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, Pseudoarthrosis

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...
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, 2,317 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.
| 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      | Lipula377 | Fe and Fibula66                                | 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; Absence of 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 Neurul            | 195                | 52.4| 44.0      | Auto icbg/Fibula | St and no motion                             | 97.0        |
| 9. Deburg A  | J Bone Joint Surg Br   | 8                  | 71.0| 1.0 to 7.0| All fibula all plated | None                                          | 100.0       |
| 10. Zdeblick TA | J Bone Joint Surg Am  | 35                 | 50.0| 44.0      | All auto icbg | None                                          | 100.0       |
| 11. Tominaiga T | Surg Neurul       | 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. Herma J  | Neurosurgery           | 20                 | 28.0| 0         | Icbg 95 Allo 5 per | None                                          | 97.0        |
| 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                                            | 83.0        |
| 19. Connolly PJ | J Spinal Disord | 43                 | 0   | 16.5      | Auto icbg 25 plated | St                                            | 100.0       |
| 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      | None                                          | 66.0        |
| 22. Chang K  | J Spinal Disord        | 27                 | 49.0| 12.0 to 24.0| Icbg     | None                                          | 100.0       |
| 23. Iwaki 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. Connolly E | Neurosurgery     | 63                 | 47.0| 373.0     | Icbg       | Bt                                            | 79.0        |
| 29. Siqueira E | Surg Neurul       | 221                | 52.0| 0         | Calf bone | None                                          | 100.0       |
| 30. Zhang Z  | Spine                  | 121                | 50.0| 22.0      | Auto 83 | None                                          | 84.30       |
|              |                        |                   |     |           | Allo 38 | None                                          | 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. Kostui J | Spine                  | 42                 | 4730| 0         | Icbg plated | None                                          | 100.0       |
| 34. Casper W | J Spinal Disord        | 356                | 45.0| 1.0 to 90 | Auto 259 allo 97 | None                                          | 96.0        |
|              |                        |                   |     |           | Plated 146 non pl 210 | None                                          |            |
| 35. Yangjia O | Spine                  | 15                 | 45.6| 93.0      | Icbg       | None                                          | 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)                                 | 98.0        |
| 40. Savolainen S | Acta Neurochir | 250                | 48.0| 6.0       | Auto 149 | None                                          |            |
|              |                        |                   |     |           | Allo 104 | None                                          |            |
| 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
Table 1. Literature review data from 1996 to 2000 study

