Comparison of Bioresorbable and Titanium Plates in Cervical Spinal Fusion

Early Radiologic and Clinical Results

Abdullah Nabhan, MD, Basem Ishak, Cand Med,* Oliver Steimer, MD,† Anna Zimmer, MD,*‡ Tobias Pitzen, MD,* Wolf-Ingo Steudel, MD,* and Dietrich Pape, MD†*

Study Design: This is a prospective, randomized, and controlled study, approved by the local ethical committee of Saarland (Germany), no. 209/06.

Objective: The aim of this study was to compare clinical results, segmental motility, magnetic resonance imaging (MRI) compatibility, and change of the bone density of a cervical spine segment that was treated with either bioresorbable or titanium plates in single level.

Summary and Background Data: Anterior cervical discectomy and fusion including plate fixation is an accepted technique for treatment of symptomatic degenerative disc disease. Titanium plates have been used but cause imaging artifacts. Radiolucent bioresorbable plates and screws were developed to reduce the imaging artifacts associated with titanium.

Methods: Forty patients with single level cervical radiculopathy were randomized to anterior discectomy and fusion with bioresorbable plate (19 patients, study group) or titanium plate (18 patients, control group). Follow-up used a visual analog scale (VAS) with regard to brachial pain and Neck Disability Index (NDI) for neck pain. Radiostereometry was performed immediately postoperative and after 6 weeks, 3, and 6 months. MRI of the cervical spine was obtained immediately postoperatively at 3 and 6 months to assess hematoma, infection, and swelling. Computed tomography of the operated cervical spine segment was performed to assess bone density, expressed in Hounsfield units.

Results: Three-dimensional analysis of segmental motion (medio-lateral, cranio-caudal and anterior-posterior) did not reveal any statistical difference between both groups at any time postoperatively ($P > 0.05$). Fusion rate and speed evaluated on Radiostereometric analysis and computed tomography of cervical spine segment were similar in both groups. MRI of cervical spine did not show any pathology, especially hematoma and infection. The VAS and NDI did not differ between both groups after 6 months ($P > 0.05$).

Conclusions: Anterior plate fixation by using a bioresorbable plate has the same fusion progress and stability as titanium. During the study, no complications like soft tissue swelling and infection occurred.

Key Words: spine, fusion, implants, MRI, bioresorbable, clinical study

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Surgery for degenerative disc disease of the cervical spine is one of the commonest procedures undertaken by spinal surgeons when conservative treatment fails. The gradual progression in degenerative disc disease begins with the weakening of the anulus fibrosis followed by protrusion or herniation of disc material into the spinal canal causing of cervical pain and radiculopathy. Myelopathy generally has a delayed onset and more insidious course.

Anterior cervical discectomy and fusion (ACDF) using cage with plate fixation is an accepted technique for treatment of radiculopathy and myelopathy owing to degenerative disease of the cervical spine.[1–3]

Plate fixation has been introduced to improve stability, maintain cervical lordosis, reduce pseudarthrosis rate, and improve clinical results.[4,5] However, its value has been questioned especially in monosegmental fusion.[6–8] ACDF of single level with or without internal fixation both have reported fusion rates at or above 90%.[4,6,9,10]

A recent study suggests a statistically significant advantage for anterior plating.[2] Implant failure, plate migration, stress shielding, and compression of anterior soft tissue structures are possible complications that may require further surgery.[11–13] Follow-up imaging using computerized tomography (CT) or magnetic resonance imaging (MRI) in postoperative ACDF with metal implant contains artifacts that make radiologic interpretation more challenging[1,14] and invasive myelography may be needed to assess patency of the spinal canal and neural foramina. Radiolucent, bioresorbable polymer plate and screws have potential added benefit of stabilization with internal immobilization while possibly

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From the Departments of *Neurosurgery; †Orthopaedics; and ‡Neuroradiology, University of Saarland, Homburg, Germany.
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Reprints: Abdullah Nabhan, MD, Department of Neurosurgery, University of Saarland, Homburg, Germany (e-mail: dr_a_nabhan@hotmail.com).
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reducing some of the long-term complications and imaging artifacts associated with titanium instrumentation.[15,16] Also, because the material is fully absorbed, further surgical intervention at adjacent levels need not involve removal of an implant. But bioresorbable materials must not only be tolerated well in vivo but must provide similar fusion rate and speed to currently available implants. This study compares clinical results, segmental motility, MRI compatibility, and change of the bone density of a cervical spine segment treated with bioresorbable versus titanium plate.

