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# The concurrent use of lumbar total disc arthroplasty and anterior lumbar interbody fusion: The lumbar hybrid procedure for the treatment of multi-level symptomatic degenerative disc disease a prospective study

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1 **Title:** The concurrent use of lumbar total disc arthroplasty and anterior lumbar interbody fusion:  
2 the lumbar hybrid procedure for the treatment of multi-level symptomatic degenerative disc  
3 disease- a prospective study

4 **Running Title:** Long term follow up of lumbar hybrid surgery

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18 **No funding was received to conduct this study.**

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20 **(0000015881).**

21

22 **ABSTRACT**

23 **Study Design:** A prospective study

24 **Objective:** The aim of this paper is to evaluate clinical and patient outcomes post combined  
25 Total Disc Arthroplasty (TDA) and Anterior Lumbar Interbody Fusion (ALIF), known as hybrid  
26 surgery for the treatment of multi-level symptomatic degenerative disc disease (DDD).

27 **Summary of Background Data:** Class I studies comparing the treatment of one level lumbar  
28 DDD with TDA and ALIF have confirmed the effectiveness of those treatments through clinical  
29 and patient outcomes. While the success of single level disease is well documented, the evidence  
30 relating to the treatment of multi-level DDD with these modalities is emerging. With the  
31 evolution of the TDA technology, a combined approach to multi-level disease has developed in  
32 the form of the hybrid procedure.

33 **Methods:** A total of 617 patients underwent hybrid surgery for chronic back pain between July  
34 1998 and February 2012. Visual Analog Pain Scale (VAS) for the back and leg were recorded  
35 along with the Oswestry Disability Index (ODI) and Roland Morris Disability Questionnaire  
36 (RMDQ).

37 **Results:** Both statistically and clinically significant ( $p<0.005$ ) reductions were seen in back and  
38 leg pain, which was sustained for at least 8 years post-surgery. In addition, significant  
39 improvements ( $p<0.001$ ) in self-rated disability and function were also maintained for at least 8  
40 years. Patient satisfaction was rated at *good* or *excellent* in over 90% of cases.

41 **Conclusions:** The results of this research indicate that improvements in both back and leg pain  
42 and function can be achieved using the hybrid lumbar reconstructive technique.

43 **Key Points:**

- 44 1. Hybrid surgery provides stability at an unstable degenerated lumbar segment while still  
45 allowing for motion preservation at the adjacent level.
- 46 2. Both statistically and clinically significant benefits can be achieved with hybrid surgery,  
47 with results maintained for at least eight years post surgery.
- 48 3. Patient satisfaction is rated at good or excellent in over 90% of cases.

49 **INTRODUCTION**

50 Chronic low back pain often occurs as a consequence of degenerative disc disease (DDD) and it  
51 is a leading cause of work absenteeism, disability and quality of life reduction, as well as having  
52 a significant impact on societal and health care costs.<sup>1</sup> The pathophysiology of DDD has a  
53 complex multifactorial aetiology, whereby patients present for surgical management at various  
54 stages in the degenerative cycle.<sup>2-4</sup> Often the symptomatic disease involves multiple levels.  
55 Symptomatic DDD treated by surgery is a topic of debate amongst surgeons, insurers and  
56 government agencies with regards to its merits over non-surgical treatments. Fritzell *et al*<sup>5</sup>, with  
57 the Swedish Lumbar Spine Study Group, provided the first systematic evidence that fusion for  
58 DDD resulted in superior outcomes when compared to non-surgical treatments. The surgical  
59 group had a 33% reduction in back pain score and a 25% decrease in disability, measured using  
60 the Oswestry Disability Index (ODI), whilst the non-surgical group had 7% and 6% reductions  
61 respectively.

62 A variety of surgical options exist for those who do not respond to conservative treatment,  
63 including anterior lumbar interbody fusion (ALIF) and total disc arthroplasty (TDA).<sup>6</sup> A  
64 systematic review in 2010 found no clinically relevant differences between TDA and spinal

65 fusions.<sup>7</sup> Its recommendations were for long term follow up to evaluate the effectiveness and  
66 safety of TDA. A Cochrane review in 2012 found statistically significant differences in back  
67 pain and function in favour of TDA over fusion but concluded these differences were not  
68 clinically significant.<sup>2</sup> In the authors' opinion, the results of TDA and ALIF, if applied  
69 appropriately, should yield similar results as stabilizing the motion segment, the former  
70 dynamically and the latter statically. However, treating multi-level DDD by TDA or ALIF in  
71 isolation of each other creates secondary problems. In regards to TDA, increased facet joint  
72 stress and arthrosis have been reported, as well as rotational instabilities that result in coronal  
73 plain deformity.<sup>8</sup> Multi-level DDD treated by ALIF can result in adjacent motion segment  
74 disease, above and below the fused level, and increased non-union rates.<sup>9</sup> A solution to these  
75 issues can be found in combining the technologies in a hybrid procedure, where the potential side  
76 effects can be reduced and the beneficial effects optimized. The rationale for the hybrid  
77 technique is that the ALIF provides stability at an unstable degenerated lumbar segment, while  
78 the TDA allows for motion preservation, which is not achievable with traditional fusion.<sup>10</sup> The  
79 overarching principle of hybrid surgery is to utilise an evidence based model to match the  
80 pathology of a given motion segment to appropriate technology.

