Reoperation rates for symptomatic nonunions in posterior cervicothoracic fusions with and without bone morphogenetic protein in a cohort of 450 patients

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OBJECTIVE Fusions across the cervicothoracic junction have been challenging because of the large biomechanical forces exerted resulting in frequent reoperations for nonunions. The objective of this study was to investigate a retrospective cohort using chart review of posterior cervicothoracic spine fusions with and without bone morphogenetic protein (BMP) and to determine the reoperation rates for symptomatic nonunions in both groups.

METHODS Between January 2009 and September 2013, posterior cervicothoracic spine fusion cases were identified from a large spine registry (Kaiser Permanente). Demographics, diagnoses, operative times, lengths of stay, and reoperations were extracted from the registry. Reoperations for symptomatic nonunions were adjudicated via chart review. Logistic regression was used to estimate odds ratios and 95% confidence intervals. Kaplan-Meier curves for the non-BMP and BMP groups were generated and compared using the log-rank test.

RESULTS In this cohort there were 450 patients (32.7% with BMP) with a median follow-up of 1.4 years (interquartile range [IQR] 0.5–2.7 years). Kaplan-Meier curves showed no significant difference in reoperation rates for nonunions using the log-rank test ($p = 0.088$). In a subset of patients with more than 1 year of follow-up, 260 patients were identified (43.1% with BMP) with a median follow-up duration of 2.4 years (IQR 1.6–3.3 years). There was no statistically significant difference in the symptomatic operative nonunion rates for posterior cervicothoracic fusions with and without BMP (0.0% vs 2.7%, respectively; $p = 0.137$) for more than 1 year of follow-up.

CONCLUSIONS This study presents the largest series of patients using BMP in posterior cervicothoracic spine fusions. Reoperation rates for symptomatic nonunions with more than 1 year of follow-up were 0% with BMP and 2.7% without BMP. No statistically significant difference in the reoperation rates for symptomatic nonunions with or without BMP was found.

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KEY WORDS posterior cervicothoracic fusion; reoperation; pseudarthrosis; nonunion; spine registry; retrospective; bone morphogenetic protein; BMP; cervical

DUE to its unique anatomical structure and biomechanical forces, the cervicothoracic junction poses challenges for surgical stabilization. Several posterior constructs have been used to fuse across the cervicothoracic junction.^{12,28,34,35,38,40} Nonunions, however, continue to occur, even with advancement in instrumentation.⁵⁴ The use of bone grafting material also plays a significant role in obtaining solid fusions. Iliac crest bone

graft (ICBG) has been the gold standard,⁴⁹ but in the past decade the use of bone morphogenetic protein (BMP) has shown promise as a good alternative.^{7,9,13,50}

Recombinant human BMP (rhBMP-2, or BMP, INFUSE, Medtronic) was first approved by the US FDA for use in anterior lumbar interbody fusion surgery as equivalent to ICBG for bone fusion.^{5,7} Over the following decade, the use of BMP in all spinal fusions in the US increased

ABBREVIATIONS ASA = American Society of Anesthesiologists; BMI = body mass index; BMP = bone morphogenetic protein; ICBG = iliac crest bone graft; ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification; IQR = interquartile range; LOS = length of stay.

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to 26.9%,⁴³ with at least 85% of its use for off-label applications.³⁶ Controversy over its use, however, has also increased over the years^{18,42} with several studies reporting complications.^{3,8,10,30,41,45–48,51,52,55} One of the justifications for its use has been its cost savings associated with prevention of fusion failures.^{1,19,39} A few studies have advocated for its use in the posterior cervical spine because of its high fusion rates.^{4,14,23,25,33,53}

For almost all of the studies on BMP fusion rates, the definition of nonunion has been based solely on radiographic studies. Several studies,^{9,13,17,27,44} however, have shown that radiographic nonunions do not necessarily translate into symptomatic nonunions. In previous articles we have introduced the use of reoperation rates for nonunions as a possible outcome measure, combining both radiographic studies and clinical symptoms.^{20–22} We believe this is an important outcome measure for both patients and health care payers and is worthy of adding to the literature. Hence, the objective of our study is to report the reoperation rates for symptomatic nonunions in a large cohort of patients with posterior cervicothoracic spine fusions from a spine registry and to compare these rates with and without the use of BMP.