PATIENTS AND METHODS

This is a randomized, controlled, prospective study, approved by the local ethical committee of Saarland (Germany), no. 209/06.

Forty patients [23 men and 17 women, mean age 48, standard deviation (SD) 2.8 y] suffering from symptomatic degenerative disc disease with radiculopathy, not responding to a trial of conservative treatment were treated between September 2006 and May 2007. All patients have had confirmatory imaging studies and were informed of the purpose of the study, giving written informed consent at least 24 hours before surgery.

Randomization evolved by drawing cards in sealed envelopes. Twenty patients received ACDF in single level with bioresorbable plate (study group) and 20 patients had ACDF in single level with titanium plate fixation (control group). Two patients from the control group were excluded from the study because of insertion of other cages and a third patient from the study group moved to America. Inclusion and exclusion criteria are listed in Table 1.

Surgery was performed by one of the authors (A.N.). A standard left-sided anterior approach was performed, the symptomatic disc was removed, and the lateral parts of the annulus were preserved. However, the posterior longitudinal ligament was removed. The plate (either bioresorbable or titanium) and a cage filled with Tribone were inserted according to the manufacturers recommendation. Lastly, 7 to 9 tantalum markers of 0.8-mm diameter (RSA Biomedical, Box 7972, S-907 19 Umea, Stockholm, Sweden) were placed into the adjacent vertebrae (Fig. 1).

Clinical symptoms such as cervical and brachial pain were investigated preoperatively and 1, 6 weeks, and 3, 6 months, postoperatively. Visual analog scale (VAS) was used for grading brachial pain. The Neck Disability Index (NDI) was used to assess cervical neck pain (Table 2).

Implants Used in Study

The cage is "MC+, LDR-Medical", (Technopole de l'Aube-BP 2-10902 Troyes Cedex 9, France). It is made from poly-ether-ether-ketone (PEEK). The choice can be made between 14, 15.5, or 17 mm widths. The depths are 12 or 14 mm and the heights are 4.5, 5, 6, or 7 mm. It has a large central perforation to allow bony ingrowths.

The titanium alloy plate is the ABC (advanced biomechanical concept) plate (Aesculap AG, AM Aesculap-Platz, Tuttlingen, Germany) for anterior osteosynthesis of the cervical spine. It is a dynamic, titanium plate that can be bent to the patient's individual lordosis. The screw for monocortical fixation is a titanium, self-tapping, conical screw of 10, 12, 14, 16, and 18 mm length with an outer diameter of 4.0 mm. The single level plate is offered with a length of 20, 22, 24, 26, 28, 30, and 32 mm.

The bioresorbable plate was the INION S-1 Biodegradable Anterior Cervical Fusion System comprising plates and screws made of degradable copolymers composed of L-lactic and D,L-lactic acid at a ratio of 80%:20%, which can be contoured after treatment in hot water. The single level plates are provided in 4 different sizes (length 25, 27, 29, and 31 mm with width of 19 mm and thickness of 2.0 mm). The diameters of the screws are 4.5 mm and 5.0 mm with lengths of 12, 14, and 16 mm. The plate used here cannot be seen on x-ray although the screw holes can be. In this study, we could identify the plate on the MRI, which is an expensive method for routine diagnosis, therefore the new plate design includes tantalum marker on the upper and lower end of the plate and in the screw.

CT was performed postoperatively at 3 and 6 months after surgery. An axial CT scan (Aquilion 32 slice, TOSHIBA Medical Systems GmbH, Hellersbergstraße, Neuss, Germany) through the cage was taken. This scan was placed precisely parallel to the adjacent endplates to come into contact with the cage and precisely at 50% of the height of the cage. Within this scan, a line was drawn to connect the titanium markers. The bone density was measured between the 2 titanium markers.

TABLE 1. Criteria for Patients With ACDF Using Titanium or Bioresorbable Plate

Inclusion Criteria	Exclusion Criteria
Monosegmental cervical disc disease between C3-C7	More than single level pathology
Unresponsive to conservative treatment or presence of signs of nerve root compression with paresis	Osteoporosis and infection
Soft or hard disc herniation	Spondylodiscitis and active infection
Age between 20 and 60 y	Malignant disease
Signed informed consent	System disease, eg, Hepatitis, HIV, AIDS
	Known allergy to titanium or poly-lactic-acid
	Traumatic injury of spine
	Pregnant or possible pregnancy in the next 3 y

ACDF indicates anterior cervical discectomy and fusion.

