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Direct Current Electrical Stimulation Increases the Fusion Rate of Spinal Fusion Cages

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Keywords:

bone healing; direct current stimulation; electric stimulation; lumbar vertebrae; spinal fusion; spine fusion cages

Abstract

Study Design. A randomized experimental evaluation of direct current stimulation in a validated animal model with an experimental control group, using blinded radiographic, biomechanical, histologic, and statistical measures.

Objectives. To evaluate the efficacy of the adjunctive use of direct current stimulation on the fusion rate and speed of healing of titanium interbody fusion cages packed with autograft in a sheep lumbar interbody fusion model.

Summary of Background Data. Titanium lumbar interbody spinal fusion cages have been reported to be 90% effective for single-level lumbar interbody fusion. However, fusion rates are reported to be between 70% and 80% in patients with multilevel fusions or with risk factors such as obesity, tobacco use, or metabolic disorders. The authors hypothesized that direct current stimulation would increase the fusion rate of titanium interbody fusion cages packed with autograft in a sheep lumbar interbody fusion model.

Methods. Twenty-two sheep underwent lumbar discectomy and fusion at L4–L5 with an 11- × 20-mm Bagby and Kuslich (BAK) cage packed with autograft. Seven sheep received a BAK cage and no current. Seven sheep had a cage and a 40- μ A current applied with a direct current stimulator. Eight sheep had a BAK cage and a 100- μ A current applied. All sheep were killed 4 months after surgery. The efficacy of electrical stimulation in promoting interbody fusion was assessed by performing radiographic, biomechanical, and histologic analyses in a blinded fashion.

Results. The histologic fusion rate increased as the direct current dose increased from 0 μ A to 40 μ A to 100 μ A ($P < 0.009$). Histologically, all animals in the 100- μ A group had fusions in both the right and left sides of the cage. Direct current stimulation had a significant effect on increasing the stiffness of the treated motion segment in right lateral bending ($P < 0.120$), left lateral bending ($P < 0.017$), right axial rotation ($P < 0.004$), left axial rotation ($P < 0.073$), extension ($P < 0.078$), and flexion ($P < 0.029$) over nonstimulated levels.

Conclusion. Direct current stimulation increased the histologic and biomechanical fusion rate and the speed of healing of lumbar interbody spinal fusion cages in an ovine model at 4 months.

Back or spine musculoskeletal impairment represents 51.7% (15.4 million) of the musculoskeletal impairments reported in the United States.²³ In the 18–84 age group, back or spine impairment is the leading cause of activity limitation and results in more lost productivity than any other medical condition,²³ Approximately 4.4 million people 25–74 years of age report intervertebral disc problems

in the United States. ²³ Although 80–90% of patients with low back pain recover by 12 weeks with nonsurgical therapies such as bed rest and anti-inflammatory medications, ¹ nonsurgical therapies are largely unsuccessful for certain injuries or disorders, including degenerative disc disease and stenosis, spondylolysis, and/or spondylolisthesis.

When conservative treatment fails, spinal fusion (arthrodesis) may be performed. In the United States, there were 279,000 operations for low back pain in 1990, with 26 lumbar fusions performed per 100,000 persons. ¹ In 1995, there were approximately 160,000 spine fusion surgeries. ²³ In a literature review of 47 studies, Turner et al ³⁰ reported that 68% of patients had a satisfactory outcome after lumbar fusion, but the range was between 16% and 95%. Of most concern was a 20–40% failure rate reported for lumbar spine fusion.

The use of spine fusion cages has become prevalent in lumbar interbody fusion. ^{2,17–19,24,28,29,31,32} Clinically, on the basis of primarily radiographic evaluation, lumbar interbody fusion with titanium spinal fusion cages has been reported to be effective for single-level lumbar interbody fusion, with a fusion rate of 90% or higher at 1–2 years after surgery. ^{17,19,24,32} However, fusion rates may be between 70% and 80% in patients with multilevel fusions or with risk factors such as obesity, tobacco use, or metabolic disorders.

