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A Prospective, Randomized Study Evaluating Clinical and Radiographic Efficacy of Lumbar Interbody Fusion Performed Using a Truss Technology–Based Interbody Fusion Device With Homologous Bone or Bone Marrow Aspirate

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ABSTRACT

Background: Our group used vertebral bone marrow aspirate (BMA) with an anterior truss-based interbody implant to promote fusion. This implant has biomechanical characteristics that may enhance bone on-growth and through-growth and allow for the use of BMA clot alone. The primary end point was comparison of the proportion of patients who achieved fusion with the implant packed with either crushed cancellous homologous bone chips (CCB) alone or with BMA clot alone.

Methods: Patients were randomized to receive either BMA clot or CCB in the implant. Both groups also had supplemental fixation. Clinical assessments were performed preoperatively and postoperatively at 3, 6, and 12 months, including for the Oswestry Disability Index, leg and back visual analog scale, EQ5-D, reoperations, complications, and adverse events. Radiographs were obtained prior to discharge and at 3, 6, and 12 months postoperatively. A computed tomography scan was performed 3 months postoperatively. Radiographs were assessed by an independent radiologist to determine fusion status and evidence of subsidence.

Results: Between January 2015 and February 2016, 42 consecutive patients were randomized into 1 of the 2 study groups. There were significant postoperative changes within both groups in pain improvement across all outcome scales. There were no significant differences between groups in change scores from preoperative to assessments at any follow-up time point, with the exception of the change in EQ-5D and visual analog scale at 6 months; however, there was no difference at 3 or 12 months. There were no device-related adverse events in either group. All patients achieved grade II fusion at 3 months postoperatively. There was no significant difference in implant subsidence between groups or smokers versus nonsmokers.

Conclusions: The clinical outcomes of this study suggest that reliable fusion can be obtained using an anterior truss-based implant with either CCB or BMA alone.

Level of Evidence: 2.

Lumbar Spine

Keywords: ALIF, fusion, anterior truss based interbody implant, crushed cancellous bone, bone marrow aspirate

INTRODUCTION

Degenerative disease of the lumbar spine is highly prevalent, and as such, is a significant contributor to overall health care spending and lost productivity worldwide.[1] Interbody lumbar spinal fusion is a very common treatment for resolving back pain and leg pain due to degenerative disc disease, postlaminectomy syndrome, spondylolisthesis, stenosis, failed discectomy, and recurrent disc herniation following failed nonoperative treatment. There are numerous efficacious implant and graft options available for this surgical procedure, including implants of various shapes and materials, autograft and allograft (homologous) bone chips, bone morphogenic proteins (BMPs), demineralized bone matrix, bone marrow aspirate (BMA), and many others; however, these add to the overall cost of the procedure.[1–12] Rising

global health care costs have driven the need for the development of technologies that maintain or improve results for spinal fusion while minimizing ancillary costs. Biologics such as BMP have improved fusion but have also increased per case costs, and some clinicians have concerns about safety with high dosage and off-label use.[12,13] In an effort to reduce costs while maintaining or improving clinical and radiologic outcomes, our group has used clotted BMA from the vertebral body in conjunction with an anterior truss-based interbody implant (4WEB Medical, Frisco, TX; Figure 1) to promote fusion. Prior evidence indicates that this design type allows equal loading along all of the trusses, suggesting that this may increase initial implant stability and induce osteointegration allowing for the use of BMA clot alone.[13] To our knowledge, there are no published results with BMA clot used alone, without bone graft or a carrier, in this or any other interbody implant. The primary end point of this prospective randomized controlled trial was to compare the proportion of patients who achieved fusion with an anterior truss-based lumbar interbody implant used with either crushed cancellous homologous bone chips (CCB) alone or BMA clot alone. Fusion was defined in a binary fashion according to Bridwell scale, with levels I and II considered fused, and levels 3 and 4 considered unfused. Our primary hypothesis was that there would be no difference between the groups in terms of the proportion of patients achieving fusion. Secondary outcomes included subsidence, Oswestry Disability Index (ODI),[14] visual analog scales (VAS)[15] separately assessing back and leg pain, EQ5-D,[16] reoperations (including lumbar level, reason for subsequent surgery, type of surgery, and length of time after index surgery). In addition, postoperative complications were recorded, including but not limited to infection, neurologic injury, dural tears, hospital stay extended beyond typical duration, vascular injury, and vascular complications. We further hypothesized that there would be no difference in any of these secondary outcomes.

MATERIALS AND METHODS

This prospective randomized controlled trial was conducted in accordance with the local Institutional Review Board authority under ethics committee number 178/14, at the Goethe University (Frankfurt, Germany) facility. All patients gave informed consent before entering the trial, and there was no external financial support for the conduct of the clinical trial.

Figure 1. 4WEB Anterior Spine Truss Syste (ASTS) interbody fusion implant (4WEB Medical, Frisco, TX, USA).

Inclusion/Exclusion Criteria

Inclusion Criteria

Patients with indications for dorsoventral/ventrodorsal fusions of segments L2–L3 to L5–S1 of the lumbar spine to treat one or more of the following preoperative diagnoses:

- Painful degenerative disc disease
- Postlaminectomy syndrome
- Spondylolisthesis
- Stenosis
- Failed discectomy
- Recurrent disc herniation
- Older than 18 years

Exclusion Criteria

- Patients with abdominal scarring and adhesions from previous abdominal surgery
- Patients with prior fusion procedures of the lumbar spine
- Patients unable to undergo an operative procedure
- Patients who were pregnant or planning to become pregnant during the study

Statistical Analysis Plan

The sample size of 21 patients per group for this study was selected based on practical and not on

statistical considerations. Given that we did not expect a difference between the 2 groups, the sample size would be prohibitively large to detect a small and clinically irrelevant difference. After patients gave consent, simple random allocation to 2 groups in which either CCB or BMA was used in the implant was carried out with a random number-generating table. All patients randomized and treated were included in the analysis according to the principle of intention to treat.