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TABLE 2. Visual Analog Scale (VAS) for Arm Pain and Neck Disability Index (NDI) for Neck Pain

	Preoperatively		1 Week		6 Weeks		3 Months		6 Months	
	Resorbable	Titanium	Resorbable	Titanium	Resorbable	Titanium	Resorbable	Titanium	Resorbable	Titanium
Arm pain	8.1 (1.4)	8.0 (1.3)	2.1 (1.6)	2.2 (1.4)	1.4 (1.2)	2.0 (1.4)	1.4 (1.3)	1.7 (1.8)	1.4 (1.4)	1.2 (1.4)
Neck pain	0.49 (0.13)	0.47 (0.12)	0.14 (0.09)	0.20 (0.08)	0.13 (0.09)	0.15 (0.07)	0.12 (0.09)	0.15 (0.07)	0.11 (0.09)	0.15 (0.07)

Mean Value and Standard Deviation (SD) are given for each time for study group (n = 19) and control group (n = 18).

The bone density was expressed in Hounsfield units (HU). This value was used for statistical analysis. A Scheffe post-hoc test was used to detect significant differences between the measurements after 1 week, 3, and 6 months. Statistical significance for all tests was defined as 95% probability.

Sagittal and axial MRI of the cervical spine, and spinal cord using T1 and T2 weighted, T1 weighted with contrast and proton density mode were performed on a 1.5 T Siemens Sonata system (Siemens, Erlangen, Germany), with a magnetom impact dedicated neck coil.

Patients underwent radiostereometric analysis (RSA) postoperatively. The insertion of 4 to 6 radio-opaque tantalum markers in each vertebra is required to determine the geometric characteristics of the vertebral anatomy. Radiostereometric examinations were carried out uniformly in a supine position using a uniplanar technique. Patients were positioned above the combined reference plate and calibration device with 0.8 mm tantalum indicators, placed at known positions in front of the film plane. The cage markers defined the laboratory coordinate system and were used to calculate the position of the x-ray foci. RSA radiographs were taken 1, 6 weeks, 3, and 6 months after the procedure to analyze intervertebral mobility. Mobility provocation was obtained by moving the head into 2 positions (neutral and extension with right sided rotation of the head) to load the spine. The head was passively moved to the different end points by the examiner. At subsequent evaluations, the 3-dimensional coordinates of the patient marker were determined at each examination. Intervertebral motion occurred between the 2 positions. For evaluation of the radiographs, we used a software package (UmRSA, RSA Biomedical Innovations, Umea, Sweden), mainly based on RSA measurement techniques according to Selvik.[17,18] The calculated intervertebral motion allowed visualization of persisting translation between the vertebrae. The most distal cervical vertebra was used as a fixed reference segment. All motion was related to the coordinate system defined by the cage.

The relative translation of the markers in the most proximal vertebra was recorded in all cases. Translations were measured as:

1. Medio-lateral translation (mm)
2. Cranio-caudal translation (mm)
3. Anterior-posterior translation (mm)

The reliability of the measurement was calculated by double examinations on the same day of 6 patients at different times during follow-up. We calculated 99% confidence limits for significant translations as the absolute mean value ± 2.8 SD based on a normal distribution. The mean value for left-right translation was 0.65 mm, for cranio-caudal 0.30 mm and anterior-posterior, 0.35 mm. The precision of our RSA set-up was determined similar to the method used by Zoegea et al,[19] who published comparable values for the 3 axes of motion.

The accuracy of the RSA method depends most importantly on stability, spacing, and number of tantalum markers inserted into the bony region of interest.[18] The degree of marker instability is expressed in millimeters as the mean error of rigid body fitting.

Mann-Whitney *U* test for unpaired values was used to determine a statistical difference of residual intervertebral translations between both groups in the 3 axes of motion ($P < 0.05$).

RESULTS

Two patients from the control group were excluded from the study because of insertion of other cages and a third patient from the study group moved, job-related, to America.