There is a plethora of literature on the effectiveness of the use of electrical stimulation for bone healing in orthopedics, ³ especially for the treatment of recalcitrant nonunions ^{6,7} and posterolateral and interbody lumbar spine fusions. ^{5,9–16,20–22,25} Perhaps the literature was best summarized and critically reviewed by Kahanovitz ¹¹ in *Spine* in 1996. Direct current (DC) bone stimulation, a modality successfully used clinically in conjunction with both posterolateral and interbody lumbar fusions, could increase the success rate and accelerate bone healing when used as an adjunctive treatment with interbody fusion cages. In a canine bilateral posterior facet fusion model, Kahanovitz and Arnoczky ¹² reported a 100% fusion rate at 12 weeks with a DC of 10 μA and a 0% fusion rate at 12 weeks with 0 μA . More recently, in the same model, they reported a significant improvement in fusion mass scores at 6 and 9 weeks with currents of 15 $\mu\text{A}/\text{cm}$ and 0.83 $\mu\text{A}/\text{cm}$, respectively. ¹⁵

Clinically, DC bone stimulation has been used as an adjunct to lumbar interbody fusions. Using the Crock procedure with allograft, Meril ²⁰ reported a 93% fusion rate with DC of 20 μA applied for 24 weeks and a 75% fusion rate with no DC stimulation. In the posterolateral spine, Rogozinski and Rogozinski ²⁵ clinically evaluated adjunct use of DC stimulation in a prospective posterolateral fusion study with autograft, pedicle screws, and rod instrumentation. They reported a 96% fusion rate with a current of 20 μA and an 85% fusion rate without DC stimulation. ²⁵

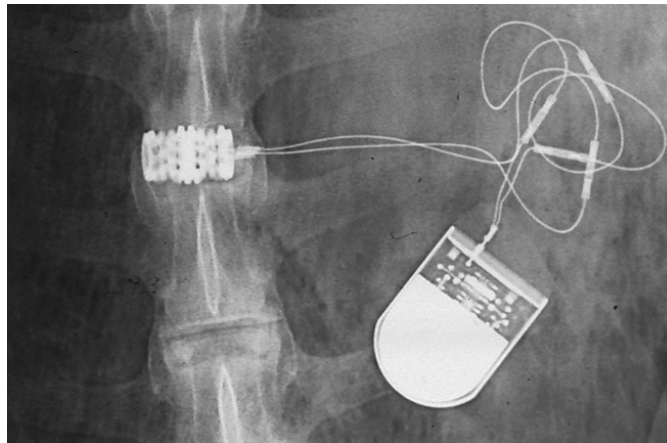
The primary objective of this study was to assess the effectiveness of DC stimulation of titanium interbody fusion cages packed with autograft in a sheep lumbar interbody spine fusion model. Using radiographic, biomechanical, and histologic measures, this study examines the effects of DC stimulation on fusion success and speed of fusion. The authors hypothesized that adjunctive use of DC stimulation would increase the fusion rate of lumbar interbody spinal fusion cages loaded with autograft.

Materials and Methods

Animal Model and Study Design.

Because of the biomechanical similarities of sheep and human spines demonstrated by Wilke et al, [33](#) the sheep lumbar interbody spine fusion model has been advocated for evaluation of spinal implants and was chosen as the animal model for this study. This study was approved by the Institutional Animal Care and Use Committee (CSU IACUC 97-180A-01).

To test the hypothesis, 22 skeletally mature sheep were placed in right lateral recumbency and underwent single-level lumbar discectomy and interbody fusion at L4–L5 by left retroperitoneal approach. After discectomy, an 11 × 20-mm Bagby and Kuslich cage (BAK; Sulzer Spine-Tech, Minneapolis, MN) packed with morselized iliac crest cancellous autograft was placed at L4–L5. The animals were randomly assigned to one of three treatment groups at the time of surgery. Seven sheep received a BAK cage with autograft with no DC, although two leads were attached to the cage with no generator attached to the leads. Seven sheep had a BAK cage with autograft and a low current (40 μ A) applied to the cage through two leads connected to the cage and a DC stimulator (SpF XLII, Electro-Biology, Inc., Parsippany, NJ). Finally, eight sheep had the BAK cage packed with autograft and a high current (100 μ A) applied to the cage with a DC stimulator (SpF 100, Electro-Biology, Inc.). A radiograph showing the hook-up of the DC stimulator to the spinal fusion cage can be seen in [Figure 1](#).