Data were extracted for analyses conducted using SAS version 9.4. Descriptive statistics were calculated on all study variables, and variables were tested in terms of response distributions. Data from all patients were collected and reviewed for the primary outcome, adverse events (AEs) and severe adverse events (SAEs), and secondary measures. The primary end point was evaluated as the proportion of patients meeting criteria for fusion. The proportion and 95% confidence intervals around the proportion were calculated.

Secondary measures included were ODI,[14] VAS[15] separately assessing back and leg pain, EQ5-D including the German index,[16] work status, and reoperations (including lumbar level, reason for subsequent surgery, type of surgery, and length of time after index surgery). In addition, all postoperative complications were recorded, including but not limited to infection, neurologic injury, dural tears, hospital stay extended beyond typical duration, vascular injury, and vascular complications.

Descriptive statistics (means, standard errors, minimum, maximum, range, and upper and lower 95% confidence interval around the mean) were tabulated for all variables. Graphical methods, including frequency histograms and box plots, were used to check for outlying observations and to graphically characterize variable distributions during administration of treatment and the study follow-up period. Values from each patient were plotted and overlaid with mean values (i.e., spaghetti plot). Data points were monitored in terms of clinical outcomes, well as in terms of individual fluctuations over time that reflect safety concerns. Missing data at follow-ups were reported and analyzed descriptively. Within-patient changes in ODI, VAS, and EQ5-D from preoperative scores to scores reported at each follow-up visit (3, 6, and 12 months), as well as preoperative and postoperative subsidence measures, were analyzed with a 2-sided, paired Student t test with $\alpha = .05$. Changes in patient-reported outcomes were compared between the 2 groups during the 12-month follow-up period using a 2-sided, independent Student t test with $\alpha = .05$.

Analysis Populations

The following analysis population was used: intent-to-treat population—all patients who provided informed consent and were randomized.

Patient Completion/Disposition

Every possible effort was made by the study site personnel to contact the patient, obtain assessments, and determine the reason for discontinuation. Each patient who failed to attend the follow-up visit was first contacted by phone. Three phone contact attempts were made during a 2-week period. If phone contact attempts failed, a letter sent via registered mail was sent to the patient's last known address. If there was no response to the registered letter, or the patient was reported as being deceased, the patient was declared lost to follow-up.

The AEs and SAEs were monitored throughout the 12-month follow-up period, in the event that patients may have needed to be terminated from the study early in the event of safety concerns.

Device

The 4WEB Anterior Spine Truss System (ASTS) Interbody Fusion Device was used in conjunction with supplemental spinal fixation (Figure 1). The implants used were manufactured from titanium using 3-dimensional additive manufacturing technology to produce a network of intersecting struts or trusses. This design maintains biomechanical strength by distributing the axial load throughout the implant, while preserving an open architecture for bone incorporation. The geometric configuration of the truss design distributes axial forces along the individual strut members throughout the entire cage such that the graft material within the cage experiences microstrain, stimulating bone growth and remodeling. Additionally, the truss structure of the end plate contact area distributes load evenly across a larger cross-sectional area, resulting in decreased point loading and more adjacent bone stimulation. We hypothesized that this design may facilitate fusion better than traditional implant designs and allow us to use BMA alone.

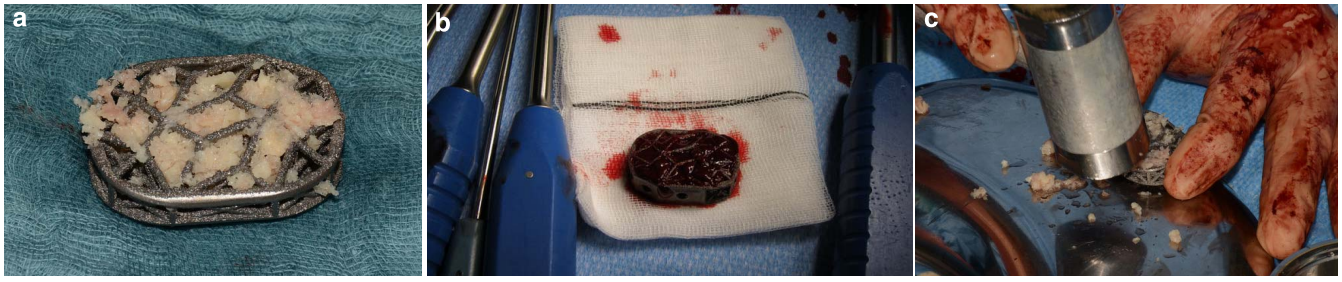

Figure 2. (a) Cage with crushed cancellous bone (CCB) alone packed into the cage. (b) Cage with bone marrow aspirate (BMA) clot packed into the cage. (c) CCB being packed into the cage.

Surgical Procedure

Patients requiring anterior lumbar interbody fusion were randomized into 1 of 2 treatment groups, with either CCB alone (Figure 2a) or with the maximum available volume (5–10 mL) of vertebral BMA alone (Figure 2b) packed into the 4WEB ASTS Interbody Fusion Device used in conjunction with supplemental spinal fixation with either an anterior plate, or posterior screws and rods.

The BMA was taken from the adjacent vertebra using a biopsy needle. The Anterior Lumbar Interbody Fusion (ALIF) cage was placed into a bowl with BMA or filled with a syringe. Because of the special truss design of this device and the roughness of every strut within the cage, the bone marrow could easily clot inside of the cage. On average, 5–10 mL of BMA and 5–10 cm^3 of CCB were used (Figure 2 depicts the cages with BMA and CCB).