81 There is considerable evidence on the benefits of hybrid surgery, with studies demonstrating the  
82 maintenance of pre-operative range of motion, post-operative decreases in back pain and self-  
83 rated disability and function and low complication rates, with some studies having no  
84 requirement for revision or re-operation.<sup>11-13</sup> The hybrid technique has shown significantly  
85 greater improvements in both Visual Analogue Scale (VAS) back pain and disability scores,  
86 when compared to a standalone ALIF.<sup>14</sup> Despite early short term clinical success, minimal  
87 longitudinal data following the hybrid approach are available. Given this lack of long term

88 information, the purpose of this study is to provide long term follow up of patients with  
89 symptomatic multi-level DDD who underwent a hybrid ALIF and TDA procedure, while  
90 demonstrating how much pain reduction and functional improvement can be achieved and how  
91 long the effect lasts.

92

93

#### 94 **MATERIALS AND METHODS**

95 The 617 patients were treated with lumbar hybrid surgery between July 1998 and February 2012  
96 and recruited to participate in this study at the time of surgery. All participants suffered chronic  
97 low back pain (>12 months) and had been unresponsive to non-operative treatment, including  
98 physical therapy and rehabilitation programs. A diagnosis of multi-level discogenic axial low  
99 back pain, with or without radicular pain, was established through clinical history, clinical  
100 examination and diagnostic imaging and testing, which included a combination of standing  
101 lumbar radiographs, MRI, and provocative discography with post-discography fine cut CT scan.  
102 In patients with radicular symptoms, electrophysiological studies were performed to confirm the  
103 presence or absence of radiculopathy. In patients with complex vascular anatomy, a CT  
104 angiogram was obtained. Surgery was offered to patients whose history and clinical findings  
105 were consistent with both findings from imaging and concordant provocative tests and whose  
106 pain was interfering with social, recreation and employment opportunities. All procedures were  
107 performed by a single surgeon.



108 Contraindications to surgery included active infection, tumors, significant scoliosis (>20deg),  
109 and pregnancy. Obesity and involvement in workers' compensation or other litigation were  
110 regarded as relative contraindications, while surgery was not offered in the presence of overt  
111 psychological derangement or maladaptive pain behavior. Surgery was performed via a midline  
112 rectus split with a left or right sided retroperitoneal approach. A number of TDA prostheses  
113 were utilized through the study and the ALIF involved PEEK cages, either with integrated cage  
114 and screw systems or with a cage and plate with screws combination. Recombinant human bone  
115 morphogenic protein – 2 (rhBMP-2) , INFUSE® Bone Graft (Medtronic Inc, Memphis, TN,  
116 USA) was used in all ALIFs. The change in prostheses was due to availability and surgeon  
117 preference at the time of surgery.

118 Participants were required to complete an ODI and Roland Morris Disability Questionnaire  
119 (RMDQ) prior to and at regular intervals post-surgery, along with a self-rated indication of pain  
120 using a VAS for back and leg pain. Patient satisfaction was assessed with a four scale written  
121 questionnaire (excellent, good, satisfactory and poor). These outcomes were recorded post-  
122 surgery at 3, 6 and 12 months and yearly thereafter. The outcome questionnaires were analyzed  
123 by an independent research team.

124 As to be expected, there was some loss to follow-up, with a total lost to follow-up of 25%.  
125 However, it is noted that 82.8% of those lost to follow up reported a patient satisfaction score of  
126 either *excellent* or *good* at the last point of follow up and also that the majority of patients were  
127 *lost* at the 12 to 24-month stage. This study was approved by the University Human Research  
128 Ethics Committee (0000015881) and all participants were free to withdraw at any stage.