[Figure 1](#)

All the animals recovered well from the surgery and were examined for neurologic deficits. All the sheep were killed 4 months after surgery. The efficacy of electrical stimulation was assessed by performing radiographic, biomechanical, and histologic analyses in a blinded fashion, as described herein.

Neurologic Evaluations.

Neurologic examinations were conducted daily for 7 postoperative days, at 2 months, and before euthanasia at 4 months. The examinations were conducted using the following scale: 0 = walking without any detectable ataxia, 1 = walking, slightly ataxic; 2 = walking, but with notable weakness on one side or both sides; 3 = able to stand on forelimbs but dragging rear limbs, 4 = recumbent and unable to rise.

Radiographic Evaluation.

Radiographs were taken immediately after surgery (anteroposterior and lateral views) and at 2 months after surgery (anteroposterior and lateral views). High-resolution radiographs were made at the time of death (anteroposterior and lateral views) using a high-resolution radiography unit (Faxitron; Hewlett–Packard, McMinnville, OR) and high-resolution film (Ektascan M EM-1; Eastman Kodak, Rochester, NY). The resultant radiographs from the treated animals and the biomechanical sham group (see description later) were read by three blinded evaluators for fusion, bone in the cage, and implant placement. The radiographs were graded in the following manner: Grade 3 was solid fusion with no radiolucent lines surrounding the cage; Grade 2 was probable fusion with some radiolucent lines surrounding the cage; and Grade 1 was nonfusion with significant radiolucent lines surrounding the cage. Radiographs were also evaluated for bone present in the cage, as seen from the lateral view as well as the presence of anterior or posterior bony bridging.

Biomechanical Testing.

Ex vivo biomechanical testing was performed to quantify the flexibility of the treated motion segment by measuring load displacement behavior. The treated lumbar motion segments were dissected from the harvested lumbar spine and cleaned of extraneous soft tissues, leaving the ligamentous and osseous tissues intact. Unconstrained biomechanical testing was performed in a nondestructive manner on all treated spines. Specially designed loading and base frames were secured on the inferior and superior vertebra, respectively. Three retroreflective markers were attached to each vertebra. Pure moments (0, 0.5, 2.5, 4.5, 6.5, and 8.5 Nm) were applied in the following loading directions: flexion, extension, left and right lateral bending, and left and right axial rotation. The location of the markers was recorded at each load using three infrared video cameras (Vicon; Oxford Metrics, Oxford, UK). The three-dimensional coordinate data were then analyzed to obtain the rotation angles and the flexibility of each motion segment.

In addition to the treated animals, 17 normal (untreated) motion segments and 9 “biomechanical sham” (BAK device implanted in normal cadaver sheep spine by the same surgical technique) motion segments were tested in the same manner. The rationale for the “biomechanical sham” is that it allows for comparison of the biomechanics of the treated survival groups to the instrumented sham levels. A fused level would then have an increased stiffness and decreased flexibility compared with the instrumented sham levels. The authors thought that the biomechanical testing data of the

biomechanical shams would provide a better comparison to the nonfused survival implant than untreated normal motion segments.

After the flexibility tests, the posterior elements were removed, and the tensile stiffness of the disc space was measured in uniaxial tension, by loading the specimen in tension under displacement control on a materials testing machine (Model 809; MTS, Minneapolis, MN) at a rate of 1 mm/min until a force of 45 N (10 lb) was detected. Load-displacement curves were obtained and used to determine the tensile stiffness of the disc space.

Histologic Analysis.

Immediately after biomechanical testing, the specimens were fixed in 10% neutral buffered formalin and bisected midsagittally to produce right and left halves. These halves were sequentially dehydrated in alcohols, cleared in xylene, and embedded in graded catalyzed methyl methacrylate for undecalcified histologic studies. After polymerization was complete, sections were cut continuously through the explant on a diamond saw (Isomet; Buehler, Lake Bluff, IL) to an approximate thickness of 150–400 μm . Approximately 10–15 sections were made in the sagittal plane through each half of the bisected level. The thickness of each section was measured with a metric micrometer. Differential staining using a trichrome stain was used to permit both histologic and cytologic differentiation. With this staining method, the following tissues can be differentiated on the basis of color: bone is stained blue-green, cartilage and fibrocartilage are stained purple, and fibrovascular tissue is stained pink. Staining of cellular and nuclear detail by this trichrome stain is similar to staining with hematoxylin and eosin, thus permitting cytologic differentiation.

