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Diagnosing Cervical Fusion: A Comprehensive Literature Review

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Study Design: Comprehensive literature review.

Purpose: To document the criteria for fusion utilized in these studies to determine if a consensus on the definition of a solid fusion exists.

Overview of Literature: Numerous studies have reported on fusion rates following anterior cervical arthrodesis. There is a wide discrepancy in the fusion rates in these studies. While factors such as graft type,
Instrumentation, and technique play a factor in fusion rate, another reason for the difference may be a result of differences in the definition of fusion following anterior cervical spine surgery.

Methods: A comprehensive English Medline literature review from 1966 to 2004 using the key words "anterior," "cervical," and "fusion" was performed. We divided these into two groups: newer studies done between 2000 and 2004, and earlier studies done between 1966 and 2000. These articles were then analyzed for the number of patients, follow-up period, graft type, and levels fused. Moreover, all of the articles were examined for their definition of fusion along with their fusion rate.

Results: In the earlier studies from 1966 to 2000, there was no consensus for what constituted a solid fusion. Only fifteen percent of these studies employed the most stringent definition of a solid fusion which was the presence of bridging bone and the absence of motion on flexion and extension radiographs. On the other hand, the later studies (2000 to 2004) used such a definition a majority (63%) of the time, suggesting that a consensus opinion for the definition of fusion is beginning to form.

Conclusions: Our study suggests that over the past several years, a consensus definition of fusion is beginning to form. However, a large percentage of studies are still being published without using stringent fusion criteria. To that end, we recommend that all studies reporting on fusion rates use the most stringent criteria for solid fusion following anterior cervical spine surgery: the absence of motion on flexion/extension views and presence of bridging trabeculae on lateral x-rays. We believe that a universal adoption of such uniform criteria will help to standardize such studies and make it more possible to compare one study with another.

Key Words: Cervical, Fusion, Arthrodesis, Ppseudoarthrosis

Introduction

Although there have been numerous studies regarding fusion rates following anterior cervical arthrodesis, there is a paucity of long-term data on the effect of fusion status on clinical outcome. In order to perform prospective outcome studies, there must first be a uniform consensus about what constitutes a solid fusion. While discrepancies in the fusion rates among various studies may be due to factors such as graft type, instrumentation, and surgical technique, an equally important factor may be the criterion used to assess

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the status of fusion. Variations in such a criterion may in part explain the wide variety of fusion rates reported in the literature. We undertook the present study to determine if there is a consensus opinion in the literature regarding the best methodology for the assessment of fusion status following an anterior cervical arthrodesis procedure.

Materials and Methods

A literature search was performed on Medline from 1966 to June, 2004. The key words entered were anterior, cervical, and fusion with the search limited to articles in the English language and human subjects. A total of 604 articles were selected by Medline. We divided these into two segments: the newer articles from 2000~2004 and the older articles from 1966~2000. These articles were then investigated as to their relevance to spine related procedures in which the authors reported on their results following anterior cervical procedures. All case reports were excluded as were articles dealing with circumferential fusion. One hundred and forty-four articles were selected due to their relevance to our study. These articles were analyzed as to the number of patients, their ages, follow-up period, graft type, diagnosis, and number of levels fused. Moreover, all of the articles were then examined for their definition of fusion along with their rate of fusion.

Tables 1 and 2 present the information obtained from each segment (prior to 2000 and 2000-2004) reviewed.