**129 Statistical Analysis**

130 Statistical analysis was conducted using the IBM Statistical Package for the Social Sciences  
131 (SPSS version 23) software and R version 3.2.5. The VAS for back and leg pain, ODI and  
132 RMDQ continuous outcomes were analyzed both as measured and as change from baseline  
133 (prior to surgery) for the multiple time-points from 3 to 120 months. The raw outcomes were  
134 skewed and therefore, medians and IQR were computed to obtain summary statistics. The  
135 change from baseline scores for ODI and RMDQ followed a normal distribution and therefore  
136 the mean differences from baseline were tested using paired *t*-tests. The change from baseline  
137 scores for both VAS measures displayed skewness, which was not improved by transformations.  
138 Hence, the median difference (Hodges-Lehmann estimate) and the corresponding 95%  
139 confidence intervals were calculated, as well as the *p*-value obtained from the sign test. To  
140 account for multiplicity, the reference *p*-value of 0.05 was adjusted according to the number of  
141 comparisons being made, using Bonferroni correction.

142 Graphical representations of median changes in leg and back pain VAS and mean change in ODI  
143 and RMDQ with 95% CI were plotted, along with their corresponding minimum clinically  
144 important difference (MCID). Previous research has found the MCID for back pain VAS to be  
145 12<sup>15</sup>, leg pain VAS to be 16<sup>15</sup>, a 10-point change on the ODI <sup>2</sup> and a change of 5 points on the  
146 RMDQ.<sup>2</sup>

**147 RESULTS**

148 In total, 617 patients with a mean age (SD) of 52.9 (11.1) years were used in this study. The  
149 median follow up time was 36 months (IQR 24-60 months). Table 1 shows the summary  
150 statistics for VAS outcomes for back and leg pain and their differences from baseline, along with

151 *p*-values. The results for pairwise differences are reported up to 96 months when the sample size  
152 was still sufficiently large to enable valid conclusions to be made.

153 A statistically significant difference can be seen at all follow up points up to 96 months post-  
154 surgery when compared to baseline (from  $p < 0.001$  to  $p = 0.004$ ).

155

156 **\*\*\*Table 1 here \*\*\***

157 Table 2 displays the summary statistics for both the ODI and RMDQ. Statistically significant  
158 improvements in both measures can be seen at each time point up to 96 months post-surgery  
159 when compared to baseline ( $p < 0.001$ ). The initial pre-surgery ODI median of 44 decreased by  
160 63.6% after three months to a median post-surgery score of 16. The score of 16 after 3 months  
161 can be interpreted as being minimal disability with this outcome measure.<sup>16</sup> Likewise, the  
162 RMDQ initial measurement of 16 decreased post-surgery by 75% to 4, a score which can be  
163 interpreted as no disability.<sup>17</sup> The results from 6 to 96 months follow up was significantly lower  
164 than the initial measurement and still classed as being of no disability (RMDQ = 1.0).

165 **\*\*\*Table 2 here\*\*\***

166 Figures 1 & 2 are graphical representations of the differences from baseline for back and leg pain  
167 VAS and the ODI and RMDQ outcome measures over time. The relevant MCID for each  
168 outcome is also displayed for reference. All of the profiles showed an improvement in pain or  
169 function that is well above the corresponding MCID.

170 **\*\*\*Figures 1 & 2 here \*\*\***

171 Results of the pooled patient satisfaction questionnaires for the entire follow up period are  
 172 displayed in Table 3 below. Patient satisfaction is seen to be *good* or *excellent* in 90% of cases  
 173 throughout the follow up period up to 108 months, with only 2% expressing a *poor* level of  
 174 satisfaction (Figure 3).

175 **\*\*\*Table 3 here\*\*\***

176 **\*\*\*Figure 3 here\*\*\***

177

178

179

180 **DISCUSSION**

181 The purpose of this study was to provide long term follow up of patients' pain and function for  
 182 an evidenced based approach to modern anterior spine surgery for chronic back pain, utilising a  
 183 hybrid surgical technique. The results of this research indicate that improvements in both back  
 184 and leg pain and function can be achieved using this surgical technique. Likewise, levels of  
 185 patient satisfaction post-surgery appear to be higher than previously published post both fusion  
 186 and TDA alone. Class 1<sup>6,18,19</sup> results for single-level TDA have been published, validating safety  
 187 and efficacy;<sup>20</sup> however, there is a suggestion multiple level TDA may have poorer outcomes,<sup>21</sup>  
 188 often related to facet arthritis and segmental instability.<sup>8</sup> This highlights the concept of constraint  
 189 and has therefore impacted the evolution of design of the implants.<sup>22</sup> Technological and  
 190 biological solutions for ALIF have shown good clinical outcomes and high fusion rates.<sup>23</sup>  
 191 However, a higher incidence of adjacent motion segment disease with fusion is a consideration.<sup>24</sup>  
 192 These factors are the reasons why hybrid surgery evolved. Aunoble *et al*<sup>25</sup>, in a prospective study

193 on 47 hybrid patients, noted a mean reduction in ODI of 24.9 points (53% improvement) at 2  
 194 years follow up. The VAS back was 64.6% improved. They concluded that hybrid surgery was a  
 195 viable alternative to multilevel TDA or fusion. Hoff *et al*<sup>11</sup> reported results of a randomized trial  
 196 of hybrid construct compared with pedicle screw and trans-lumbar interbody cages with a mean  
 197 of 37 months follow-up. The hybrid group was associated with lower VAS scores, a low  
 198 complication rate, better lordosis and improved motion.