Methods

Study Population

In 2009, Kaiser Permanente, a large integrated US health care system with more than 9 million members serving 8 states and the District of Columbia, developed a Spine Registry to track instrumented spinal fusions. The registry tracks procedures that use spinal implants including anterior cervical plates, interbody devices, pedicle and lateral mass screws, total disc replacement devices, and BMP. The data collection and validation process has been previously described.^{22,37} In brief, patients with instrumented spinal fusion were identified using electronic medical record data and a combination of spinal procedural codes from the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) and reference numbers from manufacturers' implant catalogs, as well as chart review. Electronic screening algorithms were used to determine reoperations and revisions from the index spinal procedure. Adjudication via chart review following Centers for Disease Control and Prevention and the Agency for Healthcare Research and Quality guidelines was used to identify complications. Patient age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) score, operative time, length of stay (LOS), diagnosis, region of the spine fused, number of spine levels fused, implant characteristics, procedural information, and outcomes (i.e., complications, revisions, and reoperations) were captured in the registry.

Data Collection

Using the registry data, we identified all patients who underwent posterior cervical spine fusions using lateral mass or pedicle screws from January 1, 2009, to September 30, 2013. Patients who received occipitocervical, C1–2, and subaxial cervical (C2–7) spinal fusions were excluded, hence only identifying a cohort of patients with

posterior cervicothoracic spinal fusions (previous anterior fusions at C7–T1 were also excluded). Length of follow-up was determined from the date of surgery to the end of the study period, end of health plan membership, or death. A subset cohort of patients with more than 1 year of follow-up was also identified.

In our cohorts, patients were divided into 2 groups: those in whom BMP was used (BMP group), and those in whom it was not used (non-BMP group). Bone grafts used in each group consisted of local bone, ICBG, allograft, or any of these combinations. No differentiation of these bone grafts was made in each of the groups.

Reoperations were defined as all spine surgeries subsequent to the index spinal fusion within the study period. Review of electronic medical records including imaging was completed on all the reoperation cases by the 2 senior authors (K.H.G. and J.A.B.) to accurately identify the reason for the reoperation. Reoperations were typically performed for infections, seromas, inadequate decompression, hardware failures (including loose screws), adjacent-segment disease, and nonunions. Reoperations for symptomatic nonunions were identified.

Statistical Analysis

Descriptive statistics (means, medians, standard deviations, interquartile ranges [IQRs], and percentages) for the non-BMP and BMP groups were calculated and compared via Pearson's chi-square, Fisher's exact, and Wilcoxon rank-sum tests. Kaplan-Meier curves for the BMP and non-BMP groups were generated and compared via the log-rank test. Either death or ending health plan membership constituted a censored case. Data analysis was performed using SAS software (version 9.4, SAS Institute). Statistical significance was defined as $\alpha = 0.05$.

Results

Patient Characteristics

We identified 450 instrumented posterior cervicothoracic spine cases between January 1, 2009, and September 30, 2013 (Table 1), with a median follow up of 1.4 years (IQR 0.5–2.7 years). The median duration between index surgery and revision surgery was 0.84 years (IQR 0.54–1.14 years). Because there were 18 possible levels of fusions (C-1 to T-12), we divided the levels fused into 1, 2, 3, 4, and ≥ 5 levels (Table 1). The longest fusion was 16 levels (1 case), with 95.3% of the fusions ≥ 5 levels being 5-level (27.7%), 6-level (37.4%), 7-level (22.0%), and 8-level (8.2%). There were only 3 nonunions in the group ≥ 5 levels fused (2 at 5 levels, 1 at 6 levels).