In addition to stained undecalcified sections, four undecalcified sections from each treated level were radiographed using Copper k- α radiation at 20 kV and 30 mA using a microradiography unit (Kristalloflex-2; Siemens, New York, NY) and spectroscopic film (343-O emulsion; Eastman Kodak). A custom-made camera with an extension tube measuring 22.9 cm was used to obtain high-resolution microradiographs. Sections were exposed for 10–12.5 minutes for each 100 μm of thickness. The sections were placed on the spectroscopic film and then on a rectangular holder. A piece of latex was placed over the film and holder and a vacuum applied to the holder, holding the sections in place and preventing the formation of shadows on the film. The cassette assembly was inserted into the camera mounted on the radiograph unit and exposed to the x-radiation as described. The film was then developed, fixed, and analyzed for ossification, by using standard optical microscopy.

The histologic slides and microradiographs were used to evaluate histologic fusion or the presence of pseudarthroses. The criterion used to assess histologic fusion was a continuous bony bridge from the superior to the inferior vertebra. A solid fusion existed if both the right and left through-growth holes of the BAK device showed continuous bony bridging. A partial fusion existed if only one of the right or left through-growth holes of the BAK device showed continuous bony bridging. Analysis of the stained undecalcified sections was also used to determine the histologic and cytologic response to the treatments. Finally, the quality and quantity of bone in the implant and in contact with the implant were estimated.

Statistical Analysis.

The Department of Biostatistics at the Medical College of Wisconsin provided guidance and direction on the selection and application of statistical tests used to analyze the data.

Results

All 22 sheep recovered from anesthesia uneventfully and were standing and walking without signs of neurologic deficits. All sheep received a score of 0 (*i.e.*, walking without any detectable ataxia) for limb use at 7 postoperative days, at 2 months, and before euthanasia at 4 months.

Radiographic Scores

Radiographic fusion scores are presented in [Table 1](#). For the three treatment groups, as DC stimulation increased, radiographic fusion scores also increased. Radiographic fusion scores increased from biomechanical sham to 0- μA to 40- μA to 100- μA groups. Ordinal logistic regression showed that levels treated with 100 μA were more likely to receive a higher radiographic fusion score than levels treated with 0 μA ($P = 0.003$). Radiographic fusion scores for levels treated with 100 μA showed an increasing trend ($0.05 < P < 0.10$) but were not statistically different from levels treated with 40 μA ($P = 0.0594$). In addition, radiographic fusion scores for levels treated with 40 μA were not statistically different from levels treated with 0 μA ($P = 0.1995$). In the 100- μA current group, two treated levels showed anterior bony bridging in addition to fusion through the BAK device. Marked radiolucencies were not observed surrounding the cages in any of the treatment groups.

Table 1. Summary of Mean Radiographic Fusion Scores for the Biomechanical Sham Group and the Treated Survival Groups With Applied Currents of 0 μA , 40 μA , and 100 μA

	Sham	0 μA	40 μA	100 μA
Mean radiographic fusion score	2.00	2.14	2.38	2.67

[Table 1](#)

Biomechanical Analysis

Biomechanical flexibility data (presented in [Table 2](#) as stiffness in Newton-meters per degree) and disc space tensile stiffness data (mean \pm standard deviation [SD]) can be seen in [Table 2](#). By the Shapiro–Wilk test, biomechanical flexibility data were found to be nonparametric; thus, biomechanical differences in the flexibility between groups were statistically analyzed using the nonparametric Jonckheere–Terpstra (1-tailed) test. Similar to the Wilcoxon rank sum test, the Jonckheere–Terpstra (1-tailed) test ranks the biomechanical stiffness by magnitude and tests the hypothesis that the stiffness is correlated with the current dose (treatment group).

