Ultrasound Produced by a Conventional Therapeutic Ultrasound Unit Accelerates Fracture Repair

**Background and Purpose.** A recent novel application of ultrasound therapy is the treatment of bone fractures. The aim of this study was to investigate the effect on fracture repair of ultrasound produced by a conventional therapeutic ultrasound unit as used by physical therapists. **Subjects and Methods.** Bilateral midshaft femur fractures were created in 30 adult male Long-Evans rats. Ultrasound therapy was commenced on the first day after fracture and introduced 5 days a week for 20 minutes a day. Each animal was treated unilaterally with active ultrasound and contralaterally with inactive ultrasound. Active ultrasound involved a 2-millisecond burst of 1.0-MHz sine waves repeating at 100 Hz. The spatially averaged, temporally averaged intensity was set at 0.1 W/cm². Animals were killed at 25 and 40 days after fracture induction, and the fractures were assessed for bone mass and strength. **Results.** There were no differences between fractures treated with active ultrasound and fractures treated with inactive ultrasound at 25 days. However, at 40 days, active ultrasound-treated fractures had 16.9% greater bone mineral content at the fracture site than inactive ultrasound-treated fractures. This change resulted in a 25.8% increase in bone size, as opposed to an increase in bone density, and contributed to active ultrasound-treated fractures having 81.3% greater mechanical strength than inactive ultrasound-treated fractures. **Discussion and Conclusion.** These data indicate that ultrasound produced by a conventional therapeutic ultrasound unit as traditionally used by physical therapists may be used to facilitate fracture repair. However, careful interpretation of this controlled laboratory study is warranted until its findings are confirmed by clinical trials. [Warden SJ, Fuchs RK, Kessler CK, et al. Ultrasound produced by a conventional therapeutic ultrasound unit accelerates fracture repair. *Phys Ther.* 2006;86:1118–1127.]

**Key Words:** Animal, Bone, Fractures, Models, Musculoskeletal diseases, Orthopedic equipment, Orthopedic procedures, Physical therapy techniques, Skeleton, Sports medicine.

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Ultrasound is a form of acoustic energy (sound) that possesses a frequency above the limit detectable by the human ear. It has been used therapeutically for more than half a century and currently is one of the most widely and frequently used electrotherapeutic modalities applied by physical therapists. However, its full therapeutic potential is far from established, with new applications being added regularly to its repertoire. One recent novel application is in the treatment of bone fractures.

Fracture repair involves a complex cascade of cellular events incorporating appropriate cellular recruitment, timed genetic expression, and the sequenced synthesis of numerous compounds. Although it is considered to be a naturally optimized process, recent evidence has demonstrated that fracture repair can be influenced by ultrasound to occur more rapidly without compromising the final tissue-level outcome. The application of ultrasound in animal fracture models accelerated the return to mechanical strength of intact bone by 30% to 38%. Similarly, in well-designed clinical trials, ultrasound accelerated the rate of fracture repair in the tibia, radius, and scaphoid by 30% to 38%. By pooling of the clinical trial data, a weighted average effect size was calculated to be 6.41 (95% confidence interval [CI]=0.01–11.81); this value converts into a mean improvement in healing time of 64 days with ultrasound.

The results of studies of the effect of ultrasound on fractured bone are interesting from the perspective that physical therapists traditionally have been instructed to avoid the application of ultrasonic energy to bone. When ultrasound is applied to bone, there is an inherent risk of tissue damage. Ultrasound has selective interfacial effects at the bone surface resulting from bone having a high absorption coefficient, a high relative acoustic impedance, and an ability to propagate shear waves. When doses at the high end of the therapeutic range are used, these effects can generate considerable tissue damage attributable to heating and inertial cavitation effects. To achieve clinically significant improvements during fracture repair, without the risk for tissue damage, the ultrasound dose has been changed substantially from that traditionally introduced in physical therapist clinical practice. Clinically, ultrasound is introduced at an intensity commonly in the range of 0.5 to 2.0 W/cm². In comparison, in investigations into the therapeutic effect of ultrasound on bone, low-intensity pulsed ultrasound (LIPUS) has been used. Low-intensity pulsed ultrasound is pulsed-wave ultrasound with a spatially averaged, temporally averaged intensity of less than 0.1 W/cm². With LIPUS, heat generation at the soft tissue–bone interface has been shown both theoretically and experimentally to be insignificant (<1.0°C). Similarly, the risk for tissue-damaging inertial cavitation is negligible.