Results

One hundred and twelve articles from 1966 to 2000 reported on a combined total of 8,073 patients[1-112]. Most studies included a breakdown of the number of levels fused. However, for 967 patients the number of levels fused could not be determined. There were 3,692 one-level fusions, 2317 two-level fusions, 906 three-level fusions, 177 four-level fusions and fourteen five-level or greater fusions. The follow up period ranged from six months to nine years. Fusion rates in the studies varied from a low of nine percent to one hundred percent. The definition of fusion was highly variable amongst the studies. The most stringent definition of a solid fusion was spanning trabeculae across the graft/host interface AND the absence of motion on flexion/extension lateral cervical spine radiographs. Such criteria were noted in only fifteen percent of the articles (17/112). Thirty percent of the articles (34/112) considered the presence of EITHER spanning trabeculae across the graft/host surface OR the absence of motion on flexion/extension radiographs as adequate for determining successful fusion. Eighteen percent of the articles (20/112) based their definition of a solid fusion SOLELY on the presence of spanning trabeculae, while nine percent (10/112) of the articles based their criteria SOLELY on the absence of motion on flexion/extension lateral radiographs. The vast majority of studies gave no criteria for their definition of a solid fusion (61/112). Some studies based their arthrodesis rate solely on clinical grounds. Four of the studies used CT scans along with plain radiographs and one study used MRI to diagnose fusion. In addition, many of the studies examining fusion rates did not take post-operative radiographs on their entire sample but still managed to determine fusion rates.

Thirty two articles from 2000 to 2004 reported on a total of 3,006 patients[113-144]. There were 767 one-level fusions, 765 two-level fusions, 270 three-level fusions, twenty-two four-level fusions, and 1,182 patients whose operated levels were unknown. Follow up periods ranged from a few months to several years. Fusion rates ranged from sixty nine percent to one hundred percent. The more recent articles (2000-2004) were more particular about including their definition of fusion as only one study failed to report their definition of fusion. The most stringent definition of solid arthrodesis which was the presence of spanning trabeculae and absence of motion on flexion/extension cervical spine radiographs was used by sixty-three percent of the articles (20/32). Thirty-eight percent (12/32) considered EITHER the presence of spanning trabeculae OR the absence of motion on flexion/extension radiographs as adequate for determining successful fusion. Eleven of the thirty-two articles based their definition SOLELY on the presence of spanning trabeculae while one of the studies SOLELY looked at dynamic films. With regards to flexion/extension radiographs, however, there was discrepancy with respect to the amount of motion that was acceptable to deem a fusion solid. Some articles based their fusion rate on no motion, while others would accept 2° of angular motion and some would accept 4° of angular motion. Five of the articles gave their own classification system for fusion.