Radiology

Study Group (Bioresorbable Plate)

Six weeks postoperative, there was a significant decrease in motion in medio-lateral, cranio-caudal,

TABLE 3. Translation in (mm) at Postoperative, 6 wk, 3, and 6 mo: Mean Value and Standard Deviation for Each Time for Study Group (n = 19) and Control Group (n = 18)

	1 Week		6 Weeks		3 Months		6 Months	
Translation (mm)	Resorbable	Titanium	Resorbable	Titanium	Resorbable	Titanium	Resorbable	Titanium
Medio-lateral	0.58 (0.17)	0.61 (0.09)	0.42 (0.17)	0.44 (0.08)	0.32 (0.17)	0.3 (0.08)	0.29 (0.16)	0.28 (0.14)
Cranio-caudal	0.25 (0.08)	0.24 (0.04)	0.17 (0.07)	0.17 (0.05)	0.15 (0.07)	0.17 (0.05)	0.15 (0.06)	0.16 (0.05)
Anterior-posterior	0.38 (0.1)	0.3 (0.14)	0.38 (0.09)	0.4 (0.1)	0.28 (0.1)	0.29 (0.1)	0.26 (0.09)	0.25 (0.09)

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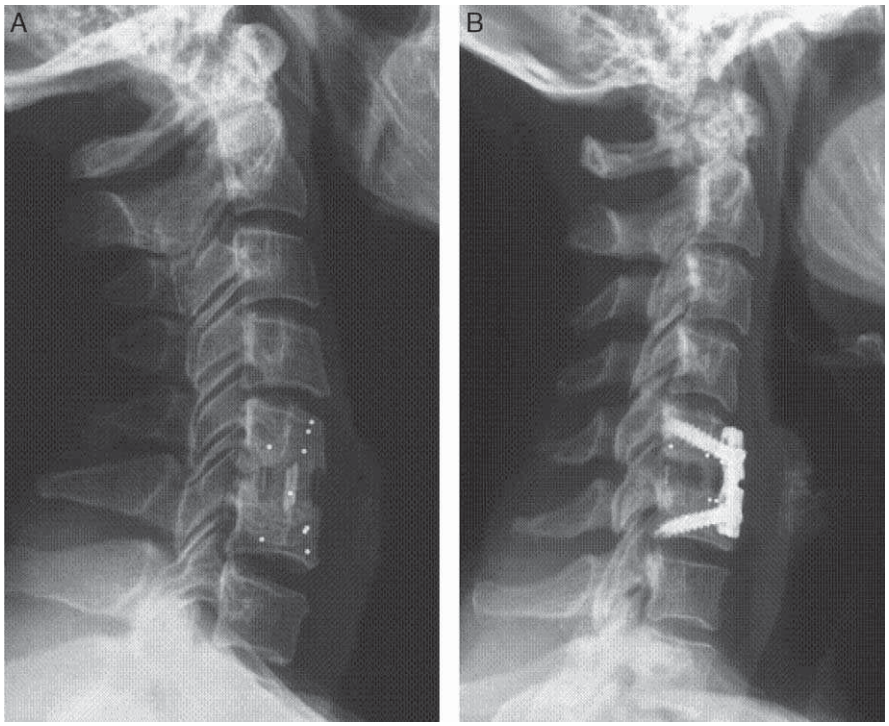

FIGURE 1. Lateral x-ray of a cervical spine showing the tantalum markers of the vertebral body C5 and C6. A, Incorporated allograft within bone fusion 6 months after surgery with bioresorbable plate. B, Same with titanium plate fixation.

and antero-posterior directions ($P = 0.01$, $P = 0.01$, and $P = 0.01$), when compared with the value obtained after a week. However, 3 and 6 months postoperative, there was no significant difference when compared with the 6 weeks value ($P > 0.05$). Data for each axis are contained in Table 3 and Figure 2.

The medial-lateral, cranio-caudal, and antero-posterior translation did not differ between 6 weeks and 6 months after surgery ($P = 0.07$, $P = 0.44$, and $P = 0.37$) (Fig. 2).

Control Group (Titanium Plate)

Six weeks postoperative, there was a statically significant decrease in motion in medio-lateral, cranio-caudal, and antero-posterior directions ($P = 0.02$, $P = 0.04$, and $P = 0.03$), when compared with the value obtained after a week. However, 3 and 6 months postoperative, there was no significant difference when compared with the 6 weeks' value ($P > 0.05$) (Fig. 2).