Although LIPUS has been found to be effective in the management of bone fractures, to date the clinical utility of this finding in physical therapy is limited. Specialized ultrasound units (Exogen 2000) have been developed for the treatment of fractured bone. Although these units are highly efficacious, their cost is prohibitive because the units are leased on a patient-to-patient basis rather than purchased by individual clinics. Despite the benefits observed with LIPUS, the high cost of the

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specialized ultrasound units has led some authors to question whether conventional therapeutic ultrasound units could be used by physical therapists to accelerate fracture repair. At the lower-intensity settings on these units, it is possible to produce a dose comparable to that shown to be effective during fracture repair with the specialized units.

The aim of this study was to investigate the effect of LIPUS produced by a conventional therapeutic ultrasound unit on fracture repair in an animal model. We hypothesized that LIPUS would facilitate fracture repair, as evidenced by more bone mineral at the fracture site and a stronger fracture callus at selected time points during healing.

**Method**

**Animals**
Thirty adult male Long-Evans rats (weight = 350–400 g) were purchased and acclimated for 1 week before experimentation. Animals had ad libitum access to standard rat chow and water at all times.

**Fracture Induction**
All animals underwent surgery upon entry into the study to create bilateral midshaft femur fractures. The fur was clipped and cleaned with alternating chlorhexidine and 70% ethanol scrubs. After a preoperative subcutaneous dose of buprenorphine hydrochloride analgesia and 70% ethanol scrubs. After a preoperative subcutaneous dose of buprenorphine hydrochloride analgesia was administered intraperitoneally. With a sterile technique, a 25-mm longitudinal incision was made over the lateral thigh, beginning just distal to the lateral knee joint and extending proximally. The intermuscular septum between the vastus lateralis and the hamstring muscles was divided by blunt dissection to localize the femur. The lateral structures stabilizing the patella were divided, and the patella was manually dislocated medially. The femur was fractured at its midshaft by means of a transverse osteotomy with a Dremel drill**. To stabilize the fracture, a 1.6-mm-diameter stainless steel K-wire** was inserted retrograde into the intramedullary canal, beginning in the knee joint and extending proximally. The pin was cut as close as possible to the knee articular cartilage and driven proximally so that the tip was flush with the cartilage. The patella was relocated and stabilized with an absorbable suture, and absorbable sutures were used to close the intermuscular septum and skin incision. The procedure was repeated on the contralateral side to create bilateral fractures.

**Ultrasound Intervention**
Ultrasound therapy commenced on the first day after fracture induction. This starting time point is consistent with previous studies and the belief that ultrasound influences early cellular processes immediately after bone injury. Each animal was treated unilaterally with active LIPUS and contralaterally with inactive LIPUS (placebo). For intervention, animals were anesthetized with inhalation of 3% isoflurane at 1.5 L/min in a plastic container and then with 1.5% isoflurane at 1.5 L/min via a face mask (for maintenance of anesthesia). Active LIPUS was produced with an Accusonic LIPUS GS 170 ultrasound unit, which produces a 2-millisecond burst of 1.0-MHz sine waves repeating at 100 Hz. The spatially averaged, temporally averaged intensity on this unit is set at 0.1 W/cm², which represents the average ultrasound output over the area of the ultrasound beam (spatial average) and the average of this intensity over a complete pulse cycle (ultrasound “on” and “off” periods; temporal average). The manufacturer reported that the transducer had an effective radiating area of 5 cm² and a beam nonuniformity ratio of less than 6.0. Ultrasound unit performance was confirmed at weekly intervals with a power meter (UPM-DT-1§§). Active LIPUS and inactive LIPUS were coupled with the skin by use of ultrasound gel (Aquasonic 100‰ and introduced 5 d/wk for 20 min/d by use of a stationary treatment head. The fur was clipped at weekly intervals to facilitate ultrasound propagation. The LIPUS parameters and treatment time were chosen on the basis of those shown to be beneficial during the healing of tissue injuries (reviewed by Warden13).