The non-BMP and BMP groups significantly differed in operative times, number of levels fused, and admitting diagnosis. Figure 1 shows Kaplan-Meier curves comparing the spinal fusions with and without BMP for the entire study cohort. We did not find the 2 curves to be statistically significantly different according to the log-rank test ($p = 0.088$).

For those patients with more than 1 year of follow-up, there was a loss to follow-up of 8.9% (40 patients) due to death and 4.4% (20 patients) due to insurance termination (Fig. 2) resulting in a subgroup cohort of 260 patients,

TABLE 1. Demographics of all patients with posterior cervicothoracic fusions with and without BMP

Demographics	All Cases (%)	Non-BMP (%)	BMP (%)	p Value*
Cases	450 (100.0)	303 (67.3)	147 (32.7)	
Age (yrs)				0.271†
Median	64.5	64	65	
IQR	56–73	56–72	57–74	
Sex				0.157‡
Female	199 (44.2)	127 (41.9)	72 (49.0)	
Male	251 (55.8)	176 (58.1)	75 (51.0)	
BMI				0.844‡
<30	312 (69.3)	209 (69.0)	103 (70.1)	
30–35	86 (19.1)	60 (19.8)	26 (17.7)	
≥35	52 (11.6)	34 (11.2)	18 (12.2)	
ASA score				0.951‡
1 or 2	163 (36.2)	109 (36.0)	54 (36.7)	
3	249 (55.3)	170 (56.1)	79 (53.7)	
4 or 5	24 (5.3)	16 (5.3)	8 (5.4)	
Unknown	14 (3.1)	8 (2.6)	6 (4.1)	
Op time (min)				0.016§
<100	17 (3.8)	16 (5.3)	1 (0.7)	
100–199	119 (26.4)	91 (30.0)	28 (19.0)	
200–299	145 (32.2)	93 (30.7)	52 (35.4)	
≥300	81 (18.0)	54 (17.8)	27 (18.4)	
Unknown	88 (19.6)	49 (16.2)	39 (26.5)	
Fused levels (C2–7)				0.007‡
1 level	22 (4.9)	8 (2.6)	14 (9.5)	
2 levels	25 (5.6)	19 (6.3)	6 (4.1)	
3 levels	24 (5.3)	14 (4.6)	10 (6.8)	
4 levels	61 (13.6)	47 (15.5)	14 (9.5)	
≥5 levels	318 (70.7)	215 (71.0)	103 (70.1)	
LOS (days)				0.894§
1–3	85 (18.9)	59 (19.5)	26 (17.7)	
4–6	198 (44.0)	134 (44.2)	64 (43.5)	
7–9	98 (21.8)	63 (20.8)	35 (23.8)	
≥10	65 (14.4)	43 (14.2)	22 (15.0)	
Unknown	4 (0.9)	4 (1.3)	0 (0.0)	
Admitting diagnosis (ICD-9-CM code)				0.008§
Degenerative	309 (68.7)	209 (69.0)	100 (68.0)	
Deformity	20 (4.4)	10 (3.3)	10 (6.8)	
Infection	11 (2.4)	8 (2.6)	3 (2.0)	
Nonunion	4 (0.9)	2 (0.7)	2 (1.4)	
Pathological	49 (10.9)	42 (13.9)	7 (4.8)	
Trauma	48 (10.7)	26 (8.6)	22 (15.0)	
Other	6 (1.3)	3 (1.0)	3 (2.0)	
Unknown	3 (0.7)	3 (1.0)	0 (0.0)	
Smoking history				0.304§
Never	199 (44.2)	140 (46.2)	59 (40.1)	
Quit	194 (43.1)	124 (40.9)	70 (47.6)	

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TABLE 1. Demographics of all patients with posterior cervicothoracic fusions with and without BMP

Demographics	All Cases (%)	Non-BMP (%)	BMP (%)	p Value*
Smoking history (<i>continued</i>)				0.304§
Current	54 (12.0)	39 (12.9)	15 (10.2)	
Unknown	3 (0.7)	0 (0.0)	3 (2.0)	
History of diabetes	131 (29.1)	93 (30.7)	38 (25.9)	0.289‡

* Boldface type indicates statistical significance.