Clinical Assessment

Clinical assessments were performed preoperatively and postoperatively at 3, 6, and 12 months. Preoperative data collection included general demographics, such as age, sex, body mass index, previous lumbar spine surgery, and smoking status. The clinical outcome measures used for the study included the ODI,[14] VAS[15] separately assessing back and leg pain, and EQ-5D.[16] The EQ-5D scores were compiled into a single utility index weighted specifically for Germany, because the study took place in Germany.[17] In addition, postoperative complications and any AEs, such as infection, neurologic injury, dural tears, hospital stay extended beyond typical duration, vascular injury, and vascular complications, were recorded.

Radiographic Assessment

Radiographs were obtained prior to hospital discharge following surgery and at 3, 6, and 12 months postoperatively (Figure 3). At 3 months a computed tomography (CT) scan was also obtained to assess fusion per standard practice in our department. Bridwell classification of progressive fusion grades was used to evaluate bone consolidation (Table 1).[18] Determination of fusion status and evidence of subsidence was also assessed via radiographic images by an independent radiologic reviewer. Radiographic assessments were based on lateral, anterior-posterior (AP), and flexion-extension X-rays after 12 months. CT scans were obtained (1-mm axial native slice thickness, with 3- to 5-mm slices for sagittal and coronal reconstructions) at the 3-month follow-up. All quantitative analyses were produced by trained analysts, per established standard operating procedures using Quantitative Motion Analysis (QMA), a proprietary radiographic image analysis software.[19] The QMA system has been previously validated to produce measurements of intervertebral rotation, translation, and change in disc height accurate to within 1 degree of rotation and 0.5 mm spatially.

RESULTS

Between January 2015 and February 2016, 42 consecutive patients were recruited and randomized into 1 of 2 previously defined study groups and underwent the index study procedure. One patient randomized to the BMA group withdrew from the study prior to surgery. There were 2 patient deaths due to cardiac events, 1 in each group, and they were determined not to be related to the surgical procedure. Two additional patients were recruited due to the cardiac patient deaths, increasing the total recruitment to 42 patients. One patient with an adjunctive posterior construct greater than 4 levels also died and was counted in both the adjunctive fusion and death groups.

Both groups were evenly distributed for patient age ($P = .93$). The proportion of males and females

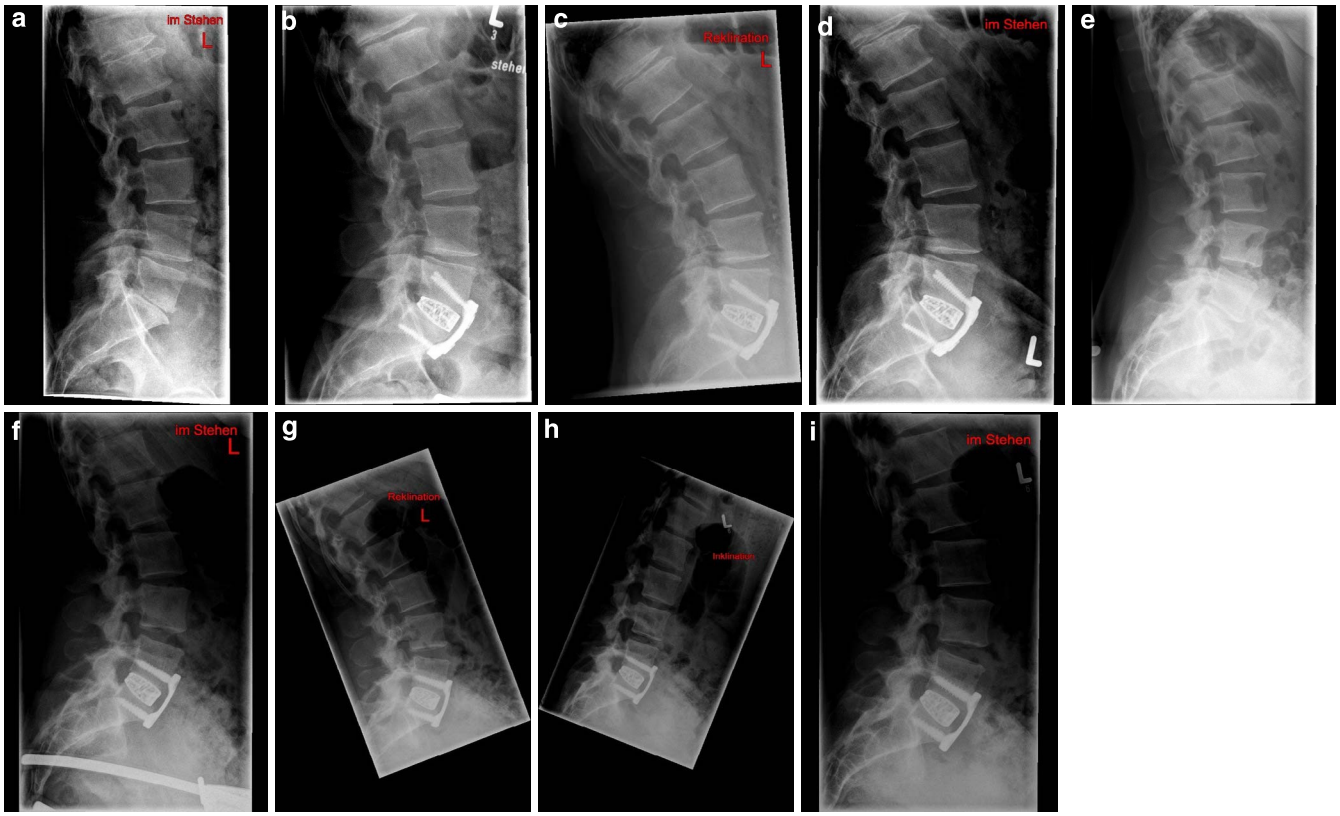

Figure 3. (a) Preoperative X-ray, bone marrow aspirate (BMA) group. (b) Six-month postoperative X-ray, BMA group. (c)12 months postoperative X-ray BMA group (functional). (d) 12 months postoperative X-ray BMA group. (e) Pre-operative X-ray CCB group. (f) 6 months postoperative X-Ray CCB group. (g) 12 months postoperative X-ray CCB group (functional1). (h) 12 months postoperative X-ray CCB group (functional2). (i) 12 months postoperative X-ray CCB group.