199 The clinical outcomes of this study compare favourably against previous studies and have shown  
 200 significant improvements in back pain, disability and quality of life. At all time frames measured  
 201 throughout this study, the mean difference in ODI score is above the MCID of 10, above 15,  
 202 which is considered clinical success and also above 18.8, which is considered to be substantial  
 203 clinical benefit.<sup>25,26</sup> The improvements in the ODI, which are maintained for at least 8 years,  
 204 build on previously published results utilising this surgical technique. Other studies using the  
 205 same procedure have shown decrease in back pain VAS from 7.0 – 2.5 at 24 months<sup>27</sup> and 7.4 to  
 206 3.73<sup>11</sup> on a 10-point scale, similar to the 74 to 8-point change on a 0-100 scale in this study.  
 207 Other research has demonstrated maintenance of significant improvements in back pain  
 208 maintained to 34 and 37 months.<sup>11,28</sup>

209 Changes of 47.42 points have been seen in TDA studies over 24 months, comparable to the 54.0  
 210 change in this study. Both of these numbers are lower than Garcia's study in which  
 211 improvements of 61-67 were seen at 24 months.<sup>28</sup> Another study, stated mean back pain VAS  
 212 scores decreased by 3.59 points from 6.93 to 3.34 on a 10 point scale after 24 months, a similar

213 decrease to the post-operative result (using a 100 point scale) in this study.<sup>29</sup> Again, at all time  
 214 points in this study, the reduction in VAS back pain is above 12, suggested to be the MCID.

215 The significant improvements in leg pain post-surgery are maintained in this study up to 96  
 216 months post-surgery. The original concept of TDA was to treat back pain; however, leg pain  
 217 secondary to neural compression can be treated equally or better. Previous studies have shown  
 218 decreases in leg pain from 4.1 to 2.5, similar to the 37-point median change using a 100-point  
 219 scale in this study.<sup>25</sup> Results from other studies report pain using a VAS but do not clarify  
 220 whether it is back or leg pain.<sup>6,18,30</sup> Studies using a TDA without fusion have found variable  
 221 results with no significant differences in leg pain at 12 and 24 months post-surgery, in some,<sup>31</sup>  
 222 and significant improvements only after 12 months, in others.<sup>19</sup> One study demonstrated  
 223 decreases in leg pain after 24 months from 5.51-2.42 using a 10 point VAS scale, which  
 224 compares well to the results of this study.<sup>29</sup>

225 Patient satisfaction appears to be higher, utilising hybrid surgery when compared to a fusion or  
 226 TDA alone. Patient satisfaction has previously been reported at 82% for TDA patients, compared  
 227 to 69% for spinal fusion patients at 24 months post operation.<sup>2</sup> Other studies have reported  
 228 satisfaction of patients post TDA surgery ranging from 88% to 90%.<sup>28,30</sup> At the same time point  
 229 with 436 respondents, 90.4% of patients in this study recorded either an excellent ( $n=296$ ,  
 230 67.9%) or good ( $n=98$ , 22.5%) level of satisfaction, with only 7.1% ( $n=31$ ) of patients recording  
 231 satisfactory and 2.5% ( $n=11$ ) having a poor level of satisfaction. The satisfaction of patients in

232 this study is also higher than the 88% at 24 months reported in the study by Yue *et al*<sup>32</sup>, utilising  
233 the same hybrid technique, and comparable to 95.7 satisfaction rate in the Chen *et al*'s study.<sup>13</sup>

234 There are limitations to the current study that need to be acknowledged. Not all patients  
235 experienced leg pain preoperatively and, therefore, their baseline score would be zero. In this  
236 case, the IQR rather than the median would provide more useful information. The very wide IQR  
237 of 14 to 80 at baseline (Table 1) indicates that 25% of the patients scored below 14 and 25%  
238 above 80. There are two possible scenarios: those who did not have any leg pain at baseline  
239 (who may or may not continue scoring zero at follow-up) and those who have some pain to  
240 severe pain (who are expected to show a great improvement after surgery). As the analyses  
241 considered all patients as a homogeneous group, this difference at baseline might explain why  
242 the improvement in leg pain is generally lower than for back pain.