† Nonparametric test (Wilcoxon rank-sum).

‡ Chi-square test.

§ Fisher exact test.

with 43.1% using BMP (Table 2). The demographics of the non-BMP and BMP groups were not statistically different except in number of levels fused. For more than 1-year follow-up (Table 3), we found 4 reoperations (2.7%) for symptomatic nonunions in the non-BMP group, and 0 (0.0%) operative nonunions in the BMP group. The Fisher's exact test showed no significant difference in nonunion rates between the 2 groups ($p = 0.137$). Unfortunately, there were not enough reoperations for symptomatic nonunion in the BMP group to compute the crude odds ratio.

Discussion

Pseudoarthrosis rates in posterior cervical fusions have been reported in the literature to vary from 0% to 38%.^{6,11,15,23,24,29,31,32,54} This large range in nonunion rates reflects variation in patient comorbidities, surgical indications, tobacco use, anterior/posterior constructs, number of cervical spine levels fused, and the type of instrumentation and bone graft used.⁵⁴ The introduction of lateral mass screw-rod fixation systems has biomechanically allowed a more rigid fixation for early bone fusions in the cervical spine. The use of pedicle screws, especially at C-2 and C-7, has also increased rigid fixation in the cervical spine.⁵⁶

ICBG has been the gold standard for autograft in spine surgery due to its osteoconductive, osteoinductive, and osteogenic properties,⁴⁹ and is responsible for low nonunion

rates in posterior cervical fusions. Another form of autograft, local bone (morcelized lamina), has reduced nonunion rates to 9.4%.²⁶ The use of allografts has avoided the complications from harvesting ICBG,^{2,16} but has not reached the same fusion rates as ICBG. The introduction of BMP, however, has shown in clinical trials that it can be as effective in promoting excellent fusion rates as ICBG in the lumbar spine.^{5,7–9,50}

Very little has been written on fusion rates in posterior cervical spine using BMP.^{4,14,23,25,33,53} The study by Xu et al.⁵³ was one of the first on BMP in the subaxial cervical spine, and involved a retrospective review of 48 patients with BMP and 156 patients without BMP. These authors used radiographic studies with more than 6 months of follow-up. CT imaging showed 0% with nonunions in the BMP group compared with 12.4% in the non-BMP group, for an average follow-up of 24.2 ± 10 months. Statistical significance was demonstrated in favor of higher fusion rates in the BMP group.

Hamilton et al.²³ presented a more inclusive study of occipitocervical, subaxial cervical, and cervicothoracic posterior fusions with various diagnoses in which BMP was used. The study found 0% nonunion rates in the subaxial spine and concluded that use of BMP as an adjunct for posterior cervical fusion was safe and effective at an average dose of 1.8 mg per level. Hodges et al.²⁵ prospectively followed 29 patients with posterior subaxial fusions

FIG. 1. Kaplan-Meier survival estimates comparing reoperation rates for symptomatic nonunions with and without BMP for the entire cohort of patients with cervicothoracic spine fusions.

FIG. 2. Chart of the loss to follow-up in the non-BMP and BMP groups for patients who underwent posterior cervicothoracic spine fusions with more than 1 year of follow-up.

