Pulsed Electromagnetic Fields:

An Adjunct to Interbody Spinal Fusion Surgery in the High Risk Patient

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LUMBAR FUSION SUCCESS RATES ARE UNPREDICTABLE. TURNER,[1] REPORTING ON 82 PUBlished studies, cites a fusion success rate that ranged from 16% to 93%, mean 66%. Spinal fusion can be compromised by a number of risk factors that have been identified which tend toward a poorer prognosis. These risk factors include smoking,[2] graft type (autograft vs. allograft),[3] and number of fusion levels.[4] Brown[2] reports a statistically different, 32% decrease in spinal fusion healing in smokers as compared to nonsmokers. Allograft has been reported to significantly lower success rate in posterolateral fusions.[3] Autograft is the preferred graft material because it is both tissue compatible and contains viable bone cells. If these bone cells can continue to be viable during the bridging process, the fusion healing process should be enhanced. Allograft bone does not have any viable bone cells within its matrix and may be rejected due to tissue incompatibility issues.[5] Wilkinson[4] reported that each additional fusion level decreased the possibility of spinal fusion success by approximately 20%.

Surgeons are attempting various treatment regimens and adjunctive procedures to increase the odds of fusion for these high risk patients. One method is through the adjunctive use of electrical stimulation by pulsed electromagnetic fields (PEMFs) following a spinal fusion procedure. PEMFs is an inductive method of generating an electric potential at the fusion site. A pulsing magnetic field surrounding the fusion site through a dual coil system creates an electronegative potential along the fusion site. This negative potential is very similar to the natural property that bone has of healing itself. This technology has proven useful in treating the nonunion of long bone and it seemed reasonable to attempt to improve fusion success rates in spinal fusions given the relative safety of PEMFs[6] and the success noted so far in long bones.[7,8] The purpose of this paper is to demonstrate the safety and efficacy of PEMFs in treating spinal fusion patients with one or more high risk factors regardless of the presence/absence of fixation.

INTRODUCTION

Surgeons familiar with interbody fusion techniques were recruited for participation in this multi-center, randomized, double-blind study. Patients of either sex who were undergoing a primary interbody spinal fusion procedure from either an anterior or posterior approach were to be enrolled. Patients were excluded who presented with severe osteoporosis, metatastatic cancer, uncontrolled diabetes mellitus, renal dysfunction, Paget's disease or any other disease process which would substantially interfere with bone metabolism. Table 1 shows the number of cases contributed by each participating physician.

Number of cases contributed by participating surgeons

Number of cases	Surgeon
59	A
26	B
19	C
17	D
12	E
11	F
11	G
9	H
9	I
7	J
5	K
4	L
3	M
2	N
2	O
2	P
1	Q
1	R
1	S
1	T
1	U
1	V
1	W
1	X

Table 1.

Following fusion surgery, patients were fitted with a Spinal-Stim® device, which emits an electromagnetic field, and were requested to wear the device for 8 hours/day in order to enhance their spinal fusion result. Patients were randomly assigned to either active or placebo (inactive device) treatment group by a computer-generated code. Neither the physician nor the patient knew whether the device was active or nonactive. All units were donated by the sponsor (American Medical Electronics, Inc.). Unbeknown to most patients, device usage was monitored by a computer chip within the device such that a calendar denoting device use for each day to the nearest half hour could be printed out in the physician's office.

Success criteria were based on radiographic evaluation. A fusion was defined as solid if it was more than 50% assimilated (trabecular bridging noted on both the inferior and superior margins of the graft). The surgeon identified the radiographic status at the time of union, but an independent blinded radiologist confirmed this reading. In cases where a disagreement between the clinician and radiologist occurred, an independent blinded orthopedic surgeon acted as the tie-breaking reviewer. The investigator's diagnosis of failure was never allowed to be overruled by the independent review. In an arthrosis spanning two segments, both levels had to be graded as solidly fused for the patient to be classified as a success.

Descriptive statistics and percentage calculations were employed to describe the characteristics of the study population with respect to age at study entrance, sex, baseline clinical characteristics, technique, and presence/absence of fixation. Appropriate statistical tests (t-test for numerical data, chi-square for categorical data) were applied to test the comparability between patients who were classified as consistent users. Analysis on treatment outcomes between the treatment group and the control group was then conducted using appropriate method upon these results.