Table 1. Literature review data from 1996 to 2000 study

	Author	Journal	Number of patients	Age	Follow-up	Graft type	Criteria	Fusion rate
1.	Wetzel FT	Yale J Biology Med	32	49.0	19.0	Fibular all	St	65.0
2.	Mutoh N	Int Orthop	433	52.4	27.2	Ilica377 Fibula66	Fe and Tomograph	96.6
3.	Baba H	Paraplegia	92	47.0	8.5	Icbg	Solid bony union	95.0
4.	Ebrahein N	Orthopedics	25	48.9	31.2	Icbg all plated	Stability on Fleion/extension; Agsence fo local pain; Bony incorporation	100.0
5.	Isu T	Neurosurgery	40	55.0	36.0	Local bone	None	100.0
6.	Katsura A	J Spinal Disord	44	56.1	17.35	Auto icbg plated	None	96.0
7.	Seifert V	Neurosurgery	22	53.0	21.0	Icbg	None	100.0
8.	Shapiro S	Surg Neurol	195	0	40.30	All fibu all plated	None	100.0
9.	Deburg A	J Bone Joint Surg Br	8	71.0	1.0 to 7.0		None	100.0
10.	Zdeblick TA	J Bone Joint Surg Am	35	50.0	44.0	Auto icbg/Fibula	St and no motion	97.0
11.	Tominaga T	Surg Neurol	12	55.8	13.0	Icbg all plated	None	100.0
12.	Shapiro S	Neurosurgery	88	52.0	22.0	All fibula plated	Fe	100.0
13.	Johnston F	Neurosurgery	32	54.0	9.6	Icbg plated	None	100.0
14.	Herman J	Neurosurgery	20		28.0	Icbg 95 Allo 5 per	None	100.0
15.	Isu T	Neurosurgery	90	51.0	24.0	Icbg	None	100.0
16.	MacDonald R	Neurosurgery	36	58.0	31.0	All fibula15 unstr	Bony Bridging No instability	97.0
17.	Coric D	Neurosurgery	18	49.1	22.4	Allo icbg stplated	St gm dep	100.0
18.	Bishop R	Neurosurgery	132	0	31.0	Allo and auto icbg	St	
19.	Connoll PJ	J Spinal Disord	43	0	16.5	Auto icbg 25 plated	St	100.0 83.0
20.	Goffin J	J of Spinal Disorder	25	32.7	1.0 to 10.0	All plated	None	100.0
21.	McGuire R	J Spinal Disord	6		2.0+	Icbg	St	66.0
22.	Chang K	J Spinal Disord	27	49.0	12.0 to 24.0	Icbg	None	100.0
23.	Iwaski M	Int Orthop	4	54.0	5.5	Icbg	None	100.0
24.	Naito M	Int Orthop	106	55.0	4.5	Icbg	None	97.0
25.	Housh G	Neurosurgery	19	47.6	15	Auto/allo fib+icbg	None	100.0
26.	Kadoya S	Neurosurgery	19	56.0	38.0	Icbg	None	89.0
27.	Aronson N	Neurosurgery	86	48.0	0	Icbg	St and fe	96.0
28.	Connoly E		63	47.0	373.0		Bt	79.0
29.	Siqueira E	Surg Neurol	221	52.0	0	Calf bone	None	100.0
30.	Zhang Z	Spine	121	50.0	22.0	Auto 83 Allo 38	None	Aut 84.30 All 50.0
31.	Kadoya S	Spine	33	55.0	34.0	Icbg	None	94.0
32.	Mann DC	Paraplegia	16	26.0	10.0	Icbg plated	None	100.0
33.	Kostuik J	Spine	42	4730	0	Icbg plated	None	100.0
34.	Casper W	J Spinal Disord	356	45.0	1.0 to 9.0	Auto 259 allo 97 Plated 146 non pl 210	None	96.0
35.	Yangjia O	Spine	15	45.6	93.0	Icbg	None Ct Mri Xray	100.0
36.	Ripa D	Spine	92	34.3	19.3	Icbg plated	Sst and fe	99.0
37.	Clements D	Spine	94	46.0	None	Icbg	Fe	97.0
38.	Muhlbauer M	Acta Neurochir	42	47.0	10.7	Icbg plated	None	100.0
39.	Krag M	J Spinal Disord	92	45.0	8.5	Icbg	St(60) Fe(89)	
40.	Savolainen S	Acta Neurochir	250	48.0	6.0	Auto 149 Allo 104	Dep	98.0
41.	Matge G	Acta Neurochir	80	0	20. to 26.0	Local with bak cage	Fe with < 4 deg	100.0
42.	Moerman J	Acta Orthop Belg	22	41.0	1.0+	Icbg plated	None	100.0