was significantly different between the 2 groups, because 81% of the patients in the CCB group were female, whereas 49% of the patients in the BMA group were female ($P = .04$). Most of the patients in both groups smoked—66% in the CCB group and 75% in the BMA group—but the proportion of smokers was not significantly different between the groups ($P = .56$). Complete patient demographics are listed in Table 2.

Patient-Reported Outcomes: ODI, VAS, and EQ-5D

There were significant changes at follow-up compared with preoperative scores within groups, particularly with regard to improvement in pain across all outcome scales (Tables 3–7).

Table 1. Bridwell grading system for radiographic assessment of anterior interbody fusion.

Grade	Description
I	Fusion with remodeling and trabeculae present
II	Intact graft with incomplete remodeling and no lucency present
III	Intact graft with potential lucency at the cranial or caudal end
IV	Absent fusion with collapse/resorption of the graft

There were no treatment-related AEs that required unscheduled clinical visits or subsequent surgery in either study group. There were no statistically significant differences between groups in the change scores from preoperative assessments to assessments at any follow-up time point, with the exception of the change in EQ-5D and VAS at 6 months; however, this appears to be an outlier, and there were no differences at 3 and 12 months (Table 8).

Radiographic Outcomes

At 3 months postoperatively, all patients achieved radiographic evidence of grade II fusion

Table 2. Patient demographics.

Patients	CCB	BMA	P Value Between Groups
Males, n (%)	4 (19.0)	10 (51)	.04
Females, n (%)	17 (81)	11 (49)	
Average age ± SD, y	58.95 ± 14.6	58.33 ± 33.99	.93
Smokers, n (%)	14 (66)	15 (75)	.56
Nonsmokers, n (%)	7 (33)	5 (25)	
BMI	25.47 ± 4.4	27.36 ± 5.3	.23

Abbreviations: BMA, bone marrow aspirate; BMI, body mass index; CCB, crushed cancellous homologous bone chips.

Table 3. Oswestry Disability Index (ODI) preoperative (preop) scores versus follow-up scores for the bone marrow aspirate (BMA) group at 3, 6, and 12 months.

BMA	Mean	SD	N	Lower 95% CL for Mean	Upper 95% CL for Mean	Paired *t* Value	*P* Value
Preop							
Pain	3.89	0.80	19	3.50	4.28	—	
Body care	2.63	0.76	19	2.26	2.99	—	
Lifting	3.47	1.12	19	2.93	4.01	—	
Ambulate	3.25	1.20	20	2.68	3.81	—	
Sit	3.30	0.92	20	2.86	3.73	—	
Stand	4.10	1.02	20	3.62	4.57	—	
Sleep	2.50	0.88	20	2.08	2.91	—	
Sex life	3.58	2.06	12	2.27	4.89	—	
Social life	4.00	1.10	19	3.46	4.53	—	
Travel	3.68	1.41	19	3.00	4.36	—	
ODI %	69.02	13.36	20	62.76	75.28	—	
3 mo							
Pain	3.05	0.97	19	2.58	3.52	2.73	<.01[b]
Body care	2.55	1.46	18	1.82	3.28	0	1
Lifting	4.15	1.46	19	3.45	4.86	−1.53	.14
Ambulate	2.23	1.48	17	1.47	2.99	3.25	<.01[b]
Sit	2.73	1.194	19	2.16	3.31	1.93	.06
Stand	3.57	1.16	19	3.01	4.14	2.19	.04[b]
Sleep	2.23	1.14	17	1.64	2.82	1.29	.22
Sex life	3.90	2.02	10	2.45	5.34	0.28	.78
Social	3.47	1.50	19	2.74	4.19	1.49	.15
Travel	3.29	1.611	17	2.46	4.121	1.62	.12
ODI %	62.43	20.53	19	52.51	72.35	1.62	.12
% Change	7.21	21.59	21	−0.57	19.07		
6 mo							
Pain	2.88	0.90	18	2.44	3.33	3.39	.004[b]
Body care	2.22	1.30	18	1.57	2.87	1.33	.20
Lifting	3.66	1.41	18	2.96	4.36	−0.50	.62
Ambulate	2.22	1.43	18	1.50	2.93	3.52	<.01[b]
Sit	2.66	1.13	18	2.10	3.23	1.83	.09
Stand	3.22	1.16	18	2.64	3.80	2.47	.02[b]
Sleep	2.22	1.06	18	1.69	2.74	1.76	.09
Sex life	4.28	2.21	7	2.23	6.33	0.78	.47
Social	3.17	1.50	17	2.40	3.95	1.72	.10
Travel	2.43	1.15	16	1.82	3.05	2.38	.03[b]
ODI %	55.87	17.98	18	46.93	64.81	2.71	<.01[b]
ODI % change	17.84	27.40	21	5.36	30.32		
12 mo							
Pain	3.15	0.95	19	2.69	3.61	2.13	.05
Body care	2.36	1.46	19	1.66	3.07	0.92	.36
Lifting	3.36	1.46	19	2.66	4.07	0.16	.87
Ambulate	2.36	1.460	19	1.66	3.07	3.52	.002[b]
Sit	2.36	0.955	19	1.90	2.82	2.69	<.01[b]
Stand	3.31	1.33	19	2.67	3.95	2.06	.05[b]
Sleep	2.42	0.96	19	1.95	2.88	0.25	.08
Sex life	3.40	2.11	10	1.88	4.91	0.63	.55
Social	3.27	1.22	18	2.66	3.8	1.65	.12
Travel	2.33	1.08	18	1.79	2.87	2.58	.02[b]
ODI %	56.35	17.91	19	47.7	64.99	2.51	.02[b]
ODI % change	14.74	26.19	21	2.82	26.66		