Table 2. Summary of Mean and Standard Deviation of Biomechanical Stiffness (Nm/°) in Right and Left Lateral Bending (RLB and LLB), Right and Left Axial Rotation (RAR and LAR), and Extension and Flexion (EXT and FLX) for the Intact Normal Levels, Biomechanical Sham Group, and the Treated Survival Groups With Applied Currents of 0 μ A, 40 μ A, and 100 μ A. The Mean Disc-Space Uniaxial Tensile Stiffness (lb/in) for all Groups is Presented in the Last Row

	Normal	Sham	0 μ A	30 μ A	100 μ A
RLB \pm STD (Nm/°)	1.17 \pm 0.19	2.07 \pm 0.88	4.97 \pm 1.56	4.69 \pm 1.54	8.76 \pm 6.51
LLB \pm STD (Nm/°)	1.18 \pm 0.17	1.84 \pm 0.50	3.95 \pm 1.04	3.38 \pm 0.75	6.18 \pm 2.40
RAR \pm STD (Nm/°)	6.57 \pm 2.25	8.25 \pm 3.43	7.90 \pm 1.73	8.81 \pm 1.68	14.8 \pm 7.49
LAR \pm STD (Nm/°)	5.41 \pm 1.57	9.09 \pm 3.55	7.55 \pm 1.08	7.82 \pm 1.44	9.47 \pm 2.65
EXT \pm STD (Nm/°)	1.60 \pm 0.46	2.41 \pm 0.81	3.67 \pm 0.51	4.54 \pm 2.67	10.57 \pm 12.85
FLX \pm STD (Nm/°)	1.39 \pm 0.43	3.52 \pm 1.60	1.92 \pm 0.52	2.08 \pm 0.57	3.14 \pm 1.93
Stiffness (lb/in) \pm STD	2902 \pm 1103	8228 \pm 4178	8408 \pm 3293	8574 \pm 4077	10010 \pm 2036

STD = standard deviation.

[Table 2](#)

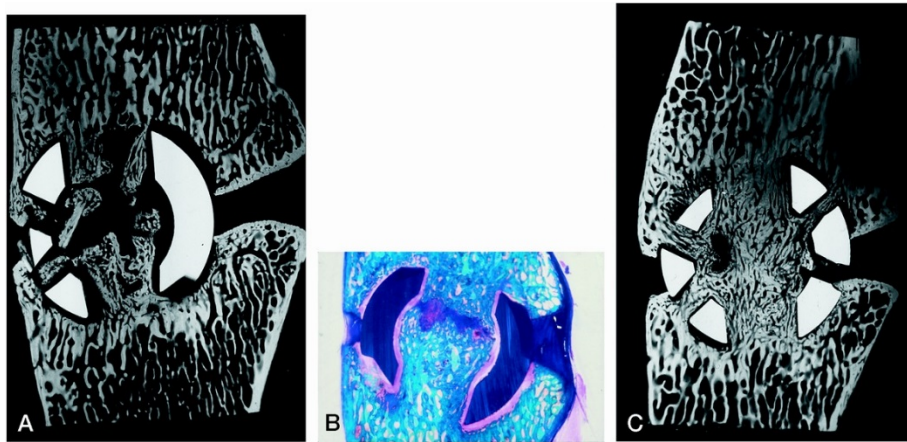
Direct current stimulation had a significant effect ($P < 0.05$) on increasing the stiffness of the treated motion segments in left lateral bending ($P < 0.017$), right axial rotation ($P < 0.004$), and flexion ($P < 0.029$) over nonstimulated motion segments. The stimulation showed a trend ($0.05 < P < 0.10$) toward increasing the stiffness of the stimulated motion segments in left axial rotation ($P < 0.073$) and extension ($P < 0.078$). Differences in right lateral bending flexibility data between the three treatment groups were not statistically significant ($P < 0.120$). Differences between treatment groups for the second biomechanical test—tensile stiffness of the disc space in uniaxial tension—were not statistically significant (Fisher’s exact test, $P > 0.05$).

Logistic regression analysis showed that biomechanical flexibility data correlated with histologic ratings of fusion and nonfusion. In fact, logistic regression showed that stiffness in some directions was predictive of histologic fusion rating. The most predictive loading direction was left lateral bending, for which logistic regression results showed that if a spinal level had a stiffness of 3.24 Nm/deg or greater, there was a 28-fold increase in the odds of histologic fusion.