243

244

## 245 **CONCLUSION**

246 There is strong evidence of statistically and clinically significant reduction in back and leg pain  
247 for patients undergoing hybrid surgery for chronic low back pain. This improvement in pain is  
248 sustained for at least 8 years. Significant improvements are also seen in self-rated physical  
249 disability and function, also maintained for at least 8 years. The results of this study suggest TDA  
250 with ALIF is a suitable option for patients suffering chronic back and leg pain secondary to multi-  
251 level DDD when conservative management fails.

## 252 **REFERENCES**

- 253 1. Last A, Hulbert K. Chronic low back pain: evaluation and management. *South African Family*  
 254 *Practice*. 2010;52(3):184-192.
- 255 2. Jacobs W, Van Der Gaag N, Tuschel A, et al. Total disc replacement for chronic back pain in the  
 256 presence of disc degeneration. *Cochrane Database Syst Rev*.2012.
- 257 3. Adams MA, Dolan P, Hutton WC, Porter RW. Diurnal changes in spinal mechanics and their  
 258 clinical significance. *The Journal of bone and joint surgery. British volume*. 1990;72(2):266.
- 259 4. Adams MA, McNally DS, Dolan P. Stress distributions inside vertebral discs. *Bone & Joint*  
 260 *Journal*. 1996;78-B(6):965-972.
- 261 5. Fritzell P, Hägg O, Wessberg P, Nordwall A. 2001 Volvo Award Winner in Clinical Studies:  
 262 Lumbar fusion versus nonsurgical treatment for chronic low back pain: a multicenter randomized  
 263 controlled trial from the Swedish Lumbar Spine Study Group. *Spine*. 2001;26(23):2521.
- 264 6. Zigler J, Delamarter R, Spivak J, et al. Results of the prospective, randomized, multicenter food  
 265 and drug administration investigational device exemption study of the ProDisc (R)-L total disc  
 266 replacement versus circumferential fusion for the treatment of 1-level degenerative disc disease.  
 267 *SPINE*. 2007;32(11):1155-1162.
- 268 7. Van Den Eerenbeemt KDM, Ostelo RWJG, Royen vBJ, Peul WC, Tulder vMW. Total disc  
 269 replacement surgery for symptomatic degenerative lumbar disc disease: a systematic review of  
 270 the literature. *European Spine Journal*. 2010.
- 271 8. van Ooij A, Oner FC, Verbout AJ. Complications of Artificial Disc Replacement: A Report of 27  
 272 Patients with the SB Charité Disc. *Spine*. 2003;28:369-383.
- 273 9. Röllinghoff M, Schlüter-Brust K, Groos D, et al. Mid-range outcomes in 64 consecutive cases of  
 274 multilevel fusion for degenerative diseases of the lumbar spine. *Orthopedic Reviews*. 2010;2(1).
- 275 10. Rasouli A, Delamarter RB, Kanim LEA, Ashraf N, Strenge B. The Hybrid ADR: Long-Term  
 276 Analysis of Sagittal Motion and Clinical Outcome after Concurrent ADR+ALIF (Minimum 2-  
 277 Year Follow-Up). *The Spine Journal*. 2009;9:83S-83S.



- 278 11. Hoff E, Strube P, Pumberger M, Zahn R, Putzier M. ALIF and total disc replacement versus 2-  
 279 level circumferential fusion with TLIF: a prospective, randomized, clinical and radiological trial.  
 280 *European Spine Journal*. 2016;25(5):1558-1566.
- 281 12. Pazmiño P, Laurysen C, Lanman T. Lumbar Hybrid Arthroplasty Outcomes Analysis. *The Spine*  
 282 *Journal*. 2008;8:175S-176S.
- 283 13. Chen B, Akpolat YT, Williams P, Bergey D, Cheng WK. Survivorship and clinical outcomes  
 284 after multi-level anterior lumbar reconstruction with stand-alone anterior lumbar interbody fusion  
 285 or hybrid construct. *Journal of Clinical Neuroscience*. 2016;28:7-11.
- 286 14. Lauridsen HH, Hartvigsen J, Manniche C, Korsholm L, Grunnet-Nilsson N. Responsiveness and  
 287 minimal clinically important difference for pain and disability instruments in low back pain  
 288 patients. *BMC musculoskeletal disorders*. 2006;7:82.
- 289 15. Copay AG, Glassman SD, Subach BR, Berven S, Schuler TC, Carreon LY. Minimum clinically  
 290 important difference in lumbar spine surgery patients: a choice of methods using the Oswestry  
 291 Disability Index, Medical Outcomes Study questionnaire Short Form 36, and Pain Scales. *The*  
 292 *Spine Journal*. 2008;8(6):968-974.
- 293 16. Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine*. 2000;25(22):2940.
- 294 17. Roland M, Fairbank J. The Roland-Morris Disability Questionnaire and the Oswestry Disability  
 295 Questionnaire. *SPINE*. Vol 252000:3115-3124.
- 296 18. Blumenthal. A prospective, randomized, multicenter food and drug administration investigational  
 297 device exemptions study of lumbar total disc replacement with the CHARITE (TM) artificial disc  
 298 versus lumbar fusion: Part I - Evaluation of clinical outcomes (vol 30, pg 1565, 2005). *SPINE*.  
 299 2005;30(20):2356-2356.
- 300 19. Gornet MF, Burkus JK, Dryer RF, Peloza JH. Lumbar disc arthroplasty with Maverick disc  
 301 versus stand-alone interbody fusion: a prospective, randomized, controlled, multicenter  
 302 investigational device exemption trial. *Spine*. 2011;36(25):E1600.