**Assessment Time Points**
All animals were evaluated intraoperatively and 1 week postoperatively to assess the rotatory stability of the fractures. Animals with a fracture that was rotationally unstable at postoperative week 1, indicating inadequate fracture site fixation, were excluded from the study. All other animals were killed at 25 and 40 days after fracture induction by inhalation of anesthetic gases followed by cervical dislocation. Animals in the 25- and 40-day groups received 16 and 27 LIPUS treatments, respectively. After death, the left and right femurs were har-

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1. Harlan Sprague-Dawley Inc, PO Box 29176, Indianapolis, IN 46229.
3. Fort Dodge Animal Health, 800 5th St NW, Fort Dodge, IA 50501.
4. Robert Bosch Tool Corp, 1800 W Central Rd, Mount Prospect, IL 60065.
5. Miltex Inc, 589 Davies Dr, York, PA 17402.
7. Abbott Laboratories, 100 Abbott Park Rd, Abbott Park, IL 60064.
8. Metron Medical Australia Pty Ltd, PO Box 2165, Carrum Downs, Victoria 3201, Australia.
9. Ohmic Instruments, 508 August St, Easton, MD 21601.
vested, wrapped in saline-soaked gauze, and stored at −20°C.

Radiography
Postmortem ex vivo radiographs were obtained with a specimen radiography system.4,4 The femurs were positioned for both anteroposterior and lateral radiographs on dental film (Kodak Ultraspeed Dental Film [size 4]). Samples were exposed to a voltage of 18 kV for 10 seconds. After film processing, the stage of fracture healing was quantified with a 4-point radiographic scoring system (0 = no evidence of healing; 1 = callus formation evident but fracture gap not yet bridged; 2 = callus formation evident with possible bridging of the fracture gap; and 3 = fracture union). The examiner was unaware of both femur side and time since fracture during grading.

Microcomputed Tomography
The stabilizing steel K-wires were carefully removed from the intramedulary canal before further assessment, as metal causes beam-hardening artifacts during quantitative radiographic imaging. Microcomputed tomography was performed on a randomly selected subgroup of fractures to visualize 3-dimensionally the stage of fracture healing at 25 and 40 days. Each femur was placed in a 13.3-mm-diameter plastic tube filled with saline and centered in the gantry of a desktop microcomputed tomography machine (μCT-20). A scout scan was performed to enable fracture site localization, and 230 slices were taken with an isotropic voxel size of 26 μm and an integration time of 150 milliseconds. A standard convolution-back projection procedure with a Shepp-Logan filter was used to reconstruct the computed tomography images in 1,024×1,024-pixel matrices.

Dual-Energy X-ray Absorptiometry
Dual-energy X-ray absorptiometry (DXA) was performed to assess fracture site bone mineral content (BMC, in milligrams). Femurs were positioned on their caudal surface on a mouse densitometer (PIXImus) with ultrahigh resolution (0.18×0.18 mm per pixel). Left and right femur pairs from each animal were scanned side by side on the same scan. Upon completion of each scan, a mutually exclusive region of interest (13×10 mm) was centered over each fracture site.