Table 1. Literature review data from 1996 to 2000 study

	Author	Journal	Number of patients	Age	Follow-up	Graft type	Criteria	Fusion rate
43.	Schnee C	Spine	142	48.1	8.1	Icbg some plated	St	96.7
44.	Phillips F	Spine	16	47.0	32.0	Icbg	St and Fe with < 2mm	88.0
45.	Hilibrand A	Spine	38	0	68.0	Icbg fibula	Fe > 2mm Or lucency	76.0
46.	Malca S	Spine	52	34.0	7.4	Xenograft plated	St Fe with zero moti	100.0
47.	Lowery G	Spine	20	47.0	28.0	Auto 35% plated Allo 65%	St or Fe > 2 mm	45.0
48.	An H	Spine	77	Aut 46.1 All 48.0	Aut 18.4 All 17.5	Both	St and Fe	Aut 73.7 All 53.8
49.	Bringham C	Spine	43	48.0	14.0	Icbg	St and Fe	93.0
50.	Villas C	Acta Orthop Scand	21	54.0	36.0	Icbg 9 plated	St and Fe	95.0
51.	Cauthen J	Spine	348	40.0	62.0	Auto 30% Allo 70%	Fe	83.0
52.	Emery S	Spine	16	59.0	37.0	Icbg	St and Fe	56.0
53.	Walters W	Spine	64	46.0	73.0	Icbg	Fe and st (assumed)	90.0
54.	Emery S	Spine	29	47.0	28.30		St and Fe	95.6
55.	Capen D	Clin Orthop Relat Res	88	27.0	44.0	Fibul 85 icbg 3	None	100.0
56.	Doi K	Spine	6	54.5	26.0	Vascularizedfibula	None	100.0
57.	Herkowitz H	Spine	18	58.4	2.0+	Icbg	St and Fe	63.0
58.	Brown J	Spine	10	45.0	15.0	Icbg 10 fib 3	St or Fe or absence of pain	100.0
59.	Gore D	Spine	146	48.0	5.0	Icbg	None	97.0
60.	Zdeblick TA	JBJS	14	45.7	28.0	8 fibula 6 icbg	St and Fe and tomograms	100.0
61.	Laus L		11	45.0	None	Icbg plated	None	100.0
62.	Jacobs B	JAMA	65	30.0 to 59.0	38.0	Notmentioned	None	98.5
63.	Anderson L	J Trauma	16	32.8	None	Tibia	None	100.0
64.	Tunturi T	Arch Orthop Traumat	29	43.0	Yrs 6.5	Icbg	None	100.0
65.	Depalure A	Clin Orthop Relat Res	146	17.0 to 62.0	27.4	None	Fe	89.1
66.	Brown M	Clin Orthop Relat Res	98	None	None	53 all 45 auto	St	96.0
67.	Fielding J	Clin Orthop Relat Res	3	47.0	None	Icbg	None	100.0
68.	Kambin P	Clin Orthop Relat Res	93	None	2.0+	Icbg	Fe and New bone formation	99.0
69.	Gore D	Clin Orthop Relat Res	58	47.0	1.0+	Tibia 37 Fibula 21	St or Fe	100.0
70.	Brunton F	J Bone Joint Surg Br	75	20.0 to 73.0	4.5yrs	Icbg	None	77.0
71.	Simmons	J Bone Joint Surg Br	84	20.0 to 70.0	34.0	Icbg	None	96.0
72.	Tippets R	Neurosurgery	28	39.9	4.9	Icbg plated	None	100.0
73.	Kojima t	Neurosurgery	45	55.0	None	Icbg	None	100.0
74.	Young W	Spine	23	35.0	6.0	Fib all	St	92.0
75.	Brodke D	Spine	51	45.0	12.0	Icbg	St and Fe With no motion	94.0
76.	Brodsky A	Spine	17	49.8	60.0	Icbg	St dissol of end plates Evidence of remodeling	94.0
77.	Zdeblick TA	Spine	87	43.0	28.0	All 27 auto 60	St	87.0
78.	Grossman W	Spine	50	53.0	22.1	Fib all	One end plate fusion	100.0
79.	Suh P	Spine	13	43.0	13.0	Icbg plated	St	100.0
80.	Kozak J	J Spinal Disord	40	44.0	15.0	Icbg	St	87.5