- 303 20. Interventional Procedure Guidance 306. Prosthetic intervertebral disc replacement in the lumbar  
304 spine 2009.
- 305 21. Cinotti G, David T, Postacchini F. Results of disc prosthesis after a minimum follow-up period of  
306 2 years. Vol 211996:995-1000.
- 307 22. Lazennec J-Y, Aaron A, Brusson A, Rakover J-P, Rousseau M-A. The LP-ESP ® lumbar disc  
308 prosthesis with 6 degrees of freedom: development and 7 years of clinical experience. *European*  
309 *Journal of Orthopaedic Surgery & Traumatology*. 2013;23(2):131-143.
- 310 23. Burkus JK, Heim SE, Gornet MF, Zdeblick TA. Is INFUSE bone graft superior to autograft  
311 bone? An integrated analysis of clinical trials using the LT-CAGE lumbar tapered fusion device.  
312 *Clinical Spine Surgery*. 2003;16(2):113-122.
- 313 24. Hiratzka J, Rastegar F, Contag AG, Norvell DC, Anderson PA, Hart RA. Adverse Event  
314 Recording and Reporting in Clinical Trials Comparing Lumbar Disk Replacement with Lumbar  
315 Fusion: A Systematic Review. *Global spine journal*. 2015;5(6):486.
- 316 25. Aunoble S, Meyrat R, Al Sawad Y, Tournier C, Leijssen P, Le Huec J. Hybrid construct for two  
317 levels disc disease in lumbar spine. *Eur. Spine J*. 2010;19(2):290-296.
- 318 26. Glassman SD, Copay AG, Berven S, Polly DW, Subach BR, Carreon LY. Defining substantial  
319 clinical benefit following lumbar spine arthrodesis. . *J Bone Joint Surg Am*. 2010;90(9):1839-  
320 1847.
- 321 27. Le Huec J, Pelosa J, Tournier C, Aunoble S. Hybrid Construct Fusion L5S1 and Disc  
322 Arthroplasty L4L5 for DDD: 2 Years Follow-Up. *The Spine Journal*. 2007;7:154S-155S.
- 323 28. Garcia R, Yue JJ, Blumenthal S, et al. Lumbar Total Disc Replacement for Discogenic Low Back  
324 Pain: Two-year Outcomes of the activL Multicenter Randomized Controlled IDE Clinical Trial.  
325 *Spine*. 2015;40(24):1873.
- 326 29. Boss O, Tomasi S, Bäurle B, Sgier F, Hausmann O. Lumbar total disc replacement: correlation of  
327 clinical outcome and radiological parameters. *The European Journal of Neurosurgery*.  
328 2013;155(10):1923-1930.

329 30. Park C-K, Ryu K-S, Lee K-Y, Lee H-J. Clinical outcome of lumbar total disc replacement using  
 330 ProDisc-L in degenerative disc disease: minimum 5-year follow-up results at a single institute.  
 331 *Spine*. 2012;37(8):672.

332 31. Berg S, Tullberg T, Branth B, Olerud C, Tropp H. Total disc replacement compared to lumbar  
 333 fusion: a randomised controlled trial with 2-year follow-up. *European Spine Journal*.  
 334 2009;18(10):1512-1519.

335 32. Yue J, Bertagnoli R, Fenk-Mayer A, et al. The Concurrent Use of Lumbar Total Disc  
 336 Arthroplasty and Adjacent Level Lumbar Fusion: Hybrid Lumbar Disc Arthroplasty - A  
 337 Prospective Study. *The Spine Journal*. 2006;6:152S-152S.