| Author       | Journal          | Number of patients | Age | Follow-up | Graft type          | Criteria                  | Fusion rate |
|--------------|------------------|--------------------|-----|-----------|---------------------|---------------------------|-------------|
| Schnee C     | Spine            | 142                | 48.1| 8.1       | Icbg some plated    | St                        | 96.7        |
| Phillips F   | Spine            | 16                 | 47.0| 32.0      | Icbg                | St and Fe with < 2mm      | 88.0        |
| Hilibrand A  | Spine            | 38                 | 0   | 68.0      | Icbg fibula         | Fe > 2mm                  | 76.0        |
| Malca S      | Spine            | 52                 | 34.0| 7.4       | Xenograft plated    | St Fe with zero moti      | 100.0       |
| Lowery G     | Spine            | 20                 | 47.0| 28.0      | Auto 35% plated     | St or Fe > 2 mm           | 45.0        |
| An H         | Spine            | 77                 | Aut46.1| All48.0 | Aut 18.4 | Both               | St and Fe | Aut 73.7 |
| Bringham C   | Spine            | 43                 | 48.0| 14.0      | Icbg                | St and Fe                 | 93.0        |
| Villas C     | Acta Orthop Scand | 21             | 54.0| 36.0      | Icbg 9 plated       | St and Fe                 | 95.0        |
| Cauthen J    | Spine            | 348                | 40.0| 62.0      | Auto 30%            | Fe                        | 83.0        |
| Emery S      | Spine            | 16                 | 59.0| 37.0      | Icbg                | St and Fe                 | 56.0        |
| Walters W    | Spine            | 64                 | 46.0| 73.0      | Icbg                | Fe and st (assumed)       | 90.0        |
| Emery S      | Spine            | 29                 | 47.0| 28.30     | Icbg                | St and Fe                 | 95.6        |
| Capen D      | Clin Orthop Relat Res | 88          | 27.0| 44.0      | Fibul 85 icbg 3     | None                      | 100.0       |
| Doi K        | Spine            | 6                  | 54.5| 26.0      | Vascularizedfibula  | None                      | 100.0       |
| Herrkowitz H | Spine            | 18                 | 58.4| 2.0+      | Icbg                | St and Fe                 | 63.0        |
| Brown J      | Spine            | 10                 | 45.0| 15.0      | Icbg 10 fib 3       | St or Fe or ab. of pain   | 100.0       |
| Gore D       | Spine            | 146                | 48.0| 5.0       | Icbg                | None                      | 97.0        |
| Zdeblick TA  | JBJS             | 14                 | 45.7| 28.0      | 8 fibula 6 icbg     | St and Fe                 | 100.0       |
| Lais L       | JAMA             | 11                 | 45.0| None      | Icbg plated         | None                      | 100.0       |
| Jacobs B     | J Trauma         | 65                 | 30.0 to 59.0 | 38.0 | None | Notmentioned | None      | 98.5        |
| Anderson L   | Arch Orthop Traumat | 16           | 32.8| None      | Tibia               | None                      | 100.0       |
| Tunturi T    | Arch Orthop Traumat | 29           | 43.0| Yrs 6.5   | Icbg                | None                      | 100.0       |
| Depalure A   | Clin Orthop Relat Res | 146     | 17.0 to 62.0 | 27.4 | None | Fe               | 89.1        |
| Brown M      | Clin Orthop Relat Res | 98          | None| None      | Icbg plated         | None                      | 100.0       |
| Fielding J   | Clin Orthop Relat Res | 3           | 47.0| None      | Icbg                | None                      | 100.0       |
| Kambin P     | Clin Orthop Relat Res | 93          | None| 2.0+      | Icbg                | Fe and new bone formation | 99.0        |
| Gore D       | Clin Orthop Relat Res | 58          | 47.0| 1.0+      | Tibia 37            | St or Fe                  | 100.0       |
| Brunton F    | J Bone Joint Surg Br | 75           | 20.0 to 73.0 | 4.5yrs | Icbg | None               | 77.0        |
| Simmons      | J Bone Joint Surg Br | 84           | 20.0 to 70.0 | 34.0 | Icbg | None               | 96.0        |
| Tippets R    | Neurosurgery      | 28                 | 39.9| 4.9       | Icbg plated         | None                      | 100.0       |
| Kojima t     | Neurosurgery      | 45                 | 55.0| None      | Icbg                | None                      | 100.0       |
| Young W      | Spine            | 23                 | 35.0| 6.0       | Fib all             | St                        | 92.0        |
| Brodke D     | Spine            | 51                 | 45.0| 12.0      | Icbg                | St and Fe                 | 94.0        |
| Brodsky A    | Spine            | 17                 | 49.8| 60.0      | Icbg                | St dissol of end plates   | 94.0        |
| Zdeblick TA  | Spine            | 87                 | 43.0| 28.0      | All 27 auto 60      | St                        | 87.0        |
| Grossman W   | Spine            | 50                 | 53.0| 22.1      | Fib all             | One end plate fusion      | 100.0       |
| Suh P        | Spine            | 13                 | 43.0| 13.0      | Icbg plated         | St                        | 100.0       |
| Kozak J      | J Spinal Disord  | 40                 | 44.0| 15.0      | Icbg                | St                        | 87.5        |
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 1. Literature review data from 1996 to 2000 study