The clinician identified whether the clinical result was excellent, good, fair, or poor. Other characteristics such as disability time before surgery, smoking, and number of previous surgeries were recorded. Safety was evaluated on the basis of the incidence of subject complaints and adverse events.

RESULTS

A total of 206 patients were enrolled in this phase of the study (107 patients, active group; 99 patients, placebo group) from February, 1986 through November, 1987. Reasons for disqualification were four patients for medical reasons in the active group and one in the placebo group: one patient in the active group and one patient in the placebo group did not have an interbody fusion; one active patient did not finish the study because of alcohol dependency; and two active patients required repeat surgery for continued degenerative disease. One active and one placebo patient had surgical complications that required revision. Four patients in the active group were lost to followup. The number of completed patients included 195 patients (98 patients, active; 97 patients, placebo).

Because the PEMF device was constructed to monitor patient usage (compliance), patients could be identified as those who complied or did not comply with recommended wear time.

Randomized Double-Blind Phase Completed, Withdrawals, and Lost to Follow-up Subjects

	Active Group		Placebo Group	
T e	n	%	n	
Completed				
Consistent use	64	59.8%	53	53.5%
Inconsistent use	34	31.8%	44	44.4%
Withdrawn from analysis				
Surgical intervention		0.9%		1.0%
Medical disqualification	4	3.7%	1	1.0%
Lost to follow-up	4	3.7%	0	0.0%
Total Subjects	107	100.0%	99	100.0%

Table 2.

Stratification of the data (wear time by fusion success) demonstrated that patients who wore the device two or more hours per day for at least a 90-day period had nearly equally high successful rates of fusion as those who wore the device for 8 or more hours per day. Patients who wore the device for less than 2 hours per day and/or discontinued wearing the device prior to 90 days of treatment had rates of fusion equivalent to that of the placebo-treated patients. Therefore, it appeared from the data that 2 or more hours/day for at least 90 days was a threshold dosage for PEMF treatment. Based on these data (Table 3), a consistent user was defined as a patient who used the device for 2 or more hours/day for at least 90 days; an inconsistent user, as a patient who used the device for less than 2 hours/day and/or fewer than 90 days. Active consistent users had statistically significantly increased heal rates (92.2%) as compared to placebo consistent users (67.9%, $p<0.001$), all placebo users (64.9%, $p<0.001$), and all placebo users plus active inconsistent users (i.e., no effective treatment, 85/131=64.9%, $p<0.001$). All the rest of the data presenting efficacy will include only the consistent users.

Smokers in the placebo group showed a lower fusion success rate (60%) as compared to nonsmokers in the placebo treatment group (72.7%), demonstrating the effects of smoking on fusion success rate. Smokers in the active treatment group showed a statistically significantly higher fusion success rate (88.9%) as compared to the smokers in the placebo group (60.0%, $p=0.021$).

Choice of autograft vs. allograft made no apparent difference in the rate of spinal fusion success (Table 5). Allogenous bone bank graft (92.0%) gave similarly high fusion success rates as autogenous iliac crest graft (92.6%) when combined with PEMF therapy. Successful fusion was substantially less in the placebo groups (73.7% autograft; 72.7% allograft. The distribution of type of bone graft was approximately equal between the two groups.

As presented in Table 6, multi-level fusion surgery shows an approximate 20% reduction in heal rates as compared to a single level fusion (72.5% single level fusion, placebo; 53.8% double level fusion, placebo group). However, when PEMF therapy is used adjunctively in these interbody fusions, the successful fusion rate increases to 93.5% for a single level fusion and to 88.9% for a double level fusion. The difference between active and placebo groups are statistically significant ($p=0.009$ for single level fusion; $p=0.028$ for double level fusion).

The use of internal fixation to immobilize the fusion segment until fusion can occur is enhanced by the use of PEMF therapy (Table 7). In the placebo group, the fusion success rate when internal fixation was used was 57.1% ($p=0.018$) which increased to 93.8% when combined with active PEMF treatment.

Analyses not presented here showed that successful fusion was not dependent on surgical diagnosis, age, nor sex of the patient. An analysis looking at the successful fusion results by high and low risk patients showed that the high risk patient (defined as having one or more of

Randomized Double-Blind Phase Results by Consistent Use versus Inconsistent Use

	Active Group			Placebo Group		
Category	Total Number	Total Healed	Success Rate	Total Number	Total Healed	Success Rate
Consistent Use	64	59	92.2%	53	36	67.9%
Inconsistent Use	34	22	64.7%	44	27	61.4%
Total	98	81	82.7%	97	63	64.9%

Statistically significant differences were found between the active consistent group and the active inconsistent group ($\chi^2=11.70$, $p<0.01$); and placebo consistent group ($\chi^2=11.18$, $p<0.01$); and all placebo ($\chi^2=15.59$, $p<0.01$); and all placebo plus active inconsistent ($\chi^2=16.59$, $p<0.01$).