Table 1. Literature review data from 1996 to 2000 study

	Author	Journal	Number of patients	Age	Follow-up	Graft type	Criteria	Fusion rate
81.	Shinomiya K	J Spinal Disord	443	52.4	None	Ilium 377 Fibula 66	None	96.6
82.	Lindberg L	Acta Orthop Scand	20	47.0	18.8	Icbg	None	100.0
83.	Svengaard N	Acta Neurochir	24	32.0	None	Tibial	None	100.0
84.	White A		65	53.8	3.25	Icbg	St or Fe	74.0
85.	Riley LH	J Neurosurg	93	46.0		Icbg	None	86.0
86.	Rosenorn J	J Neurosurg	31	51.0	12.0	Allo	None	None
87.	Herkowitz HH	Spine	28	42.0	50.0	Icbg	None	93.0
88.	Okada K	J Bone Joint Surg Am	37	58.0	49.0	24 icbg	None	100.0
89.	Oterovich JM	J Neurosurg	37			14 auto	None	100.0
90.	Paramore CG	J Neurosurg	49	47.0		36 icbg 13 fiball plated	None	100.0
91.	Dowd CF	J Neurosurg	40	53.0	53.0	Icbg	None	97.0
92.	Eleraky MA	J Neurosurg	185	48.2	36.0	Auto 141 Allo 44 all plated	None	99.0
93.	Majd ME	Spine	34	50.7	32.0	Auto 30/34 plated	None	97.0
94.	Thalgott JS	Spine	26	55.0	30.0	Allo all plated	None	100.0
95.	Tribus CB	Spine	16	42.1	19.2	Icbg all plated	Fusion scale 1 to 4	100.0
96.	Saunders RL	Spine	31		24.0	17 autofib 14 all fib	None	89.0
97.	Heidecke V	Spine	96	49.0	12.0	Bariable all plated	None	100.0
98.	Madawi AA	Spine	50	50.0	17.0	Icbg	Bt	96.0
99.	Savolainen S	Neurosurgery	60	49.0	48.0	Icbg	Bt	100.0
100.	Chiles BW	Neurosurgery	76	56.0	8.9	Allo 65 auto 11	None	
101.	Kawakami M	J Spinal Disord	60	51.1	54.0	Icbg	Fe	100.0
102.	Schneeberger AG	J Spinal Disord	35	51.0	54.0	Icbg plated	Bt and fe	94.0
103.	Ibanez J	Acta Neurochir	82	51.0	17.0	Surgibon 41 Bop 41	Bt and fe	Bop 9.0 Sur 38.0
104.	Yang K	Clin Orthop Relat Res	132	50.1	47.0	Icbg	None	62.9
105.	Depalma AF	Clin Orthop Relat Res	146	43	27.4		Fe	89.1
106.	Bosacco DN	Orthopedics	232	50	80.0	Icbg	None	89.2
107.	Bose B	Surg Neurol	97	50.3	9.0	Allofib 13 icbg 84 all plated	None	98.0
108.	Randle MJ	Surg Neurol	54	29.2	6.0	Icbg all plated	None	100.0
109.	Yonenobu K	Spine	50	51.4	54.0	Icbg	None	64.0
110.	Cabarela ME	Spine	8	24.5	36.0	Icbg plated	None	100.0
111.	Green PW	J Bone Joint Surg Br	29	53.0	54.0	Icbg	None	82.7
112.	Martin G	Spine	289		33.0	Allofib	Bt	88.0

bt/st: bridging/spanning trabeculae, Fe: flexion/extension.

Discussion

Fusion depends on a variety of factors such as the stability and type of graft, the status of the grafting bed, and the condition of the host. The variance of these can lead to a wide discrepancy in fusion rates following anterior cervical spine surgery. On the other hand, uniformly performed studies utilizing similar procedures, grafts, diagnoses, patient populations and surgical techniques should have fairly uniform fusion rates. Such an assumption can only be tested if the criteria for the determination of fusion are uniform.

We undertook this study to determine if a consensus opinion for fusion exists in the literature.