The mean value for segmental motion for x, y, and z axis representing the medio-lateral, cranio-caudal, and anterior-posterior translation showed no significant difference between both groups for any direction and at any time ($P > 0.05$).

Results of MR Assessment

MRI revealed no signs of soft tissue inflammation or swelling in both groups 6 months after surgery (Fig. 3). There were also no plate or screws fractured. In the study

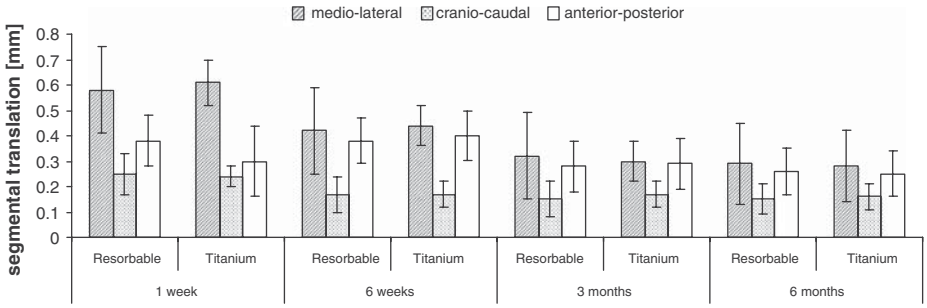

FIGURE 2. Graphic illustrating segmental translation in medio-lateral, cranio-caudal, and anterior-posterior direction (Mean value and standard deviation) for each follow-up examination. Follow-up examinations did not show significant difference of segmental micro-motion in both groups.

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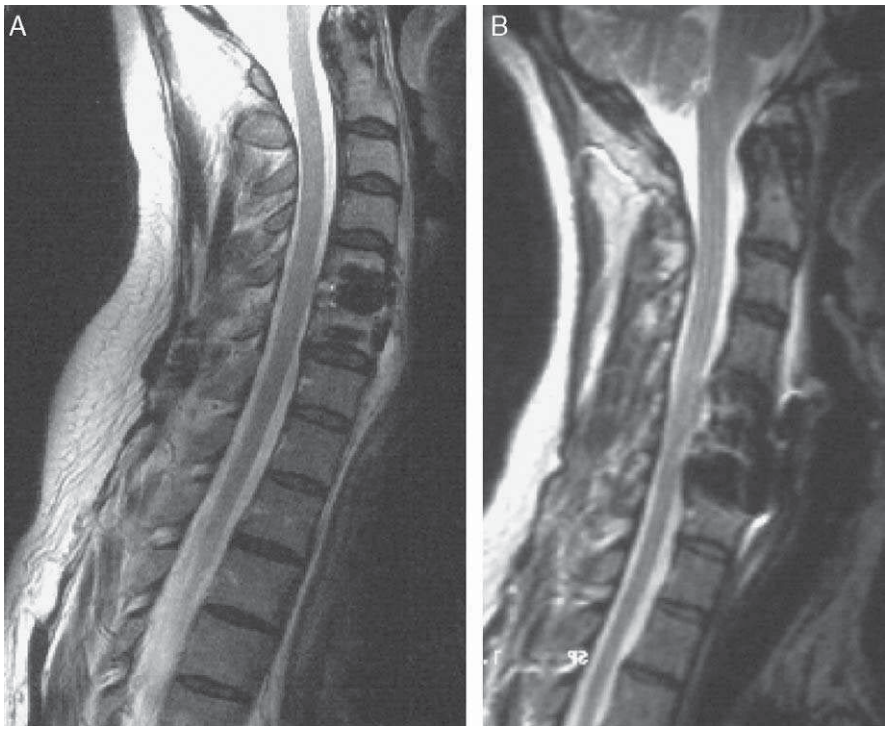

FIGURE 3. T2-weighted magnetic resonance imaging of cervical spine showing early postoperative changes after implantation of bioresorbable plate (A) and after implantation of titanium plate (B). Notice the obvious imaging artifacts in B compared with A.

group, plates caused no imaging artifacts (Fig. 3A) whereas in the control, little artifacts were seen despite artifact reduced MRI (Fig. 3B).

The bioresorbable plate could be identified on the MRI, which is an expensive method for routine diagnosis, therefore the new plate design includes tantalum marker on the upper and lower end of the plate and also in the screw.