Peripheral Quantitative Computed Tomography
Peripheral quantitative computed tomography (pQCT) was used to assess fracture site volumetric bone mineral density (vBMD, in milligrams per cubic centimeter), BMC (in milligrams per millimeter), and bone area (B.Ar, in square millimeters). Each femur was placed in a plastic tube filled with saline and centered in the gantry of a pQCT machine (XCT Research SA). After a scout view was obtained to enable scan localization, 5 cross-sectional scans were obtained with a 70-μm voxel size. The middle scan was centered through the fracture line, and the other scans were positioned 1.5 mm and 3.0 mm above and below the center scan. During analyses, the bone edge was detected with contour mode 1 at a threshold of 400 mg/cm³ within the Stratec software. The data for the 5 slices per bone were averaged.

Destructive Mechanical Testing
The mechanical properties of the fracture site were assessed by testing the femurs in 4-point bending (Fig. 1A). Bones were slowly brought to room temperature overnight in a saline bath. Femurs were positioned cranial side up across the lower contacts of a custom-built 4-point bending rig on an Alliance RT/5 Materials Testing System. The lower contacts had a span width of 20.0 mm. The upper contacts were pivoted to ensure that both contacts simultaneously touched the cranial surface of the bone when the cross head was lowered. The upper contacts had a span width of 8.0 mm, centered between the lower contacts. The upper contacts were lowered to fix the bone in place with a 1.0 N static preload. The bone was subsequently broken in 4-point bending with a cross-head speed of 20.0 mm/min. During testing, force and displacement data were collected every 0.1 second (at a frequency of 10 Hz) with TestWorks 4 software (version 4.08A). Force-displacement curves were visually inspected, and ultimate force (in newtons), stiffness (in newtons per millimeter), and energy to ultimate force (in millijoules) were recorded (Fig. 1B).

Data Analysis
Statistical analyses were performed with the Statistical Package for Social Sciences software, with a level of significance set at .05 for all tests. The significance of radiographic scores was determined with the Wilcoxon signed rank test, whereas fracture site bone mass and mechanical properties were compared with paired t tests. Ultrasound intervention (active LIPUS versus inactive LIPUS) was the within-animal independent variable for all tests. In addition, effect sizes on fracture site bone mass and mechanical properties were determined with mean percent differences (%diff) and 95% CIs of the

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**Footnotes**

3 Faxitron X-ray Corp, 225 Larkin Dr, Unit 1, Wheeling, IL 60090.
4 Eastman Kodak Co, 345 State St, Rochester, NY 14650.
5 Scanco Medical AG, Auenring 6–8, 8303 Bassersdorf, Switzerland.
6 Lunar Corp, 315 W Beltlime Hgwy, Madison, WI 53714.
555 Stratec Medizintechnik GmbH, Durlacher Strasse 35, D-75172 Pforzheim, Germany.
7 MTS Systems Corp, 14000 Technology Dr, Eden Prairie, MN 55344.
8 SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.
mean percent differences between active LIPUS-treated fractures and inactive LIPUS-treated fractures.

Results

Animal Characteristics
One animal from the 40-day group died from surgical complications during fracture induction. Three other animals (1 animal and 2 animals from the 25-day and 40-day groups, respectively) were excluded at postoperative week 1 because of rotatory instability at the fracture site. Therefore, 14 and 12 animals were left for statistical analyses in the 25-day and 40-day groups, respectively. The mean (SD) weights at the end of the study of animals in the 25-day and 40-day groups were 394.8 g (39.7) and 417.7 g (37.3), respectively.

Effect of LIPUS on Fracture Site Radiographic Healing
Representative images of fractures in the 25-day and 40-day groups are shown in Figure 2. There were no significant differences in radiographic scoring between active LIPUS-treated fractures and inactive LIPUS-treated fractures in either the 25-day group ($P = .79$) or the 40-day group ($P = .26$) (Table).