In the present study, we reviewed a total of 144 articles on anterior cervical fusion in order to determine if there is a consensus on the definition of fusion. As can be seen from the data, no such consensus existed in the earlier literature. However, it appears that a consensus is beginning to emerge

Table 2. Literature review data from 2000 to 2004 study

	Author	Journal (year)	Number of patients	Follow -up period	Number of fused levs	Fusion rate	Grafttype	Fusion accessed by :				
								Presence of spanning trabeculae	Absence of motion on flexion/extension lateral cervical spine radiographs	Absence of a radiolucent gap between graph and endplate	Rating scale Used	Other
113	Cauthen J	Spine J (2003)	88	Mean, 2.4 yr Range, 1.0-5.5 yr	43-1 lev 45-2 lev	Overall, 89%	none				Five point scale used: 1) Fused with bridging 2) Fused with perigraft 3) Not fused with atrophy/lucency 4) Not fused with motion 5) Indeterminate successful fusion occurring in ratings of 1or 2	
114	Kaiser M	Neurosurgery Online (2002)	233	Mean, 15.6 mo Range, 9-40 mo	157-1 lev 76-2 lev	Overall, 94%	Cortical allograft					
115	Hacker R	Clin Orthop Relat Res (2002)	542	Mean, 24-36 mo	1 or 2 lev fusions	Overall, 97.9%	Iliac crest autograft or allograft		< 2° of segmental movement	< 50% radiloucency		
116	Gore D	Spine (2001)	145	Not mentioned	112-2 lev 32-3 lev	Overall 90%	Autogenous fibula					
117	Wang J	J Spinal Disord (2001)	52	Mean, 3.6 yr Range, 2-7 yr	20-1 lev 32-2 lev	Overall 98%	Autogenous tricortical iliac crest bone graft					
118	Goldberg E	Spine J (2002)	80	Mean, 4.0 yr Range, 2-7 yr	57-1 lev 21-2 lev 2-3 lev	Overall, 69%	Autogenous iliac crest, iliac Crest allograft				Grade 1 represented an obvious Pseudoarthrosis with motion on F/E views. Grade 2 Represented possible Pseudoarthrosis with no motion bout a visible cleft	

Table 2. Literature review data from 2000 to 2004 study

	Author	Journal (year)	Number of pa-tients	Follow -up period	Number of fused levs	Fusion rate	Grafttype	Fusion accessed by :
								Grade 3 Represented a solid fusion with no motion on F/E view and bony trabeculae.
119	Moreland D	Spine J (2004)	131	Mean, 6 mo	80-1 lev 36-2 lev 13-3 lev 2-4 lev	Overall, 95%	Unicortical iliac crest allograft	Stable cage positioning
120	Bolesta M	Spine J (2002)	40	Mean, 51 mo Range, 24-85 mo	20-1 lev 20-2 lev	Overall, 72%	Autogenous tricortical iliac crest graft	Evidence of remodeling of bony architecture
121	Shen F	Spine J (2003)	80	Mean, 16 mo Range, 9-79 mo	61-2 lev 19-3 lev	Overall, 97.5%	Tricortical allograft, autogenous iliac crest tricortical graft	
122	Yue W	Singapore Med J (2003)	15	Mean, 42.8 mo	14-1 lev 1-2 lev	Overall, 93.4%	Bicortical patellar allografts	Union: Complete bridging of trabeculae between adjacent vertebral bodies and bone graft in < 20 wks. Delayed union: union between 20-52 wks. Partial union: <50% bridging trabeculae of bone at one or more-graft vertebral body interface. Non-union: Lack of trabecular bridgingat both endplates with or without motion on flexion and extension lateral films between 20-52 wks.