TABLE 2. Demographics of patients with posterior cervicothoracic fusions with and without BMP and more than 1 year of follow-up

Demographics	All Cases (%)	Non-BMP (%)	BMP (%)	p Value*
Cases	260 (100.0)	148 (56.9)	112 (43.1)	
Age (yrs)				0.903†
Median (IQR)	65	66	65	
IQR	58–73	58–73	57–74	
Sex				0.406‡
Female	120 (46.2)	65 (43.9)	55 (49.1)	
Male	140 (53.8)	83 (56.1)	57 (50.9)	
BMI				0.735‡
<30	184 (70.8)	105 (70.9)	79 (70.5)	
30–35	43 (16.5)	26 (17.6)	17 (15.2)	
≥35	33 (12.7)	17 (11.5)	16 (14.3)	
ASA score				0.497‡
1 or 2	101 (38.8)	55 (37.2)	46 (41.1)	
3	137 (52.7)	80 (54.1)	57 (50.9)	
4 or 5	11 (4.2)	8 (5.4)	3 (2.7)	
Unknown	11 (4.2)	5 (3.4)	6 (5.4)	
Op time (min)				0.939§
<100	4 (1.5)	3 (2.0)	1 (0.9)	
100–199	64 (24.6)	39 (26.4)	25 (22.3)	
200–299	113 (43.5)	66 (44.6)	47 (42.0)	
≥300	59 (22.7)	34 (23.0)	25 (22.3)	
Unknown	20 (7.7)	6 (4.1)	14 (12.5)	
Fused levels (C2–7)				0.015‡
1 level	14 (5.4)	3 (2.0)	11 (9.8)	
2 levels	14 (5.4)	11 (7.4)	3 (2.7)	
3 levels	12 (4.6)	5 (3.4)	7 (6.3)	
4 levels	33 (12.7)	22 (14.9)	11 (9.8)	
≥ 5 levels	187 (71.9)	107 (72.3)	80 (71.4)	
LOS (days)				0.934‡
1–3	52 (20.0)	31 (20.9)	21 (18.8)	
4–6	112 (43.1)	62 (41.9)	50 (44.6)	
7–9	58 (22.3)	33 (22.3)	25 (22.3)	
≥10	34 (13.1)	18 (12.2)	16 (14.3)	
Unknown	4 (1.5)	4 (2.7)	0 (0.0)	
Admitting diagnosis (ICD-9-CM code)				0.094§
Degenerative	188 (72.3)	110 (74.3)	78 (69.6)	
Deformity	16 (6.2)	6 (4.1)	10 (8.9)	
Infection	5 (1.9)	3 (2.0)	2 (1.8)	
Nonunion	4 (1.5)	2 (1.4)	2 (1.8)	
Pathological	16 (6.2)	13 (8.8)	3 (2.7)	
Trauma	23 (8.8)	9 (6.1)	14 (12.5)	
Other	5 (1.9)	2 (1.4)	3 (2.7)	
Unknown	3 (1.2)	3 (2.0)	0 (0.0)	
Smoking history				0.659§
Never	117 (45.0)	68 (45.9)	49 (43.8)	
Quit	108 (41.5)	59 (39.9)	49 (43.8)	

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TABLE 2. Demographics of patients with posterior cervicothoracic fusions with and without BMP and more than 1 year of follow-up

Demographics	All Cases (%)	Non-BMP (%)	BMP (%)	p Value*
Smoking history (<i>continued</i>)				0.659§
Current	33 (12.7)	21 (14.2)	12 (10.7)	
Unknown	2 (0.8)	0 (0.0)	2 (1.8)	
History of diabetes	82 (31.5)	51 (34.5)	31 (27.7)	0.244‡

* Boldface type indicates statistical significance.

† Nonparametric test (Wilcoxon rank-sum).

‡ Chi-square test.

§ Fisher exact test.

during 12 months with BMP. They found only 3 cases of radiographic nonunions (10.3%), but none required surgery. They concluded that BMP was associated with increased costs but did not entirely prevent nonunions.