338 **TABLES**

339 **Table 1. Summary statistics for VAS outcomes for back and leg pain over time**

VAS <sup>1</sup> outcome				Change from baseline			
Time (months) post-surgery	n	Median	IQR	n	Median difference <sup>2</sup>	95% CI	p-value <sup>3</sup>
<b>Back pain</b>							
<b>0 baseline</b>	601	74.0	60.0-86.0				
<b>3</b>	592	15.0	5.0-33.0	583	50.0	47.5 to 52.5	<0.001*
<b>6</b>	573	10.0	3.0-24.5	564	55.0	52.5 to 57.5	<0.001*
<b>12</b>	574	9.0	0.0-22.0	565	56.0	53.0 to 58.0	<0.001*
<b>24</b>	444	8.0	1.0-25.8	435	54.0	51.0 to 57.0	<0.001*
<b>36</b>	349	9.0	1.0-32.0	340	53.0	49.5 to 56.0	<0.001*
<b>48</b>	273	9.0	2.0-35.0	263	48.5	44.5 to 52.5	<0.001*
<b>60</b>	173	9.0	1.0-31.0	164	51.0	45.5 to 56.5	<0.001*
<b>72</b>	109	10.0	2.0-34.5	99	52.0	45.5 to 57.5	<0.001*
<b>84</b>	77	11.0	2.5-41.0	69	51.5	43.5 to 58.5	<0.001*
<b>96</b>	32	14.5	3.3-42.8	22	47.5	35.5 to 59.5	<0.001*
<b>108</b>	12	22.0	10.3-67.5	4			
<b>120</b>	9	20.0	4.5-64.5	2			
<b>Leg pain</b>							
<b>0 baseline</b>	594	51.0	14.0-80.0				
<b>3</b>	589	4.0	0.0-26.0	573	32.0	28.5 to 35.5	<0.001*
<b>6</b>	572	1.0	0.0-15.0	557	37.5	34.5 to 40.5	<0.001*
<b>12</b>	570	1.0	0.0-12.3	555	37.5	34.5 to 41.0	<0.001*
<b>24</b>	446	2.0	0.0-10.3	433	37.0	33.5 to 40.5	<0.001*
<b>36</b>	348	2.0	0.0-15.0	333	38.0	34.0 to 41.5	<0.001*
<b>48</b>	275	3.0	0.0-14.0	261	39.5	34.5 to 43.5	<0.001*
<b>60</b>	174	3.0	0.0-19.0	162	40.5	34.5 to 46.5	<0.001*
<b>72</b>	110	4.0	0.0-24.3	97	42.5	35.0 to 49.5	<0.001*

<b>84</b>	78	3.0	0.0-31.0	67	35.5	24.0 to 44.5	<0.001*
<b>96</b>	32	6.0	0.3-15.0	20	46.0	25.5 to 65.5	0.004*
<b>108</b>	12	10.0	1.0-62.3	4			
<b>120</b>	9	4.0	2.5-60.0	2			

340 <sup>1</sup>The Visual Analogue Scale (VAS) is scored on a 0 (no pain) to 100 (worst imaginable pain) scale.  
 341 <sup>2</sup>The median difference is the Hodges-Lehmann estimate. A positive median difference indicates an  
 342 improvement or reduction in pain score from baseline (prior to surgery).  
 343 <sup>3</sup>The *p*-value is the result of the sign test. Significance is achieved when *p*<0.005 using Bonferroni  
 344 correction, as applied to multiple comparisons.  
 345 \*Statistically significant at the 0.005 level.  
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350 **Table 2. Summary statistics for ODI and RMDQ outcomes over time**

Disability outcome				Change from baseline			
Time (months) post-surgery	<i>n</i>	Median	IQR	<i>n</i>	Mean difference <sup>2</sup>	95% CI	<i>p</i> -value <sup>3</sup>
<b>ODI<sup>1</sup></b>							
<b>0 baseline</b>	601	44.0	34.0-54.0				
<b>3</b>	590	16.0	6.0-26.0	582	25.8	24.2 to 27.4	<0.001*
<b>6</b>	575	8.0	2.0-20.0	566	31.7	30.3 to 33.1	<0.001*
<b>12</b>	573	8.0	0.0-20.0	564	32.2	30.7 to 33.7	<0.001*
<b>24</b>	445	8.0	0.0-20.0	436	31.3	29.7 to 32.9	<0.001*
<b>36</b>	349	10.0	0.0-23.0	340	29.3	27.3 to 31.3	<0.001*
<b>48</b>	275	8.0	0.0-24.0	264	28.6	26.5 to 30.8	<0.001*
<b>60</b>	171	6.0	0.0-22.0	161	30.3	27.3 to 33.3	<0.001*
<b>72</b>	106	8.5	0.0-22.8	95	30.9	27.1 to 34.6	<0.001*
<b>84</b>	77	12.0	2.0-29.0	68	26.6	21.4 to 31.8	<0.001*
<b>96</b>	32	12.0	0.0-26.0	21	27.1	16.4 to 37.9	<0.001*
<b>108</b>	12	28.5	11.0-41.5	3			
<b>120</b>	9	16.0	1.0-40.0	1			
<b>RMDQ<sup>4</sup></b>							
<b>0 baseline</b>	601	16.0	13.0-19.0				
<b>3</b>	589	4.0	1.0-8.0	581	10.4	9.9 to 10.9	<0.001*
<b>6</b>	571	1.0	0.0-5.0	562	12.4	11.9 to 12.9	<0.001*
<b>12</b>	572	1.0	0.0-5.0	563	12.7	12.2 to 13.2	<0.001*
<b>24</b>	445	1.0	0.0-4.0	436	12.8	12.2 to 13.3	<0.001*
<b>36</b>	346	1.0	0.0-5.0	338	12.0	11.3 to 12.6	<0.001*
<b>48</b>	277	1.0	0.0-4.0	267	12.0	11.3 to 12.8	<0.001*
<b>60</b>	172	1.0	0.0-6.0	162	12.5	11.4 to 13.5	<0.001*
<b>72</b>	108	1.0	0.0-6.0	97	12.6	11.3 to 13.8	<0.001*
<b>84</b>	77	1.0	0.0-6.0	68	12.4	10.9 to 13.9	<0.001*
<b>96</b>	32	1.0	0.0-10.8	21	12.1	9.0 to 15.3	<0.001*