Abbreviations: CL, confidence limit; —, not applicable.
[a]Paired *t* test. A higher score indicates more disability.
[b]Statistically significant $P = .05$.

(probable fusion, graft intact [CCB group], not fully remodeled, no areas of radiolucency). There was no subjective radiographic evidence of bone-to-implant radiolucency, implant migration, or marked implant subsidence at any follow-up in any patient. Average subsidence in the CCB group was 0.4 ± 0.4 mm at 6 months and 0.6 ± 0.5 mm at 12 months postoperatively ($P = .613$). In the BMA group, the average subsidence was 1.0 ± 1.7 mm at 6 months and 1.1 ± 1.7 mm at 12 months ($P = .797$; Table 9). There was no statistically significant difference across groups at 6 months ($P = .184$) or at 12 months ($P = .235$) postoperatively (Table 9). The average subsidence in smokers was 0.5 ± 0.6 mm at 6 months and 0.7 ± 0.6 mm at 12 months postoperatively ($P = .278$). In nonsmokers, the average subsidence was 0.8 ± 1.2 mm at 6 months and 0.9 ± 1.2 mm at 12 months ($P = .944$). There was no statistically significant

Table 4. Oswestry Disability Index (ODI) preoperative (preop) scores versus follow-up scores for the crushed cancellous homologous bone chips (CCB) Group at 3, 6, and 12 months.[a]

ODI CCB	Mean	SD	N	Lower 95% CL for Mean	Upper 95% CL for Mean	Paired *t* Value	*P* Value
Preop							
Pain	3.90	0.79	20	3.53	4.27	—	—
Body care	1.90	0.91	20	1.47	2.33	—	—
Lifting	3.60	1.10	20	3.09	4.11	—	—
Ambulate	2.32	1.11	19	1.78	2.85	—	—
Sit	3.00	1.34	20	2.37	3.63	—	—
Stand	3.80	1.15	20	3.26	4.34	—	—
Sleep	2.55	0.89	20	2.13	2.97	—	—
Sex life	3.21	1.53	14	2.33	4.10	—	—
Social life	3.50	1.19	20	2.94	4.06	—	—
Travel	3.45	1.57	20	2.71	4.19	—	—
ODI %	62.68	15.27	20	55.53	69.82	—	—
3 mo							
Pain	3.10	1.18	21	2.56	3.63	2.71	<.01[b]
Body care	2.05	1.36	21	1.43	2.67	−0.33	.75
Lifting	3.84	1.54	19	3.10	4.58	−1.36	.19
Ambulate	2.48	1.69	21	1.71	3.25	−0.74	.47
Sit	3.00	1.18	21	2.46	3.54	0	1.0
Stand	2.95	1.36	21	2.33	3.57	3.11	<.01[b]
Sleep	2.52	1.12	21	2.01	3.04	0	1.0
Sex life	2.44	1.59	16	1.59	3.28	1.59	.14
Social	3.43	1.29	21	2.84	4.01	1.49	.15
Travel	3.10	1.65	20	2.33	3.87	0.66	.51
ODI %	58.54	24.01	20	47.30	69.77	1.62	.12
% Change	4.14	25.73	20	-7.90	16.18	—	—
6 mo							
Pain	2.86	1.15	21	2.33	3.38	4.07	<.01[b]
Body care	2.00	1.34	21	1.39	2.61	−0.30	.77
Lifting	3.40	1.39	20	2.75	4.05	0.45	.65
Ambulate	2.20	1.47	20	1.51	0.36	0.36	.72
Sit	2.55	1.23	20	1.97	3.13	1.29	.21
Stand	2.90	1.52	20	2.19	3.61	3.14	<.01[b]
Sleep	2.29	1.10	21	1.78	2.79	1.0	.33
Sex life	2.47	1.73	15	1.51	3.42	1.69	.12
Social	2.90	1.61	21	2.17	3.64	1.68	.11
Travel	2.50	1.64	20	1.73	3.27	2.31	.03[b]
ODI %	51.26	24.21	21	40.24	62.28	2.29	.03[b]
ODI % change	12.06	23.55	20	1.04	23.07	—	—
12 mo							
Pain	2.74	1.24	19	2.14	3.33	4.11	<.01[b]
Body care	2.05	1.39	19	1.38	2.72	−0.18	.86
Lifting	3.42	1.57	19	2.66	4.18	0.82	.42
Ambulate	2.16	1.42	19	1.47	2.84	0.34	.73
Sit	2.42	1.07	19	1.91	2.94	2.41	.03[b]
Stand	2.79	1.47	19	2.08	3.50	4.89	<.01[b]
Sleep	2.32	1.06	19	1.81	2.83	1.19	.25
Sex life	2.21	1.76	14	1.20	3.23	1.92	.08
Social	2.68	1.57	19	1.93	3.44	3.13	<.01[b]
Travel	2.44	1.62	18	1.64	3.25	2.92	<.01[b]
ODI %	50.74	23.96	19	39.19	62.28	2.81	<.01[b]
ODI % change	17.88	23.17	20	7.03	28.72	—	—

Abbreviations: CL, confidence limit; —, not applicable.
[a]Paired *t* test. A higher score indicates more disability.
[b]Statistically significant $P = .05$.

difference across smokers versus nonsmokers at 6 months ($P = .365$) or at 12 months ($P = .511$) postoperatively (Table 10).