Results of CT

Study Group

The mean value of the bone density obtained by CT was 505 (114) HU after 1 week, 635 (133) after 3 months, and 1055 (136) after 6 months. There was a significant difference when the value after 6 months was compared with that obtained after 3 months ($P < 0.001$) and after 1 week ($P = 0.004$) (Fig. 4).

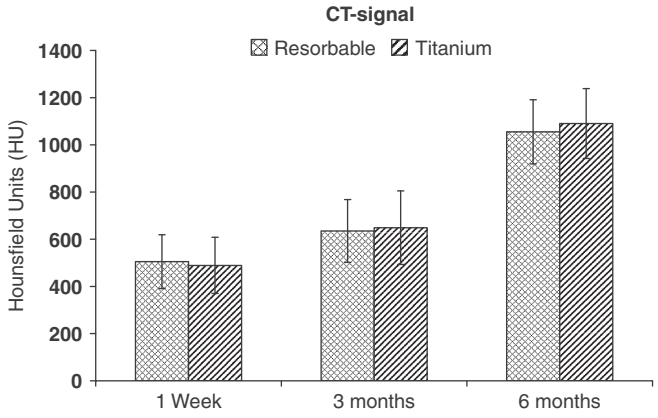

FIGURE 4. Bone density expressed in Hounsfield units (HU) after 1 week, 3, and 6 months postoperatively.

Control Group

The mean value and SD of the bone density obtained by CT was 489 (119) HU after 1 week, 649 (156) after 3 months, and 1090 (148) after 6 months. There was a significant difference when the value after 6 months was compared with that obtained after 3 months ($P < 0.001$) and after 1 week ($P = 0.004$).

There was no significant difference when the values obtained were compared at 1week, 3, and 6 months ($P = 0.805$) (Fig. 4).

Results of the Clinical Study

Study Group

Mean values (SD) for cervical pain measured using NDI decreased significantly from 0.49 (0.13) before surgery to 0.11 (0.09) after 6 months ($P = 0.03$). Mean values (SD) for brachial pain using VAS decreased significantly from 8.1(1.4) before surgery to 1.4(1.4) after 6 months ($P = 0.04$) (Figs. 5, 6).

Control Group

Mean values (SD) for cervical pain measured using NDI decreased significantly from 0.47 (0.12) before surgery to 0.15 (0.07) after 6 months ($P = 0.042$). Mean values (SD) for brachial pain using VAS decreased

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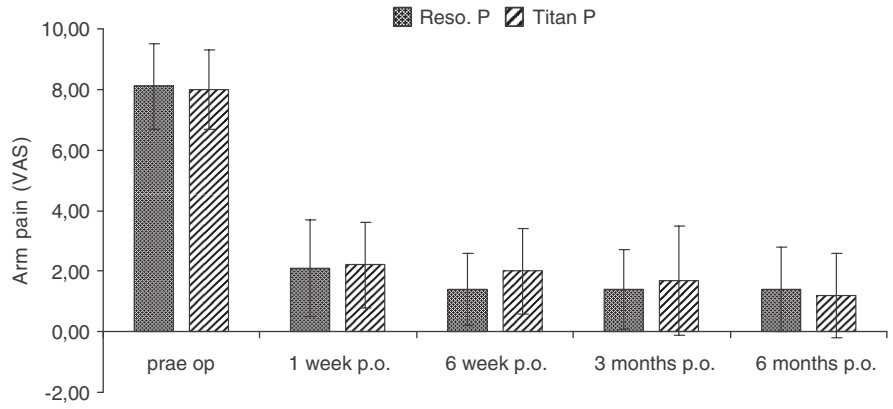

FIGURE 5. Visual analog scale (VAS) for arm pain. Mean value and SD are given for each time. Both groups could show the same pattern of pain relief in arm to all examination times without statistically significant difference ($P>0.05$).

significantly from 8.0 (1.3) before surgery to 1.2 (1.4) after 6 months ($P = 0.03$) (Figs. 5, 6).

There was no significant difference in pain relief for cervical or brachial pain ($P = 0.1$ and $P = 0.21$).

DISCUSSION

Since the first description of bioresorbable technology for clinical applications in the mid 1960s, its use has been gaining popularity in surgery.[20] Bioresorbable implants have been used successfully in craniomaxillofacial, neurologic, general surgical, and orthopedic procedures.[21] Their use continues to increase in orthopedic subspecialties such as sports medicine, foot and ankle surgery, shoulder surgery, and of spinal surgery.