Effect of LIPUS on Fracture Site Bone Mass
There was no significant difference in BMC between active LIPUS-treated and inactive LIPUS-treated fractures when assessed by DXA at 25 days (%diff = 2.4%, 95% CI = $-7.5\%$–$12.5\%$) ($P = .71$) (Fig. 3). Similarly, BMC (%diff = 4.1%, 95% CI = $-6.3\%$–$14.5\%$), vBMD (%diff = 0.4%, 95% CI = $-9.1\%$–9.9%), and B.Ar (%diff = $-0.2\%$, 95% CI = $-24.6\%$–$24.3\%$) did not differ between active LIPUS-treated and inactive LIPUS-treated fractures at 25 days when assessed by pQCT (all $P$ values = $>.81$–.96) (Fig. 4). In contrast, at 40 days, active LIPUS-treated fractures had 14.3% (95% CI = $1.0\%$–$27.5\%$) greater fracture site BMC on DXA than inactive LIPUS-treated fractures ($P < .05$) (Fig. 3). This increase was confirmed by pQCT, which found BMC in active LIPUS-treated fractures to be 16.9% (95% CI = $2.3\%$–$31.4\%$) greater than that in inactive LIPUS-treated fractures ($P < .05$) (Fig. 4A). The increase in fracture site BMC with active LIPUS at 40 days did not result in an increase in the amount of bone mineral per unit volume, as vBMD did not differ from that in inactive LIPUS-treated fractures (%diff = $-4.7\%$, 95% CI = $-12.4\%$–$2.9\%$) ($P = .14$) (Fig. 4B). Instead, there was an increase in bone size, with active LIPUS-treated fractures having 25.8% (95% CI = $3.9\%$–$47.6\%$) greater B.Ar than inactive LIPUS-treated fractures ($P < .05$) (Fig. 4C).

Effect of LIPUS on Fracture Site Mechanical Properties
During mechanical testing, all femurs broke at the fracture site. At 25 days, there were no significant differences between active LIPUS-treated fractures and

Figure 1.
(A) Experimental setup for testing of fracture site mechanical properties in 4-point bending. The fracture site (white arrow) was centered between the upper contacts. (B) Representative force-displacement curve generated from a 4-point bending test of a fracture in the 40-day group. Mechanical properties derived from this graph included ultimate force (peak of the curve on the y-axis), stiffness (slope of the linear portion of the curve), and energy to ultimate force (area under the curve to ultimate force).
inactive LIPUS-treated fractures in ultimate force (%diff=2.6%, 95% CI=-41.2%–46.4%), stiffness (%diff=4.4%, 95% CI=-77.3%–86.0%), or energy to ultimate force (%diff=2.2%, 95% CI=-33.0%–37.3%) (all P values=.49–.66) (Fig. 5). In contrast, at 40 days, active LIPUS-treated fractures had 81.3% (95% CI=0.8%–162.7%) greater ultimate force and 63.4% (95% CI=10.3%–116.4%) greater stiffness than inactive LIPUS-treated fractures (all P values<.05) (Figs. 5A and 5B). Compared with inactive LIPUS, active LIPUS had no effect on energy to ultimate force at 40 days (%diff=146.3%, 95% CI=-37.8%–330.4%) (P=.18) (Fig. 5C). However, this latter finding most likely resulted from insufficient statistical power to detect a difference because of the variance within the data.

Discussion and Conclusions
The present study investigated the effect of LIPUS produced by a conventional therapeutic ultrasound unit on fracture repair in an animal model. LIPUS did not have a significant effect on fracture healing when assessed at 25 days postfracture. This finding may have been influenced by insufficient statistical power, with post hoc power analyses indicating that differences of greater than 11% in side-by-side comparisons were required in order to achieve 80% statistical power. In contrast, by 40 days, fractures treated with active LIPUS had significantly greater bone mass than fractures treated with inactive LIPUS (placebo). This increase in bone mass resulted in an increase in bone size, as opposed to an increase in bone density, and contributed to active LIPUS-treated fractures having enhanced mechanical properties compared with inactive LIPUS-treated fractures. The latter was indicated by active LIPUS-treated fractures having 81% greater ultimate force and 63% greater stiffness than inactive LIPUS-treated fractures. These data indicate that LIPUS produced by a conventional therapeutic ultrasound unit as traditionally used by physical therapists may be used to facilitate fracture repair.