One patient presented with bilateral sacral fractures related to osteoporosis. Another patient presented postoperatively with a sacral fracture following a fall. In both fracture patients, the ASTS implants were unaffected and the sacral fractures were surgically fixed using iliac bone screws without further complication. These patients remained in the study and achieved all follow-up assessments.

DISCUSSION

Lumbar fusion for degenerative disease is one of the most common surgical procedures in the Western world, and as such, contributes substantially to health care spending.[1] Goals of lumbar interbody fusion include the creation of a stable

Table 5. EQ-5D preoperative (preop) scores versus follow-up scores for the bone marrow aspirate (BMA) group at 3, 6, and 12 months.[a]

BMA EQ5-D	Mean	SD	N	Lower 95% CL for Mean	Upper 95% CL for Mean	Paired *t* Value	*P* Value
Preop							
Mobility	3.47	0.96	19	3.01	3.94	—	—
Self-care	2.74	1.05	19	2.23	3.24	—	—
ADL	3.58	0.61	19	3.29	3.87	—	—
General pain	3.63	0.68	19	3.30	3.96	—	—
Preop anxiety	2.37	1.12	19	1.83	2.91	—	—
Health today	33.37	19.51	19	23.97	42.77	—	—
Index	0.47	0.21	19	0.37	0.57	—	—
3 mo							
Mobility	2.75	1.21	20	2.18	3.32	2.17	.04[b]
Self-care	2.40	1.23	20	1.82	2.98	0.97	.34
ADL	2.95	1.23	20	2.37	3.53	2.12	.05[b]
General pain	3.15	0.88	20	2.74	3.56	1.92	.07
Anxiety	2.10	1.17	20	1.55	2.65	1.24	.23
Health today	61.42	20.99	19	51.30	71.54	−5.06	<.01[b]
Index	0.58	0.27	20	0.46	0.70	−1.53	.14
6 mo							
Mobility	2.33	1.08	18	1.79	2.87	3.36	<.01[b]
Self0care	2.22	1.26	18	1.59	2.85	1.0	.28
ADL	2.61	1.24	18	1.99	3.23	3.11	<.01[b]
General pain	2.72	0.89	18	2.28	3.17	4.24	<.01[b]
Anxiety	1.88	0.99	17	1.37	2.39	2.67	.02[b]
Health today	66.72	18.88	18	57.33	76.11	−6.19	.00[b]
Index	0.71	0.23	17	0.60	0.84	−3.50	<.01[b]
12 mo							
Mobility	2.32	1.11	19	1.78	2.85	4.24	<.01[b]
Self-care	2.00	1.05	19	1.49	2.51	0.92	.37
ADL	2.67	1.19	18	2.08	3.26	3.05	.01[b]
General pain	2.95	0.78	19	2.57	3.32	2.83	<.01[b]
Anxiety	1.89	1.28	18	1.25	2.52	1.37	.19
Index	0.70	0.20	17	0.60	0.80	−2.66	.02[b]
Health today	61.84	23.13	19	50.69	72.99	−4.10	<.01[b]

Abbreviations: ADL, activities of daily living; CL, confidence limit; —, not applicable.
[a]Paired *t* test. A higher score for the "health today" measure indicates better health. A lower score for all other measures indicates better health.
[b]Statistically significant $P = .05$.

spine segment and the formation of a solid and durable bone union between the affected vertebral bodies.[20] This prospective randomized clinical study suggests that BMA clot with no carrier or bone, used in conjunction with the 4WEB Medical ASTS Interbody Fusion Device, results in similar clinical and radiographic outcomes compared with the same device used in conjunction with CCB, despite the inclusion of complex, multilevel cases. To our knowledge, there are no other studies published in which native BMA clot with no carrier or bone was used in an interbody device to promote fusion. Use of BMA in conjunction with the ASTS Interbody Fusion Device allowed a reduction in overall cost of the surgery, with a cost for Tutoplast of approximately 350€–400€ for 10 cm^3 compared with approximately 50€–60€ for a biopsy needle, with equivalent clinical and radiologic outcomes.

It is unclear if the same results could be achieved with traditional lumbar interbody fusion devices which typically consist of solid or porous/roughened surfaces with annular designs. These implants generally have a large central fusion window for packing a variety of bone or bone substitute materials for enhancing fusion. A number of patient-specific factors, such as body mass index, smoking, age, American Society of Anesthesiologists level and other comorbidities affect fusion; however, these were controlled with randomization in this study. Benzel[21] identified 4 device- and procedure-related variables that are necessary for successful lumbar interbody fusion, including surface area contact of the bone graft to end plate, surface area contact of the implant to end plate, construct integrity, and endplate preparation. The authors also suggest that balancing the area of graft to end plate contact versus the area of implant to graft contact may affect fusion. An anterior truss-based implant design with its open architecture creates a multidimensional load-bearing scaffold for structural support, fixation, and incorporation (Figure 1). This design allows for adequate support without compromising BMA or bone graft surface area contact at the end plate. The truss structure of the end plate contact area also distributes load evenly across a larger cross-sectional area, resulting

Table 6. EQ-5D Preoperative (preop) scores versus follow-up scores for the crushed cancellous homologous bone chips (CCB) group at 3, 6, and 12 months.[a]