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

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

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**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
| Author       | Journal               | Number of patients | Follow-up period | Number of fused levels | Fusion rate | Graft type                  | Presence of spanning trabeculae | Absence of motion on flexion/extension lateral cervical spine radiographs | Absence of a radiolucent gap between graft and endplate | Rating scale Used | Other |
|--------------|-----------------------|--------------------|------------------|------------------------|-------------|----------------------------|---------------------------------|---------------------------------|---------------------------------|----------------|--------|
| 113 Cauthen J | Spine J (2003)        | 88                 | Mean, 2.4 yr     | 43-1 lev               | Overall, 89% | none                       |                                 |                                 |                                 |                     |        |
|              |                       |                    | Range, 1.0-5.5 yr| 45-2 lev               |             |                            |                                 |                                 |                                 |                     |        |
| 114 Kaiser M | Neurosurgery Online (2002) | 233               | Mean, 15.6 mo    | 157-1 lev              | Overall, 94% | Cortical allograft         |                                 |                                 |                                 |                     |        |
|              |                       |                    | Range, 9-40 mo   | 76-2 lev               |             |                            |                                 |                                 |                                 |                     |        |
| 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% radilucency |
| 116 Gore D   | Spine (2001)          | 145                | Not mentioned    | 112-2 lev              | Overall, 90% | Autogenous fibula          |                                 |                                 |                                 |                     |        |
|              |                       |                    |                  | 32-3 lev               |             |                            |                                 |                                 |                                 |                     |        |
| 117 Wang J   | J Spinal Disord (2001) | 52                 | Mean, 3.6 yr     | 20-1 lev               | Overall, 98% | Autogenous tricortical iliac crest bone graft |                                 |                                 |                                 |                     |        |
|              |                       |                    | Range, 2-7 yr    | 32-2 lev               |             |                            |                                 |                                 |                                 |                     |        |
| 118 Goldberg E | Spine J (2002)        | 80                 | Mean, 4.0 yr     | 57-1 lev               | Overall, 69% | Autogenous iliac crest, iliac Crest allograft |                                 |                                 |                                 |                     |        |
|              |                       |                    | Range, 2-7 yr    | 21-2 lev               |             |                            |                                 |                                 |                                 |                     |        |
|              |                       |                    |                  | 2-3 lev                |             |                            |                                 |                                 |                                 |                     |        |

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 1 or 2

Grade 1 represented an obvious Pseudoarthrosis with motion on F/E views.
Grade 2 Represented possible Pseudoarthrosis with no motion but a visible cleft
| Author | Journal | Number of patients | Follow-up period | Number of fused levels | Fusion rate | Graft type | Fusion accessed by: |
|--------|---------|-------------------|----------------|-----------------------|------------|-----------|-------------------|
| 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 | |

Grade 3:
Represented a solid fusion with no motion on F/E view and bony trabeculae.

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 bridging at 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                  | Number of patients | Follow-up period | Number of fused levels | Fusion rate | Graft type                                                                 | 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% | Iliogenic 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                           | Lack of bone absorption 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                                                  |                                                                                      |
| 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 | Overall, 95% | Autogenous iliac crest                                                     | 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. |
| Author       | Journal               | Number of patients | Follow-up period | Number of fused levels | Fusion rate | Graft type                                           | 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     | 59-3 lev               | Overall, 76%| Autogenous, tricortical, iliac crest bone grafts    |                                                     |
| 131 Bolesta M| Spine (2000)          | 15                 | Mean, 42 mo      | 12-3 lev               | Overall, 47%| Autogenous tricortical iliac crest graft            | Evidence of remodeling                               |
| 132 Hillbrand A | Spine (2002)       | 190                | Mean, 68 mo      | 16-1 lev               | Overall, 75%| Autogenous iliac crest, fibular strut grafting      | ≤ 1 mm change in interspinous distance across a fused segment |
| 133 Shapiro S | J Neurosurg           | 246                | Mean, 60 mo      | not mentioned          | Overall, 99.6%| Cadaveric fibula and locking plate, autogenous iliac crest |                                                     |
| 134 Steinmetz M | J Neurosurg         | 34                 | Mean, 13 mo      | 4-1 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   | 9-1 lev                | Overall, 77%| Allograft fibular strut with demineralized bone matrix |                                                     |
| Author   | Journal   | Number of patients | Follow-up period | Number of fused levels | Fusion rate / Graft type | Fusion accessed by: |
|----------|-----------|--------------------|------------------|------------------------|-------------------------|---------------------|
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| Author  | Journal                     | Number of patients | Follow-up period | Number of fused levels | Fusion rate | Graft type                  | Fusion accessed by:                                                                 |
|---------|-----------------------------|--------------------|------------------|------------------------|-------------|-----------------------------|-------------------------------------------------------------------------------------|
| Epstein N | J Spinal Disorder (2003)    | 46                 | Mean, 3.2 yr     | 46-1 lev               | Overall, 96%| Reversed iliac crest strut autografts | Roentgenograms and 2D CT studies used. Fusion on dynamic roentgenograms required the absence of translation and lack of motion between contiguous spinous processes (<1mm) |
| Futoshi S | Spine J (2001)              | 36                 | Mean, 4.5 yr     | 36-1 lev               | Overall, 89%| Porous hydroxyapatite ceramics | 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. |
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 articles145,146, 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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