Table 2. Literature review data from 2000 to 2004 study

	Author	Journal (year)	Number of pa-tients	Follow -up period	Number of fused levs	Fusion rate	Grafttype	Fusion accessed by :		
123	Parthiban J	Neurol India (2002)	68	24 mo	28- 1 lev 34- 2 lev 6- 3 lev	Overall, 91%	Iliac crest autografts, ethylene oxide sterilized cadaver bone allograft			Increase in density of vertical trabeculae
124	Bose B -	J Spinal Disord (2001)	106	Minimum 1 yr	37-2 lev 60-3 lev 9-4 lev	Overall, 97.2%	Tricortical iliac crest autograft, fibular allograft			
125	Nui C	Spine J (2002)	23	Mean, 2.8 yr	19-1 lev 3-2 lev 1-3 lev	Overall, 87%	llogenic fibula			
126	Hacker R	J Neurosurg Spine (2000)	54	Minimum 2 yr	1 and 2 lev fusions performed	Overall, ~90%	Iliac crest autograft, allograft, hydroxyapatite	$<2^{\circ}$ of motion		Lack of bone abs orption adjacent to bone graft
127	Vavruch L	Spine (2002)	89	Mean, 36 mo Range, 24 to 72 mo	Not mentioned	Overall, 73%	Bicortical iliac autograft		Type 1A: Bridging bone anterior and through disc space. Type 1B: Bridging bone anterior but not through the disc space. Type 2A: Bridging bone not anterior but through disc space. Type 2B: No Bridging bone. Fusion occurred in absence of a 2B healing.	
128	Epstein N -	J Spinal Disord (2000)	178	Mean, 82 mo Range, 31 to 118 mo	78-1 lev 84-2 lev 12-3 lev 4-4 lev	Overall, 95%	Autogenous iliac crest			

Table 2. Literature review data from 2000 to 2004 study

	Author	Journal (year)	Number of pa-tients	Follow -up period	Number of fused levs	Fusion rate	Grafttype	Fusion accessed by :
129	Wang J	Spine (2000)	60	Mean, 2.7 yr	60-2 lev	Overall, 80%	Autogenous iliac crest bone graft	
130	Wang J	Spine (2001)	59	Mean, 3.2 yr Range, 2.3 to 7.8 yr	59-3 lev	Overall, 76%	Autogenous, tricortical, iliac crest bone grafts	
131	Bolesta M	Spine (2000)	15	Mean, 42 mo Range, 25-73 mo	12-3 lev 3-4 lev	Overall, 47%	Autogenous tricortical iliac crest graft	Evidence of remodeling
132	Hillbrand A	Spine (2002)	190	Mean, 68 mo	16-1 lev 119-2 lev 53-3 lev 2-4 lev	Overall, 75%	Autogenous iliac crest, fibular strut grafting	$\leq$ 1 mm change in interspinous distance across a fused segment
133	Shapiro S	J Neurosurg Spine (2001)	246	Mean, 60 mo Range, 12 to 94 mo	not mentioned	Overall, 99.6%	Cadaveric fibula and locking plate, autogenous iliac crest	
134	Steinmetz M	J Neurosurg Spine (2002)	34	Mean, 13 mo Range, 6 to 42 mo	4-1 lev 22-2 lev 8-3 lev	Overall, 91%	Allograft, iliac crest autograft	
135	Epstein N	Official J Int Spinal Cord Society (2003)	42	Mean, 34 mo	42-1 lev	Overall, 90%	Iliac crest autograft, fibula allografts	< 1 mm of active motion
	-							
136	Vaccaro A	Orthopedics (2002)	9	Mean, 206 days Range, 114 to 289 days	9-1 lev	Overall, 77%	Allograft fibular strut with demineralizd bone matrix	