There were only two studies^{14,23} that specifically investigated the use of BMP in the cervicothoracic spine (Table 4). Hamilton et al.²³ found 100% fusion among 23 patients with cervicothoracic spinal fusions spanning an average of 8 levels, in which an average BMP of 1.8 mg per level was used. Dorward et al.¹⁴ found 3 radiographic nonunions (8.6%) with 1 operative nonunion (2.9%) at T2–3 for a C-5 to T-3 posterior cervical fusion among the 35 patients with BMP. They concluded that BMP could not always overcome the biomechanical challenges entailed in spanning the cervicothoracic junction. One criticism of these studies^{14,23} was the small number of patients in which BMP was used. In our study we had 112 patients in which BMP was used with more than 1 year of follow-up (Table 4), the largest series so far. We found 4 reoperations for nonunions among 148 patients (2.7%) without BMP and no reoperations for nonunions (0%) in the 112 patients with BMP. There was no statistically significant difference between these rates.

Although not specifically examining the effects of BMP in cervicothoracic fusions, Yang et al.⁵⁴ in their recent study investigated the risk factors for nonunion in cer-

vicothoracic fusions using “small rods” (3.2-mm/3.5-mm rods) versus “transitional constructs.” BMP was used in both groups (34.2% vs 44%, respectively). These authors found no significant difference in the nonunion rates between the two instrumentation groups. This result implied that either the instrumentation provided enough mechanical support that it did not make any difference in the type of bone graft type used (among BMP, ICBG, local bone, and allograft), or the bone grafts provided the best fusion regardless of the type of instrumentation used. With either of these conclusions, it appeared that BMP was no different from its alternatives.

One possible criticism of our study is the use of reoperation rates for nonunions to evaluate the efficacy of BMP in cervicothoracic fusions. Dorward et al.¹⁴ used both radiographic and operative nonunions as outcome measures to study the effect of BMP on cervicothoracic fusions. Their paper points out a significant difference in reoperation rates for nonunion rates (2.9%) versus radiographic nonunion rates (8.6%) using BMP. Similarly we reported low reoperation rates for nonunions (2.7% [no BMP] vs 0% [BMP]). We acknowledge that there are patients with symptomatic radiographic nonunions who may have decided not to undergo reoperations, or patients who had asymptomatic radiographic nonunions who may not have been offered surgery, both leading to lower numbers of reoperations for nonunions. Dawson et al.¹³ and Singh et al.⁴⁴ noted that the radiographic definition of “nonunions” may have been too stringent in many studies presented in the literature and may not be representative of normal clinical

TABLE 3. Comparison of number of levels fused and reoperations for symptomatic nonunions in posterior cervicothoracic fusions with and without BMP with more than 1 year of follow-up

Fused Levels	Total	Cohort (%)		Reoperation Nonunions (%)	
		Non-BMP	BMP	Non-BMP	BMP
1 level	14	3 (2.0)	11 (9.8)	0 (0.0)	0 (0.0)
2 levels	14	11 (7.4)	3 (2.7)	0 (0.0)	0 (0.0)
3 levels	12	5 (3.4)	7 (6.3)	1 (20.0)	0 (0.0)
4 levels	33	22 (14.9)	11 (9.8)	0 (0.0)	0 (0.0)
≥5 levels	187	107 (72.3)	80 (71.4)	3 (2.8)	0 (0.0)
Total (cervicothoracic)*	260	148	112	4 (2.7)	0 (0.0)

* The Fisher's exact test was used to test the reoperation nonunion rate between the BMP and non-BMP groups ($p = 0.137$). There was not enough nonunion in the BMP group to compute the crude odds ratio.

TABLE 4. Nonunion rates for posterior cervicothoracic fusions from various studies compared with our study

Study	Type of Nonunion	Nonunion % (Nonunions/Fusions)	
		Non-BMP	BMP
Hamilton et al., 2011*	Radiographic	NA	0% (0/23)
Doward et al., 2013*	Operative/Radiographic	NA	2.9% (1/35)/8.6% (3/35)
Present study (>1 yr of follow-up)	Operative	2.7% (4/148)	0% (0/112)

NA = not applicable.