CCB EQ-5D	Mean	SD	N	Lower 95% CL for Mean	Upper 95% CL for Mean	Paired *t* Value	*P* Value
Preop							
Mobility	3.04	0.86	21	2.65	3.44	—	—
Self-care	2.00	1.00	21	1.54	2.45	—	—
ADL	3.19	0.81	21	2.82	3.56	—	—
General pain	3.57	0.67	21	3.26	3.87	—	—
Anxiety	2.00	1.00	21	1.54	2.45	—	—
Health today	47.38	20.25	21	38.15	56.60	—	—
Index	0.55	0.162	21	0.47	0.62	—	—
3 mo							
Mobility	3.90	6.54	21	0.92	6.88	−0.58	.56
Self-care	2.09	1.13	21	1.57	2.61	−0.33	.74
ADL	2.90	1.22	21	2.34	3.46	0.97	.34
General pain	2.85	1.01	21	2.39	3.31	2.75	<.01[b]
Anxiety	1.95	1.16	21	1.42	2.48	0.24	.81
Health today	62.95	21.08	21	53.35	72.54	−2.56	.02[b]
Index	0.64	0.25	21	0.53	0.76	−1.57	.13
Index change	−0.09	0.27	21	−0.21	0.03		
6 mo							
Mobility	2.42	1.26	19	1.81	3.02	2.25	.04[b]
Self-care	1.89	1.10	19	1.36	2.42	0.38	.70
ADL	2.63	1.42	19	1.94	3.31	1.87	.07
General pain	2.57	1.07	19	2.06	3.09	4.47	<.01[b]
Anxiety	2.00	1.20	19	1.42	2.57	0	1.0
Today	57.78	28.79	19	43.91	71.66	−1.68	.10
Index	0.68	0.29	19	0.54	0.822	−2.01	.06
Index change	−0.13	0.28	19	−0.26	0.00		
12 mo							
Mobility	2.11	1.27	18	1.47	2.74	4.03	<.01[b]
Self-care	1.72	0.89	18	1.27	2.16	1.32	.2
ADL	2.44	1.24	18	1.82	3.064	2.73	<.01[b]
General pain	2.72	1.07	18	2.18	3.25	3.5	<.01[b]
Anxiety	2.05	1.16	18	1.47	2.63	0	1.0
Health today	63.94	27.34	18	50.34	77.54	−2.07	.05[b]
Index	0.70	0.25	18	0.58	0.83	−3.24	<.01
index change	−0.17	0.23	18	−0.29	−0.061		

Abbreviations: CL, confidence limit; —, not applicable.
[a]Paired *t* test. A higher score for the "health today" measure indicates better health. A lower score for all other measures indicates better health.
[b]Statistically significant $P = .05$.

in decreased point loading and more adjacent bone stimulation.

The results of this study are similar to those of other reports of ALIF procedures with supplemental fixation as well as stand-alone ALIF in the current literature. Mobbs et al[22] reported clinical and radiographic outcomes of a titanium-coated polyetheretherketone ALIF implant in 1-, 2-, and 3-level procedures, with 15 of 20 patients available for assessment. Clinical and radiographic outcomes through 12 and 15 months were similar to those in this study for improvement in ODI, relief of pain, restoration of function, and fusion. However, in all cases, the patients received an implant of allograft and bone morphogenic proteins (BMP-2) to enhance the probability of fusion.[22] A systematic review of stand-alone ALIF fusion rates by Manzur et al[23] of 55 studies with 5517 patients revealed an overall fusion rate of 88.2%. The fusion rate of patients (n = 889) treated with rhBMP-2 was 94.4% compared with 88.4% for patients (n = 3102) who were not treated with rhBMP-2; however, this difference was not significant ($P = .106$). Fusion rates of smokers versus nonsmokers were also evaluated. Three cohorts with more than 50% smokers (n = 178) had a fusion rate of 68.8% compared with 81.8% for 4 cohorts with more than 50% nonsmokers (n = 2382).[23] We did not observe any differences in either fusion or subsidence in smokers versus nonsmokers; however, our sample size was comparatively small, and we used supplemental fixation.

Implant subsidence due to the loading patterns of the device on the prepared vertebral end plate is a frequent complication in anterior spine surgery, which may result in a loss of correction, increased pain, and/or recurrence of preoperative symptoms. We observed very little implant subsidence or migration in this study in either group. This may be due to the roughened surface and larger footprint of this implant and the truss design, which may help to maximize implant stability while distributing the

Table 7. Visual analog scale (VAS) preoperative (preop) back and leg scores versus follow-up scores at 3, 6, and 12 months.[a]

Group	Mean	Std Dev	N	Lower 95% CL for Mean	Upper 95% CL for Mean	Paired t value	p value
BMA							
Pre Op							
Back Pain	6.85	1.78	20	6.01	7.68	—	—
Leg Pain	5.05	2.93	19	3.63	6.47	—	—
3 Months							
Back Pain	4.15	2.52	19	2.94	5.37	4.01	<.01*
Back change	2.76	2.98	21	1.40	4.11	—	—
Leg Pain	2.84	2.40	19	1.68	4.00	3.66	<.01*
leg change	2.00	3.16	21	0.56	3.43	—	—
6 Months							
Back Pain	3.88	2.34	17	2.67	5.08	4.74	<.01*
back change	3.38	2.87	21	2.07	4.68	—	—
Leg Pain	3.27	3.04	18	1.76	4.79	2.13	.05*
leg change	1.76	4.36	21	-0.22	3.75	—	—
12 Months							
Back Pain	4.05	2.41	18	2.85	5.25	4.03	<.01*
back change	3.04	3.12	21	1.62	4.46	—	—
Leg Pain	3.63	2.69	19	2.33	4.92	1.59	.13*
Leg Change	1.28	3.9	21	-0.49	3.06	—	—
CCB							
Pre Op							
Back Pain	7.04	1.28	21	6.46	7.63	—	—
Leg Pain	4.95	3.13	21	3.52	6.38	—	—
3 Months							
Back Pain	3.66	2.55	21	2.50	4.83	7.27	<.01*
Back change	3.38	2.13	21	2.41	4.35	—	—
Leg Pain	2.90	2.46	21	1.78	4.02	2.86	<.01*
leg change	2.04	3.27	21	0.55	3.53	—	—
6 Months							
Back Pain	4.14	3.00	21	2.77	5.51	4.86	<.01*
back change	2.90	2.73	21	1.65	4.1	—	—
Leg Pain	3.28	3.25	21	1.80	4.7	2.57	.02*
leg change	1.66	2.97	21	0.31	3.01	—	—
12 Months							
Back Pain	3.50	3.07	18	1.97	5.02	4.96	<.01*
back change	4.04	3.12	21	2.62	5.46	—	—
Leg Pain	2.77	3.09	18	1.23	4.31	1.79	.09
Leg Change	2.57	3.69	21	0.88	4.25	—	—

