer head on the skin were able to facilitate the release of vasoactive neuropeptides (Esteves Junior et al. 2004; Gherardini et al. 1998, 1999; Jansen et al. 1999). Other authors have suggested that this same mechanism may be responsible for a reduction in necrosis in ischemic flaps treated with TENS (Kjartansson et al. 1988a, 1988b; Liebano et al. 2006, 2008; Russo et al. 2006).

The mechanical stimulation with the transducer head may be compared with the light and smooth motions of classical massage (effleurage), which promote an increase in blood and lymph flow in the skin (De Domenico and Wood 1997; Goats 1994; Watson et al. 1999) due to the stimulation of cutaneous receptors and may act by reflex mechanisms on the autonomic control of capillaries, facilitating edema resorption (Watson et al. 1999) and possibly reducing blood stasis and venous congestion, which were considered by Ugland (1966) and Hjortdal et al. (1994) as the main causes of necrosis in skin flaps. This may explain the improvement in the survival of skin flaps in the sham group.

Mechanical stimuli to the skin surface may trigger mechanochemical processes by the transmission of forces through the collagen fiber network, increasing cell-to-cell and cell-to-extracellular matrix interactions, as suggested by Silver et al. (2003). These authors noted that cell metabolism during the healing process may be affected by external forces, which favor the opening of ion channels, increasing metabolic rate, gene expression and protein synthesis. Moreover, the mechanical stimuli,
a form of mechanical energy, generate chemical potentials. Possibly, the mechanical stimulation by the transducer head might have triggered metabolic interactions (Silver et al. 2003); however, new studies showing the link between molecular biology and physical stimulation are necessary. On the other hand, Emsen (2007) investigated the viability of random-pattern skin flaps treated with ultrasound (frequency of either 0.75 MHz or 3.0 MHz) and reported a significant reduction in flap necrosis in the treatment groups compared with the sham group, which differs from our results. Although this author did not mention the ERA, the difference in results may be attributed to the longer exposure time used in our study (24 min per session vs. 5 min), which could have enhanced the massage effect of the transducer head. This is in agreement with the findings of Fabrizio et al. (1996) and Noble et al. (2007), who observed a significant increase in blood flow in the skin after treatment with both the ultrasound and sham stimulation for 6 and 15 min, respectively, with no significant differences between treatments.

Because postoperative ischemic and inflammatory conditions in random-pattern skin flaps begin within the first hours after flap elevation, treatments should be performed immediately after surgery and during the postischemic phase to increase and maintain blood flow (Kerrigan 1983; Sasaki and Pang 1980) and reduce venous congestion (Hjortdal et al. 1994; Ugland 1966) before the appearance of signs of necrosis, which can be detected 3 or 4 days after surgery (Duarte et al. 1998; Kami et al. 1985; McFarlane et al. 1965). Based on this information, US treatment was administered 60 s after flap suture and on postoperative days 1 and 2, which is in agreement with other studies that produced significant results, using different physical agents, such as TENS (Liebano et al. 2006, 2008; Russo et al. 2006), iontophoresis (Esteves Júnior et al. 2004, 2009) and low-power laser irradiation (Pinifildi et al. 2009). The protocol used in the present study differed from that used by Emsen (2007) in which ultrasound treatment was delivered daily for 15 days, during the late postoperative period when necrosis has already taken place; however, the possibility of a therapeutic effect after necrosis has occurred is questionable.

Vascular density was significantly higher in the treatment groups (16-Hz group, 22%; 100-Hz group, 25%) than in the control (5%) and sham (6%) groups, confirming an increase in angiogenic response induced by ultrasound exposure as observed by other investigators in experimental studies in vitro (Doan et al. 1999; Mizrahi et al. 2007; Mortimer and Dyson 1988), in a graft model in rabbits (Gonçalves et al. 2007), wound model (Young and Dyson 1990c) and limb ischemia in rats (Barzelai et al. 2006). To the best of our knowledge, this is the first study showing an increase in vascular density in ischemic skin flaps, resulting from the application of therapeutic ultrasound. A previous study in the literature only measured the viable areas of the skin flap (Emsen 2007). Other studies have shown that ultrasound induces angiogenesis by producing shear forces on endothelial cells, which increase calcium influx. In this way, nitric oxide synthase catalyze the formation of more nitric oxide, resulting in greater production of cytokines and angiogenic factors, such as vascular endothelial growth factor (VEGF) (Barzelai et al. 2006; Doan et al. 1999; Mizrahi et al. 2007; Young and Dyson 1990c).

Angiogenic stimuli, such as the release of growth factors and cytokines by macrophages [platelet-derived growth factor (PDGF), fibroblast growth factor (FGF), interleukin (IL-8)] and mast cells (FGF, IL-8), start early in the inflammatory phase but angiogenesis is established during the proliferative phase of tissue repair, also stimulated by other growth factors [VEGF, transforming growth factor (TGF-β)] and migration and proliferation of endothelial cells (Dyson 1987; Young and Dyson 1990a, 1990b, 1990c). The proliferative phase of tissue repair occurs in the late postoperative period, when necrosis is already well established (Kerrigan 1983; Sasaki and Pang 1980) and, therefore, the reestablishment of the microcirculation by the newly formed vessels is no longer possible. This may explain the significantly higher vascular density found in the treatment groups compared with the sham group and the lack of significant differences in flap necrosis between the sham and treatment groups. Although ultrasound treatment resulted in a significant increase in vascular density, this increase had no significant influence in the prevention of necrosis (no significant differences in necrosis were found between the sham and treatment groups).

In the present study, there were no significant differences either in the percentage of necrosis or vascular density between the 16-Hz and 100-Hz groups, indicating that both PRFs may have stimulated the calcium influx (Juffermans et al. 2008; Mortimer and Dyson 1988), which in turn may have stimulated angiogenesis (Mizrahi et al. 2007). This is not in agreement with previous studies showing that 16 Hz was the most effective PRF in stimulating calcium influx (Low and Reed 2000; Young et al. 1990). Few studies have reported on the effect of ultrasound at different PRFs. Juffermans et al. (2008) observed that 1-MHz ultrasound at 20-Hz PRF stimulated calcium influx in vitro in rat myocardial cells. Mizrahi et al. (2007) induced angiogenesis in vitro by applying 1-MHz ultrasound stimulation at 40-Hz PRF to aortic bovine endothelial cells. Mortimer and Dyson (1988) observed an increase in calcium influx in vitro in embryonic chick fibroblasts exposed to 1-MHz ultrasound stimulation at 100-Hz PRF; Dinno et al. (1989)
also reported increased calcium influx in cells of frog skin exposed to 1-MHz ultrasound stimulation at 100-Hz PRF. With regard to the comparison of different PRFs, only the present study and that of Leite et al. (2003) compared the results obtained using 16- and 100-Hz PRFs; we examined the effects of ultrasound on skin repair while Leite et al. (2003) studied the effects of ultrasound on bone repair. The latter authors observed that 1-MHz ultrasound stimulation at 100-Hz PRF was more effective than at 16-Hz PRF in accelerating post-fracture repair of rat tibia. However, our results revealed that there were no differences between PRFs regarding their effect on skin repair, suggesting that PRF had no influence on the biophysical effects of ultrasound on angiogenesis and survival of skin flaps.

The 3-MHz ultrasound treatment increased vascular density but the increased viability of skin flaps in rats could be attributed to a massage effect produced by the movements of the transducer head. Further studies are needed to demonstrate the effects of ultrasound and mechanical stimulation on vasodilatation and postischemic reperfusion and to better understand the effects of ultrasound and massage therapy on ischemic flaps.

REFERENCES