Table 2. Literature review data from 2000 to 2004 study

	Author	Journal (year)	Number of pa-tients	Follow -up period	Number of fused levs	Fusion rate	Grafttype	Fusion accessed by :		
137	Payer M	J Neurosurg Spine (2003)	25	Mean, 14 mo Range, 5 to 31 mo	25-1 lev	Overall, 96%	Not mentioned	< 2° of motion	< 50% of intervertebral space was radiolucent	
138	McConnell J	Spine (2003)	29	24 mo	18-1 lev 9-2 lev 2-3 lev	Overall, 78.5%	Pro Osteon 200 (coralline-derived hydroxyapatite) iliac crest graft			
139	Casha S	J Neurosurg Spine (2003)	195	Mean, 17 mo	Majority of 2 or 3 lev fusions	Overall, 93.8%	Iliac crest autograft, iliac crest allograft, fibular autograft, fibular allograft			Used anteroposterior radiographs in addition to lateral cervical F/E radiographs
140	Bose B	J Neurosurg Spine (2003)	37	Mean, 1.3 yr Range, 0.5-2.3 yr	10-1 lev 19-2 lev 5-3 lev 3-4 lev	Overall, 80%	Autograft iliac crest graft, allograft iliac crest graft			Used anteroposterior radiographs in addition to lateral cervical F/E radiographs
141	Thome C	Neurosurg Rev (2003)	36	1 yr	27-1 lev 9-2 lev	Overall, 86%	Iliac crest autografts, titanium cages	< 2° of segmental motion	< 50% radiolucency	Measurment between spinous processes on films-interspinous distance must not change > 2 mm.
142	Baskin D	Spine (2003)	33	24 mo	18-1 lev 15-2 lev	100%	Iliac crest autograft	< 4° of angular motion	no radiolucency > 2 mm thick covering 50% of the superior inferior surface of the graft	

Table 2. Literature review data from 2000 to 2004 study

	Author	Journal (year)	Number of pa-tients	Follow -up period	Number of fused levs	Fusion rate	Grafttype	Fusion accessed by :		
143	Epstein N	J Spinal Disord (2003)	46	Mean, 3.2 yr	46-1 lev	Overall, 96%	Reversed iliac crest strut autografts			Static Roentgenograms and 2D CT studies used. Fusion on dynamic roentgenograms required the absence of translation and lack of motion between contiguous spinous processes (<1mm)
144	Futoshi S	Spine J (2001)	36	Mean, 4.5 yr	36-1 lev	Overall, 89%	Porous hydroxyapatite ceramics	< 1mm of active motion	Four grades of Classification Bony fusion. Grade 1: Nonunion with Motion noted. Grade 2: Probable Nonunion with No motion, no bone formation. And with radiolucent zones (RZ). Grade 3: Probable union With no motion noted, with bone formation, and with RZ. Grade 4: bone Union with no Motion, with Bone formation And no RZ.	No change in Lordotic angle of >3°

in the newer literature. The majority (63%) of these later articles utilize the most stringent plain radiographic definition of fusion.

Some studies in our analysis quote very high fusion rates basing their assessment solely on clinical criteria or patients' subjective feelings. Other studies reveal lower fusion rates; however, these studies use more stringent criteria of bridging trabeculae crossing the graft/host interface and absence of motion on dynamic films. What we found most surprising was that more than half of the older articles examining fusion following anterior cervical spine surgery fail to give any definition of fusion. Smith and Robinson in their landmark articles[145,146], used this more stringent definition of fusion. While there has been a lot of deviation from these criteria over the years, it appears that we are finally returning to the recommendations made fifty years ago.

We are unaware of any studies that have actually examined the accuracy of the various radiographic criteria for assessing fusion. It may be that the presence of bridging trabeculae is more accurate than the absence of motion on flexion/extension views or vice versa. The question also remains as to the interpretation of the fusion status when these two assessment methods disagree. Until a clinical-pathological study is performed where radiographic examination is followed by histological confirmation, it cannot be unequivocally determined which of these two assessment methods is the most accurate.

Nevertheless, we believe that if there are times when a pseudoarthrosis can only be detected on either dynamic or static views, and therefore both are required to confirm the diagnosis.

To date, no study has determined unequivocally if fusion status has any bearing on outcome. Before such studies are undertaken, we need to develop a uniform definition of solid arthrodesis following anterior cervical spine surgery. Further, for meaningful comparisons amongst studies, the measurement tool needs to be uniform. To that end, we recommend that all studies reporting on fusion rates use flexion/extension films in addition to static radiographs. A solid bony arthrodesis can then be based on the presence of both bridging trabeculae and the absence of motion on flexion/extension radiographs.

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