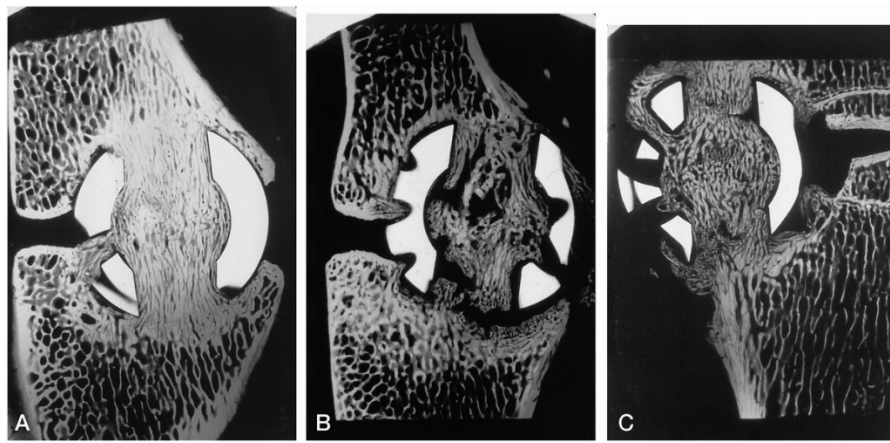
Histologic Analysis

Histologic fusion data for the three treatment groups are shown in [Table 3](#). The histologic fusion rate increased as the DC dose increased from 0 μ A to 40 μ A to 100 μ A (Fisher’s exact test, $P < 0.009$). In the

no-current group, only one animal had histologic fusion in both sides of the cage. One additional animal in the no-current group had partial fusion in the right side of the cage. Representative histology from the 0- μ A current group can be seen in [Figures 2A](#)–[2C](#). In the 40- μ A current group, four animals had fusions in both the right and left sides of the cage. One additional animal had a partial fusion in the right side only. Two of the animals in the low-current group had pseudarthroses. Representative histology from the 40- μ A current group can be seen in [Figures 3A](#)–[3C](#). Histologically, all animals in the 100- μ A group had fusions in both the right and left sides of the cage. In addition, some of the spinal levels had fusions in the anterior and posterior margins. Representative histology from the 100- μ A current group can be seen in [Figures 4A](#)–[4C](#).



[Figure 2](#)

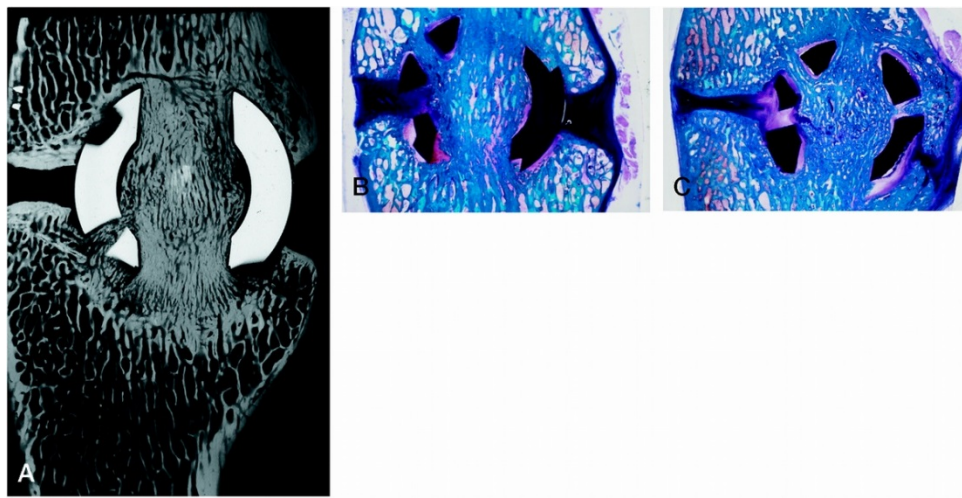


[Figure 3](#)

Table 3. Summary of Histologic Fusion Results for the Treated Survival Groups With Applied Currents of 0 μ A, 40 μ A, and 100 μ A