The findings of this study are interesting from the perspective that physical therapists traditionally have been advised to avoid exposing the skeleton to excessive...
amounts of ultrasound energy. Reflecting this fact, only 1% of therapists currently introduce ultrasound energy with the intent of treating acute bone injuries. However, this dogma is historically based and does not incorporate current research findings. There is no doubt that ultrasound energy can produce significant tissue damage when applied to the skeleton because of unique biophysical interactions between ultrasound and bone. This fact has been confirmed experimentally by ultrasound causing premature closure, slipping, and displacement of epiphyseal growth plates, bone sclerosis, diaphyseal fractures and fibrosis, and delayed healing during fracture repair. However, these effects have been elicited only by ultrasound doses at the high end of the therapeutic dose range (>1.0 W/cm²). To date, there are no known side effects of LIPUS application (<0.1 W/cm²) on the skeleton. Supporting this fact, a recent study demonstrated that pulsed ultrasound therapy at an intensity of 2.2 W/cm² produced pathologic changes in growing bone when introduced with a stationary treatment head for 20 minutes a day for 6 weeks. In contrast, similarly introduced ultrasound at a lower intensity (0.5 W/cm²) had no adverse effect on bone growth.

The data of the present study support the results of previous animal studies and clinical studies demonstrating that LIPUS accelerates fracture repair, and furthers this research by demonstrating that LIPUS produced by a conventional therapeutic ultrasound unit as used by physical therapists may be used to facilitate fracture repair. This latter finding addresses an area of recent contention. It was previously suggested that LIPUS produced by conventional therapeutic ultrasound units may delay fracture healing by stimulating the production of excessive nonmineralized cartilage. However, the data of the present study challenge this hypothesis. First, we found that fractures treated with active LIPUS achieved the same level of radiographic healing and had more mineralized callus formation (greater fracture site bone mass) than inactive LIPUS-treated fractures. Second, fractures treated with active LIPUS had better fracture site mechanical properties than inactive LIPUS-treated fractures. The restoration of mechanical integrity is the overall function of any repair process in a load-bearing structure such as bone. Therefore, we believe that LIPUS produced by a conventional therapeutic ultrasound unit can be beneficial to the fracture repair process and does not delay bone union.

Although a significant beneficial effect was observed in the present study, therapists are not currently encouraged to introduce LIPUS produced by their conventional therapeutic ultrasound units with the intent of facilitating clinical fracture repair. Animal studies are necessary precursors in the initial investigation of the safety and efficacy of an intervention; however, the examination of interventions in laboratory-based studies does not always accurately predict clinical effects. This fact is particularly pertinent to ultrasound therapy studies, as the relative size, volume, and depth of the tissue being treated in animals typically differ from those of tissue being treated clinically. These differences may

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<th>Days (No. of Animals)</th>
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<th>No. of Animals With the Following Radiographic Score*:</th>
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<th>SD</th>
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<td></td>
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<td>1</td>
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<td>2</td>
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<tr>
<td>40 (12)</td>
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<td>0</td>
<td>6</td>
<td>2</td>
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<td></td>
<td>Active</td>
<td>0</td>
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*0=no evidence of healing, 1=callus formation evident but fracture gap not yet bridged, 2=callus formation evident with possible bridging of the fracture gap, 3=fracture union.

![Figure 3.](image)

Figure 3.
Effect of low-intensity pulsed ultrasound (LIPUS) on fracture site bone mineral content (BMC), as assessed by dual-energy X-ray absorptiometry. Bars represent mean±SD. An asterisk indicates data that were significantly different from those for inactive LIPUS-treated fractures (P<.05, paired t test).
influence ultrasound energy distributions, tissue interactions, and ultimately therapeutic responses. In order for the results of the present study to have clinical relevance, the observed LIPUS effect needs to be confirmed by way of controlled clinical trials. In addition, before LIPUS intervention can be contemplated clinically, the ongoing concern regarding the output performance of ultrasound units being used in clinical practice needs to be addressed. Equipment surveys undertaken globally repeatedly have found that many ultrasound units being used in clinical practice are unable to produce an ultrasound dose that matches the metered dose to within set standards.\textsuperscript{22,23} This output variance may not only influence treatment efficacy during fracture repair but also elicit detrimental effects. Until these current limitations are addressed, the use of conventional therapeutic