Table 3.

Randomized Double-Blind Phase Results by Smoking

	Active Group			Placebo Group		
Category	Total Number	Total Healed	Success Rate	Total Number	Total Healed	Success Rate
No Smoking	37	35	94.6%	33	24	72.7%
Smoking	27	24	88.9%	20	12	60.0%
Total	64	59	92.2%	53	36	67.9%

Statistically significant differences were found between active and placebo treatment in the smoking group ($\chi^2=5.35$, $p=0.02$) and in the no smoking group ($\chi^2=6.30$, $p=0.01$).

Table 4.

the following risk factors: smoker, multilevel fusion surgery, use of allograft or mixed allograft/autograft) definitely benefits from the use of PEMF therapy (93% successful fusion, active high-risk active patient group; 67% successful fusion, high-risk placebo patient group). In this analysis, even the low-risk patients benefit from the use of PEMF therapy, but it should be observed that the numbers of patients in this category are small.

Radiographic success tabulated fairly closely with clinical success in Table 9. Approximately 86% of patients in both the active and placebo treatment groups with a successful radiographic fusion also had a good or excellent clinical assessment. Conversely, few radiographic failures had a good clinical assessment in both treatment groups. This occurred even accounting for worker's compensation patients.

Safety was monitored by the tabulation of adverse events as recorded during the course of the clinical trial (Table 10). Eighty-five percent of patients in both treatment groups experienced no adverse events. Thirteen percent of patients in both categories found the device to be bulky or uncomfortable. Other adverse events which were noted occurring in 1-2% of the study population were minor and were relieved upon discontinuation of treatment.

DISCUSSION

This study was the first randomized double-blind trial of its kind when it was per-

Randomized Double-Blind Phase Results by Graft Type

	Active Group			Placebo Group		
Graft Type	Total Number	Total Healed	Success Rate	Total Number	Total Healed	Success Rate
Autogenous	25	23	92.0%	19	14	73.7%
Allograft	27	25	92.6%	22	16	72.7%
Mixed Auto/Allo	12	11	91.7%	12	6	50.0%
Total	64	59	92.2%	53	36	67.9%

No statistically significant differences were found between active and placebo treatment in Autogenous group and Allograft group, but Mixed Auto/Allo group (χ^2=5.04, p=0.025).

Table 5.

Randomized Double-Blind Phase Results by Number of Fusion Levels

	Active Group			Placebo Group		
Fusion Level	Total Number	Total Healed	Success Rate	Total Number	Total Healed	Success Rate
Single level	46	43	93.5%	40	29	72.5%
Double level	18	16	88.9%	13	7	53.8%
Total	64	59	92.2%	53	36	67.9%

Statistically significant differences were found between active and placebo treatment in the single level group (χ^2=6.91, p=0.01) and the double-level group (χ^2=4.84, p=0.03).

Table 6.

Randomized Double-Blind Phase Results by Internal Fixation

	Active Group			Placebo Group		
Internal Fixation	Total Number	Total Healed	Success Rate	Total Number	Total Healed	Success Rate
No Fixation	16	15	93.8%	14	8	57.1%
Fixation	48	44	91.7%	39	28	71.8%
Total	64	59	92.2%	53	36	67.9%

Statistically significant differences were found between active and placebo treatment in the no fixation group (χ^2=5.96, p=0.02) and in the fixation group (χ^2=5.59, p=0.02).

Table 7.

formed. Fusion assessment was based on plain radiographs because CT was not generally available across the United States at all the investigative centers. Analysis by flexion/extension radiographs would have been hard to standardize across multiple centers. However, these shortcomings were overcome by means of blinded radiographic review by multiple reviewers which made the fusion assessment as objective as possible.

The results of this study demonstrate

Randomized Double-Blind Phase Results by Risk Analysis

	Active			Placebo		
	Total Number	Healed	Success Rate (%)	Total Number	Healed	Success Rate (%)
Low Risk*	10	9	90	10	7	70
High Risk**	54	50	93	43	29	67
Total	64	59	92	53	36	68

*nonsmoker, single level, autogenous graft
**any one or combination of the following: smoker, multi-level, allograft, or mixed graft.