* More than 2 years of follow-up.

practices. Again, we believe operative nonunion rates are useful and clinically relevant and can be used to compare BMP to non-BMP patients as we have shown in other studies.^{20–22}

We also acknowledge there are some limitations to our study. It is a retrospective study, which may have inherent selection biases. For those patients with more than 1 year of follow-up, however, we did not find any significant difference in the demographics except for the number of levels fused. BMP was used in larger percentages in 1-level and 3-level fusions, although they were very similar in ≥ 5 levels fused. The majority of nonunions, however, occurred in ≥ 5 levels fused (Table 3) in the non-BMP group. Yang et al.⁵⁴ also noted in their study that construct length (> 5 levels) was a risk factor for nonunions. Due to the rarity of reoperation for nonunions in our study (only 4), we were limited by our data to make any multivariate adjustments. From an observational point of view, it appears BMP may have a beneficial effect in ≥ 5 levels fused. However, the Fisher's exact test used to test reoperation rates between BMP and non-BMP showed no difference ($p = 0.137$). It should be noted that Dorward et al.¹⁴ observed in their study that the typical variables such as smoking history, age, and other commodities had little effect on nonunions, but biomechanical factors across the cervicothoracic junction appear to play a more significant role in nonunions, and BMP did not appear to change the outcome. This is also supported by the study of Yang et al.,⁵⁴ in which the risk factors for nonunions were tobacco use (which contradicts the findings of Dorward et al.¹⁴), posterior fusions only, corpectomy, and construct length more than 5 levels.

The follow-up duration in our study was more than 1 year, which may be viewed as a shorter period of time for nonunions when compared with lumbar fusions and fusions after deformity surgery. We believe that in the posterior cervical spine, the clinical and radiographic indications of nonunion are much shorter. The median time to nonunion in our entire cohort was 0.84 years (IQR 0.54–1.14 years) with a median follow-up of 1.4 years (IQR 0.5–2.7 years), which meant that most of the nonunions occurred in the first year. Xu et al.⁵³ noted that the time to nonunion in the posterior cervical spine was greater than 6 months. Hodges et al.²⁵ evaluated his patients for nonunion at a minimum of 12 months postoperatively. To account for time-to-event, it was helpful to use the Kaplan-Meier curves. The Kaplan-Meier curves (Fig. 1) showed a log-rank p value of 0.088, indicating no significance difference in nonunion rates between the BMP and non-BMP groups.

Finally, our study has the advantage of including a large cohort of patients from an integrated health care system's spine registry with no dependence on industry support and featuring varied patient demographics with surgical indications. It presents one of the largest cohorts of patients using BMP in the posterior cervicothoracic spine in the literature (Table 4).

Conclusions

This study presents one of the largest cohorts of patients using BMP in the posterior cervicothoracic spine. Using Kaplan-Meier curves there was no significant dif-

ference in reoperation rates for symptomatic nonunions with and without BMP among 450 patients. For a subset of 260 patients with more than 1 year of follow-up, we found reoperation rates for symptomatic nonunions in posterior cervicothoracic fusions with and without BMP to be 0.0% vs 2.7%, respectively. Although the BMP group underwent no reoperations, the non-BMP group had so few reoperations that no statistically significant difference was found between the 2 groups.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Guppy, Bernbeck. Acquisition of data: Guppy, Harris, Bernbeck. Analysis and interpretation of data: Guppy, Harris, Chen, Paxton. Drafting the article: Guppy, Harris, Bernbeck. Critically revising the article: Guppy, Harris, Paxton, Bernbeck. Reviewed submitted version of manuscript: Chen, Paxton, Bernbeck. Approved the final version of the manuscript on behalf of all authors: Guppy. Statistical analysis: Guppy, Chen. Study supervision: Guppy.

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