**Figure 4.**
Effect of low-intensity pulsed ultrasound (LIPUS) on fracture site bone mineral content (BMC) (A), volumetric bone mineral density (vBMD) (B), and bone area (B.Ar) (C) as assessed by peripheral quantitative computed tomography. Bars represent mean ± SD. An asterisk indicates data that were significantly different from those for inactive LIPUS-treated fractures (\( P < .05 \), paired \( t \) test).

**Figure 5.**
Effect of low-intensity pulsed ultrasound (LIPUS) on fracture site mechanical properties. Ultimate force (A), stiffness (B), and energy to ultimate force (C) were assessed by destructive 4-point bending tests. Bars represent mean ± SD. An asterisk indicates data that were significantly different from those for inactive LIPUS-treated fractures (\( P < .05 \), paired \( t \) test).
ultrasound units in a manner other than that approved by US Food and Drug Administration market compliance could have potential ramifications.

Although the present data confirm that LIPUS facilitates fracture repair, they do not contribute to the current, limited understanding of the mechanism underlying this effect. Considering that LIPUS introduces an intensity within a more traditional diagnostic ultrasound range, a range previously considered to have a minimal biologic effect and no therapeutic value, it is valid to consider how LIPUS induces its therapeutic effect. Unfortunately, this mechanism is not yet known, as it is not established how ultrasound signals are transduced in vivo to produce a cellular response. It is possible that ultrasound longitudinal mechanical waves exert micromechanical loading to manipulate the inherent mechanosensitivity of bone cells. However, this notion has been disputed by studies demonstrating that the mechanical loading associated with LIPUS does not induce adaptation in intact bone. Alternatively, the beneficial effect of LIPUS during fracture repair may result from the generation by ultrasound of unique phenomena within the propagating tissues, such as stable cavitation and microstreaming. These phenomena may generate shear forces on cellular membranes to induce a cellular response; however, the occurrence and significance of these phenomena in vivo have been disputed. Finally, LIPUS may have its beneficial effect during fracture repair via the generation of localized heat at the fracture site in response to molecular vibration and collisions. However, this mechanism lacks the support of a recent study, which found that ultrasound therapy augmented fracture repair but that an equivalent level of hyperthermia generated by microwave therapy did not.

Despite the fact that the underlying biophysical mechanism of action of ultrasound during fracture repair is not known, a number of studies have investigated potential cellular processes influenced by LIPUS. In vitro, LIPUS has been shown to influence directly a number of cells associated with the repair process, including fibroblasts, chondrocytes, and osteoblasts. The induced changes suggest that ultrasound may have a direct effect on the reparative processes of angiogenesis, chondrogenesis, and osteogenesis. This suggestion is supported by in vivo investigations. Principally, showed that LIPUS influenced multiple cellular reactions during fracture repair. This finding was evident from the advancement of healing irrespective of the phase of repair during which LIPUS was introduced.

In summary, the present study showed that LIPUS produced by a conventional therapeutic ultrasound unit can facilitate fracture repair. This finding was evident by active LIPUS-treated fractures having greater fracture site bone mass, size, and strength than within-animal inactive LIPUS-treated fractures. These data provide preliminary evidence to support a beneficial effect of LIPUS as produced by an ultrasound unit traditionally used by physical therapists on fracture repair. However, careful interpretation of this controlled laboratory study is warranted until its findings are confirmed by clinical trials. Until these trials are performed and until the accurate output performance of their ultrasound units is ensured, therapists are not encouraged to introduce LIPUS produced by a conventional therapeutic ultrasound unit with the intent of facilitating clinical fracture repair.

References