Abbreviations: CL, confidence limit; —, not applicable.
[a]Paired *t* test. A higher score indicates more pain.
[b]Statistically significant $P = .05$.

Table 8. Comparison of changes from preoperative patient-reported outcome scores to scores at 3-, 6-, and 12-month follow-up between bone marrow aspirate (BMA) and cancellous homologous bone chips (CCB) groups.[a]

Mean Change Preoperative Scores	BMA Mean Change Preoperative Scores ± SD; n	CCB Mean Change Preoperative Scores ± SD; n	Independent *t* Value	*P* Value
ODI				
3 mo	7.21 ± 20; 21	4.14 ± 26; 20	0.42	.67
6 mo	16.21 ± 26; 19	12.06 ± 23; 20	0.52	.60
2 mo	14.74 ± 26; 21	17.88 ± 23; 23	0.41	.69
EQ5D Index				
3 mo	−0.11 ± 0.31; 19	−0.09 ± 0.27; 21	0.17	..87
6 mo	−0.15 ± 0.31; 18	−0.13 ± 0.28; 19	0.26	.80
12 mo	−0.19 ± 0.34; 18	−0.18 ± 0.23; 18	0.11	.91
EQ5D VAS				
3 mo	−244.99 ± 26.37; 19	−15.57 ± 28.85; 21	1.09	.82
6 mo	−26.9 ± 42.3; 19	−4.9 ± 37.2; 21	2.01	.05*
12 mo	−24.8 ± 29.5; 19	−7.42 ± 38.5; 21	1.61	.12
Back VAS				
3 mo	2.76 ± 2.98; 21	3.38 ± 2.13; 21	0.77	.44
6 mo	3.4 ± 2.1; 21	2.9 ± 2.7; 21	0.55	.58
12 mo	3.0 ± 3.2; 21	4.0 ± 3.1; 21	1.04	.31
Leg VAS				
3 mo	2.0 ± 3.2; 21	2.04 ± 3.3; 21	0.05	.96
6 mo	1.8 ± 4.4; 21	1.7 ± 3.0; 21	−0.08	.93
12 mo	1.2 ± 3.9; 21	1.3 ± 3.9; 21	1.09	.28

[a]Independent *t* test.
[b]Statistically significant $P = .05$.

Table 9. Independent radiographic reviewer results of postoperative subsidence reported as mean ± SD (range: minimum, maximum).[a]

Group	6 mo, mm	12 mo, mm	*P* Value
CCB	−0.4 ± 0.4 (−1.2 to 0.0)	−0.6 ± 0.5 (−1.7 to −0.1)	.613
BMA	−1.0 ± 1.7 (−7.2 to 0.4)	−1.1 ± 1.7 (−7.3 to 0.4)	.797
P Value	.184	.235	

Abbreviations: BMA, bone marrow aspirate; CCB, cancellous homologous bone chips.
[a]Independent *t* test.

load across the implant/end plate interface, creating a stable environment for bone cell adhesion, on-growth and through-growth.[24,25]

As a small, single-center clinical trial, a major limitation of this study is the extrapolation of this case series across a large patient population. Further limitations of the study might include the lack of a third control group with a traditional interbody implant packed with BMA, quantitative control and assessment of the graft amounts across both groups, and control of supplemental spinal fixation. In addition, there were 7 patients who underwent large, corrective spine procedures that spanned between 7 and 14 levels that were included in the analysis per the intent-to-treat study design. More well-defined inclusion criteria would have eliminated this subset of patients from the study. In addition, bone mineral density was not assessed prior to surgery and may be an important variable in the consideration of mechanical performance of the implant-to-bone interface.

In conclusion, the results of this prospective, randomized clinical trial suggest that the use of BMA with the 4WEB ASTS Interbody Fusion Device results in similar clinical and radiographic results compared with use of the same implant with CCB. Further study is warranted to assess efficacy of the BMA with traditional interbody implants, the ASTS implant in combination with BMA across multiple surgeons/sites, and the reproducibility of these results across other spine truss systems implants (cervical, lateral, and posterior).

Table 10. Independent radiographic reviewer results of postoperative subsidence for smokers versus nonsmokers reported as mean ± SD (range: minimum, maximum).[a]

	6 mo, mm	12 mo, mm	*P* Value
Smokers	−0.5 ± 0.6 (−2.8 to 0.0)	−0.7 ± 0.6 (−2.8 to −0.0)	.278
Nonsmokers	−0.8 ± 1.2 (−3.0 to 0.4)	−0.9 ± 1.2 (−3.0 to 0.4)	.944
P value	.365	.511	

[a]Independent *t* test.

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