Comparison between PEMF treatment vs. Placebo:
High risk patients: χ^2=10.01 p=0.002
Low risk patients: N/A (sample size too small)

Table 8.

Randomized Double-Blind Phase Results by Clinical Assessment

	Active Group				Placebo Group			
	Radiographic Success		Radiographic Failure		Radiographic Success		Radiographic Failure	
Clinical Assessment	n	%	n	%	n	%	n	%
Excellent	30	50.8%	1	20.0%	13	36.1%	3	17.6%
Good	21	35.6%	1	20.0%	18	50.0%	5	29.5%
Fair	5	8.5%	1	20.0%	5	13.9%	4	23.5%
Poor	3	5.1%	2	40.0%	0	.0%	5	29.4%
Total	59	100.0%	5	100.0%	36	100.0%	17	100.0%

Table 9.

Randomized Double-Blind Phase Safety by Patient Complaints

	Active Group		Placebo Group	
Category	n	%	n	%
None	90	84.1%	84	84.8%
Patient finds device bulky or uncomfortable	14	13.1%	13	13.1%
Minor skin rash	2	1.9%	0	0.0%
Insomnia	0	0.0%	0	0.0%
Pain while using device	1	0.9%	1	1.0%
Fainting	0	0.0%	0	0.0%
Nausea/diarrhea	0	0.0%	0	0.0%
Polymenorrhea	0	0.0%	0	0.0%
Other	0	0.0%	1	1.0%
Total	107	100.0%	99	100.0%

Table 10.

the effectiveness of PEMF devices as an adjunct to interbody lumbar spinal fusion procedures. Spinal fusion success rate in the presence of PEMF was 92% whereas spinal fusion success rate in the placebo group (67%) was approximately equal to the average reported in the literature (66%). Though there are reports in the literature that report high success rates without PEMF, these studies are generally retrospective in nature. Prospective studies, as noted by Turner, generally have lower percentage outcomes because poorer outcome patients are followed better and more rigorous study methodology is applied to measuring patient outcome.[1] This prospective, randomized, double-blinded study reports that the addition of PEMF therapy dramatically and significantly increased fusion success rate.

Individually, the risk factors of smoking, allograft and multi-level fusions showed significant increases in the active treatment group as compared to the placebo group. A placebo nonsmoker had a 12% higher heal rate than a placebo smoker; however, a PEMF-treated smoker had an 18.9% higher heal rate than the placebo smoker. Though autograft had no noticeable advantage over allograft in the placebo group, the PEMF-treated group had a 20% higher heal rate for both types of graft. Double level placebo patients had an 18.9% higher heal rate than single level placebo patients; the addition of PEMF to the treatment regimen increased the heal rate by 35.1% in the double level and by 21% in the single level groups.

The use of internal fixation is to provide immobilization, thereby giving the motion segment a greater chance of healing. In the placebo group, the use of internal fixation in the placebo group had a 14.7% higher heal rate than placebo patients without fixation; however, the addition of PEMF to internal fixation improved the heal rate by an additional 20%.

Taking into account patients that may have multiple risk factors, patients treated with PEMF had a 24.8% higher heal rate than patients treated with placebo devices. Because the failure rate without PEMF therapy is considerable, it becomes quite cost effective to use this device, especially in all high risk patients, in order to avoid the cost and morbidity of subsequent surgery. A study regarding the cost-effectiveness of the device is published elsewhere.[9]

Other risk factors that could not be studied under this protocol included revision vs. primary fusion. Another interesting variable to study is the effect of surgical technique used for fusion. Interbody fusions account for approximately 20% of all fusions performed. Another arm of the study to be reported elsewhere[3] demonstrated a statistically significantly increased heal rate when PEMF therapy was applied to revision surgery as well as posterolateral fusions. PEMFs were also evaluated as a nonoperative salvage treatment for failed spinal fusion (interbody and posterolateral). Results reported described successful spinal fusion in 67% of patients classified as consistent users as opposed to a 19% heal rate for inconsistent users.[10]

CONCLUSION

This use of PEMF therapy adjunctively in interbody spinal fusions significantly increases heal rates, especially in the presence of one or more high risk factors such as smoking, use of allograft, and multi-level fusion surgery. ♦ ***STI***

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PMID: 25951594