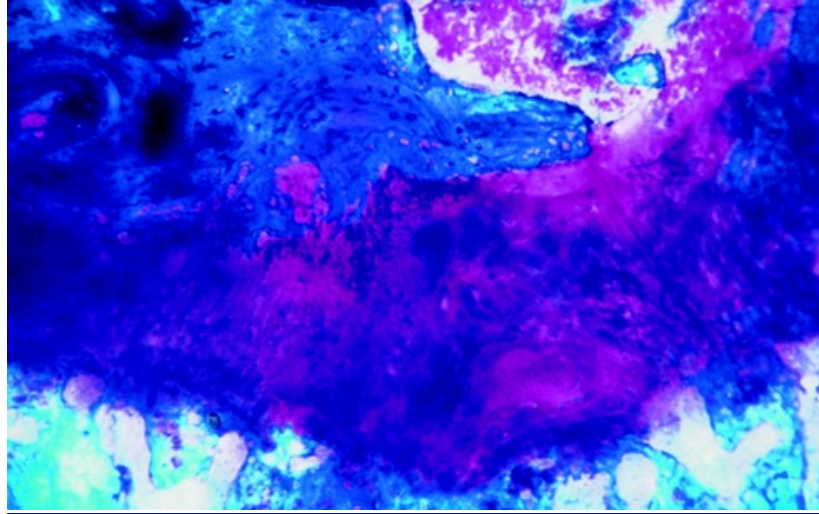
	0 μ A	40 μ A	100 μ A
Fusion incidence and percent	2/7 (29%)	5/7 (71%)	8/8 (100%)

[Table 3](#)



[Figure 4](#)

Nonfusions in the no- and 40- μ A current treatment groups consisted of thin (100–500 μ m) fibrocartilaginous pseudarthroses inside the cages, as seen in [Figure 5 , A and B](#). For the most part, pseudarthroses in the low and no-current groups were present within the cages. Thus, these pseudarthroses were not visible on plane radiographs. Cytologically, fibroblasts, and fibrovascular tissue surrounded the titanium implants. No acute or chronic inflammatory response was observed in any of the treatments. Also, adverse events such as peri-implant tissue discoloration or fluid and gas accumulation were not observed.



[Figure 5](#)

Discussion

Biologic augmentation strategies to improve fusion results of spine fusion cages have been reported previously. [4,8,26,27,29,34](#) Zdeblick et al [34](#) have reported a 48% histologic arthrodesis rate in the caprine cervical interbody fusion model when BAK cages were filled with autograft at 3 months. At the same time, they reported a 95% arthrodesis rate when the BAK cages were filled with recombinant human (rh)BMP-2 on a collagen sponge. [34](#) In the sheep three-level thoracic model, Cunningham et al [8](#) reported a 75% histologic arthrodesis rate with BAK cages filled with rhOP (osteogenic protein)-1, a 63% fusion rate when cages were packed with autograft, and a 33% fusion rate in the empty BAK cages. [8](#) A more direct comparison to the current study is the work reported by Sandhu et al [27,28](#) using the single-level sheep lumbar interbody fusion model. In this study, augmentation of titanium interbody spinal fusion cages with rhBMP-2 significantly increased the histologic fusion rate (100%) compared with the titanium cages with autograft (37.5%) at 6 months. [27,29](#)

The use of biomechanical tests to measure the stiffness (or flexibility) of the treated motion segments in response to applied loads and moments has been used as an experimental method to assess spinal fusion in animal models. It is important to note that resultant biomechanics data (flexibility and stiffness) are not an all-or-none phenomenon. A solid fusion mass reduces motion and increases stiffness but does not completely eliminate motion. Thus, the question remains of what value of stiffness and flexibility constitutes fusion. Many investigators have compared biomechanics data of treated groups with those of untreated (normal) groups, but this is clearly not appropriate. First, even a nonfused implant reduces flexibility and increases stiffness of the spinal construct immediately after surgery when compared with an untreated (normal) spinal level. In the current study, [Table 2](#) clearly shows the increase in stiffness in the sham group compared with the normal group.