The polylactide polymer in the bioresorbable plates is hydrolyzed into carbon dioxide and water over the course of 2 years.[22,23] At 6 months after implantation, studies report that the plates maintain approximately 90% of initial strength.[1] This continues to slowly decrease to 70% after approximately 9 months with complete absorption occurring after 2 years.[15,22,23] This slow decrease in strength may allow the fusion to gradually assume more of the burden of structural support, potentially enhancing the rate of fusion while reducing stress shielding.[15,16] Long-term complications associated with the permanent metallic implants are reduced by the use of bioresorbable plates and screws.

We have confirmed that a single level bioresorbable plate is MRI and tissue compatible, and shows comparable fusion characteristics to titanium plate. Lateral radiographs 6 months after surgery showed trabecular bridging in both groups, indicating bone fusion (Figs. 1A, B). There was no significant difference between both groups. One patient in each group have had pseudoarthrosis, but without clinical relevance. Therefore, the fusion rate was 94.6%.

A major advantage of the plate is its resorption rendering removal unnecessary during further surgery. This shortens the operation and makes it safer and easier.

The lucency and radiolucency of bioresorbable plates have several advantages over metallic implants. During implantation, it is possible to see the graft and vertebrae, which is more difficult to do with metallic plates. This gives reassurance that the plate is in the right place especially where x-ray is difficult in obese patients and those with short necks. The plate can be bent to fit

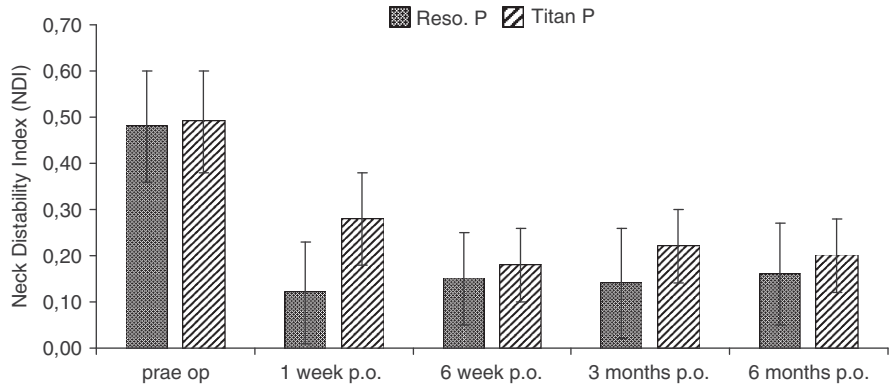

FIGURE 6. Neck Disability Index (NDI) for neck pain. Mean value and SD are given for each time. Both groups could show the same pattern of pain relief in neck to all examination times without statistically significant difference ($P>0.05$).

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the vertebral contour. Indeed, the bioresorbable plate has no translational migration as in new designed metallic plate to allow compression force through the cage, but the modulus of elasticity of the material is close to that of bone. Therefore, the plate allows load sharing with the graft. Our data confirm that the fusion incidence and rates are comparable with a titanium plate.

Our encouraging experience with single level ACDFs with bioabsorbable anterior plate has driven us to investigate the bisegmental plate in a similar study design.

Recently, several authors recommend using a bioresorbable plate[1,24] and our study shows clearly that a bioresorbable plate has a number of unique advantages over traditional metallic implants mentioned in this study.[1,23,24] Failure of a bioabsorbable cervical plate as mentioned by Brkaric et al[25] was not noted in our study.