Second, the survival group may be heterogenous with respect to histologic fusion. If this is the case, the mean biomechanical stiffness of the treatment group is composed of biomechanically stiff fused

levels and more flexible levels with pseudarthroses. In the current study, we have chosen to present the concept of a “biomechanical sham,” which allows for a comparison of the biomechanics of the treated survival groups to the instrumented sham levels. A fused level would then have an increased stiffness and decreased flexibility compared with the instrumented sham levels. The authors believe that the biomechanical testing data of the biomechanical shams provide a better comparison with the nonfused survival implant than untreated normal motion segments.

To the authors’ knowledge, the reliability of plain radiographs to assess fusion of titanium spinal fusion cages has not been validated. In the current experimental study and several other experimental studies reported in the literature, [4,8,27,29](#) nonfusions consisted of pseudarthroses within the spine fusion cages, not frank pseudarthroses along the inferior or superior device interface, which would generate radiolucencies surrounding the cages. It is unlikely that radiographs would detect pseudarthroses within the through-growth region of the cage. Unlike the biomechanical data, radiographic findings were only weakly linked to histologic ratings of fusion. Likewise, with regard to radiographic evaluation of the biomechanical sham group, the authors do not find it unusual that a radiopaque titanium cage filled with autograft that has good initial bone contact appears to be fused radiographically. The biomechanical sham group was included to assess the sensitivity of the biomechanical and radiographic methods.

Unfortunately, it is beyond the scope of the current study to validate (or invalidate) radiographic methods to assess cage fusions. Radiographic analysis was one measure used to test the hypothesis that fusion rate increased with current dose. Histologic analysis was used as the gold standard for assessing continuous–discontinuous superior-to-inferior bone growth—conclusive evidence of fusion or pseudarthrosis.

Although the 100- μA current dose used in this study seems high, the current was distributed across the surface of the cathode. The cathode in this study was the 11- \times 20-mm BAK cage, which had a surface area of 21.3 cm^2 . Thus, the 40- μA current produced a surface current density of 1.9 $\mu\text{A}/\text{cm}^2$. The 100- μA current applied to the cage produced a surface current density of 4.7 $\mu\text{A}/\text{cm}^2$. These current densities are, respectively, less than and nearly identical with the 4.2- $\mu\text{A}/\text{cm}^2$ current density generated on cathode wires by DC stimulators currently used clinically for interbody and posterolateral spine fusion. [5,11,16,20,22,25](#) Thus, adverse effects related to the current density are unlikely.

That results of logistic regression showed that left lateral bending was most predictive of histologic fusion rating is most likely because the sheep’s spines were instrumented through a left (lateral) retroperitoneal approach. In this study and similar studies, [27,29](#) a lateral bony callus forms in the left margin because of the surgical exposure and localized trauma. Thus, in left lateral bending, this callus acts as a pivot point for the applied bending moment, placing the medial and right disc space in extension (tension). Although a lateral approach was used in the sheep lumbar interbody model, the anatomy of the sheep provides a difficult surgical approach and insufficient disc space for anterior implantation of spine fusion cages. It should be noted that the purpose in this study was not to evaluate the device, but the effect of the augmentation strategy on the speed of fusion. Thus, a single laterally placed cage provides a challenging animal model to test the efficacy of augmentation strategies.

Finally, extrapolation of these results from sheep to humans is not entirely possible. However, in the current study, DC stimulation increased the histologic and biomechanical fusion rate and the speed of healing of lumbar interbody spinal fusion cages loaded with autograft at 4 months in the sheep lumbar interbody fusion model.

Conclusion

Direct current electrical stimulation increased the speed of healing and the radiographic, biomechanical, and histologic fusion rates of spinal fusion cages in an ovine lumbar interbody fusion model at 4 months.

Key Points

- A randomized experimental study of DC stimulation was performed in a validated animal model with an experimental control group using blinded radiographic, biomechanical, histologic, and statistical measures to evaluate the efficacy of adjunctive use of DC stimulation to promote lumbar interbody fusion.
- Direct current stimulation increased the histologic and biomechanical fusion rate and the speed of healing of lumbar interbody spinal fusion cages in an ovine model at 4 months.
- Clinically, DC stimulation may be efficacious as an adjunct to lumbar interbody fusion when using titanium cages packed with autograft.

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