REFERENCES

1. Aryan HE, Lu DC, Acosta FL Jr, et al. Bioabsorbable anterior cervical plating: initial multicenter clinical and radiographic experience. *Spine*. 2007;32:1084–1088.
2. Kaiser MG, Haid RW Jr, Subach BR, et al. Anterior cervical plating enhances arthrodesis after discectomy and fusion with cortical allograft. *Neurosurgery*. 2002;50:229–236.
3. Shapiro S. Banked fibula and the locking anterior cervical plate in anterior cervical fusions following cervical discectomy. *J Neurosurg*. 1996;84:161–165.
4. Caspar W, Geisler FH, Pitzen T, et al. Anterior cervical plate stabilisation in one and two level degenerative disease: over-treatment or benefit? *J Spinal Disord*. 1998;11:1–11.
5. Emery SE, Fischer JR, Bohlman HH. Three level anterior cervical discectomy and fusion: radiographic and clinical results. *Spine*. 1998;22:2622–2624.
6. Barlocher CB, Barth A, Krauss JK, et al. Comparative evaluation of microdiscectomy only, autograft fusion, polymethylmethacrylate interposition, and threaded titanium cage fusion for treatment of single-level cervical disc disease: a prospective randomized study in 125 patients. *Neurosurg Focus*. 2002;15:E4.
7. Chen JF, Wu CT, Lee Sc, et al. Use of a polymethylmethacrylate cervical cage in the treatment of single-level cervical disc disease. *J Neurosurg Spine*. 2005;3:24–28.
8. Zevgaridis D, Thome C, Krauss JK. Prospective controlled study of rectangular titanium cage fusion compared with iliac crest autograft fusion in anterior cervical discectomy. *Neurosurg Focus*. 2002;15:E2.
9. Blumenthal SL, Gill K. Can lumbar spine radiographs accurately determine fusion in postoperative patients? Correlation of routine radiographs with a second surgical look at lumbar fusions. *Spine*. 1993;18:1186–1189.
10. Bohlman HH, Emery SE, Goodfellow DB, et al. Robinson anterior cervical discectomy and arthrodesis cervical for cervical radiculopathy. *J Bone Joint Surg [Am]*. 1993;75:1298–1307.
11. Lowey GL, McDonough RF. The significance of hardware failure in anterior cervical plate fixation. Patients with 2- to 7-year follow-up. *Spine*. 1998;15:181–186.
12. Pompili A, Canitano S, Caroli F, et al. Asymptomatic esophageal perforation caused by late screw migration after anterior cervical plating: report of a case and review of relevant literature. *Spine*. 2002;27:499–502.
13. Stulik J, Pitzen TR, Chrobok J, et al. Fusion and failure following anterior cervical plating with dynamic or rigid plates: 6-months results of a multi-centric, prospective, randomized, controlled study. *Eur Spine J*. 2007;16:1689–1694.
14. Laakman RW, Kaufman B, Han JS, et al. MR imaging in patients with metallic implants. *Radiology*. 1985;157:711–714.
15. Ames CP, Cornwall GB, Crawford NR, et al. Feasibility of a resorbable anterior cervical graft containment plate. *J Neurosurg*. 2002;97(suppl 4):440–446.
16. Ciccone WJ, Motz C, Bentley C, et al. Bioabsorbable implants in orthopaedics: new developments and clinical applications. *J Am Acad Orthop Surg*. 2001;9:280–288.
17. Selvik G, Alberius P, Aronson AS. A roentgen stereophotogrammetric system, Construction, calibration and technical accuracy. *Acta Radiol Diagn (Stockh)*. 1983;24:343–352.
18. Selvik G. Roentgen stereophotogrammetric analysis. *Acta Radiol*. 1990;31:113–126.
19. Zoegea B, Kärrholm J, Lind B. Plate fixation adds stability to two-level anterior fusion in the cervical spine: a randomised study using radiostereometry. *Eur Spine J*. 1998; 7:302–307.
20. Kulkarni RK, Pani KC, Neuman C, et al. Polylactic acid for surgical implants. *Arch Surg*. 1966;93:839–843.
21. Vaccaro AR, Madigan L. Spinal applications of bioabsorbable implants. *Orthopedics*. 2002;25(suppl 10):S1115–S1120.
22. Claes LE, Ignatius AA, Rehm KE, et al. New bioresorbable pin for the reduction of small bony fragments: design, mechanical properties and in vitro degradation. *Biomaterials*. 1996;17:1621–1626.
23. Peltomiemi HH, Tulamo RM, Pihlajamaki HK, et al. Consolidation of craniotomy lines after resorbable polylactide and titanium plating: a comparative experimental study in sheep. *Plast Reconstr Surg*. 1998;101:123–133.
24. Park MS, Aryan HE, Ozgur BM, et al. Stabilization of anterior cervical spine with bioabsorbable polymer in one- and two-level fusions. *Neurosurgery*. 2004;54:631–635.
25. Brkaric M, Baker KC, Israel R, et al. Early failure of bioabsorbable anterior cervical fusion plates: case report and failure analysis. *J Spinal Disord Tech*. 2007;20:248–254.

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