<b>108</b>	12	8.0	0.3-13.0	3
<b>120</b>	9	6.0	0.0-15.5	1

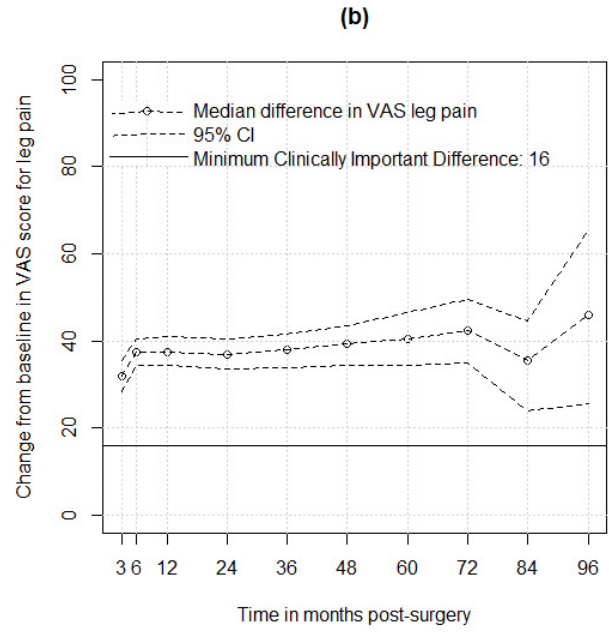
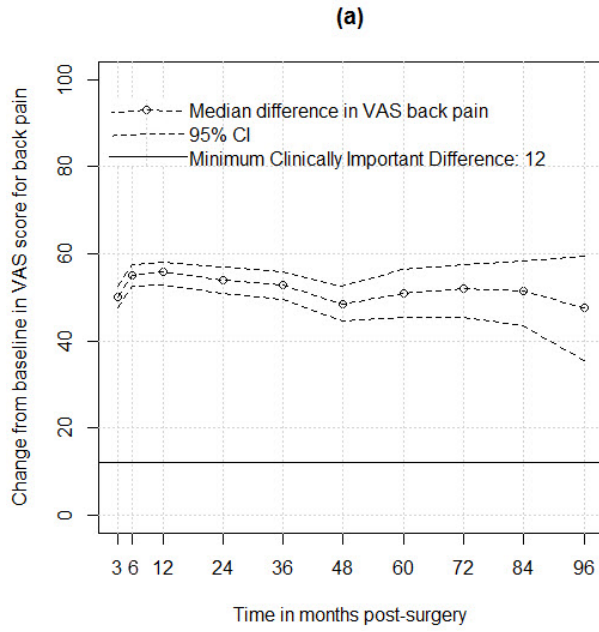
351 <sup>1</sup>The Oswestry Disability Index (ODI) is scored on a 0 (none) to 100 (worst) disability.  
 352 <sup>2</sup>A positive mean difference indicates an improvement or reduction in disability index from baseline (prior  
 353 to surgery).  
 354 <sup>3</sup>The *p*-value is the result of the paired *t*-test. Significance is achieved when *p*<0.005 using Bonferroni  
 355 correction, as applied to multiple comparisons.  
 356 <sup>4</sup>The Roland-Morris Disability Questionnaires (RMDQ) are scored on a 0 (none) to 24 (worst) disability.  
 357 \*Statistically significant at the 0.005 level.  
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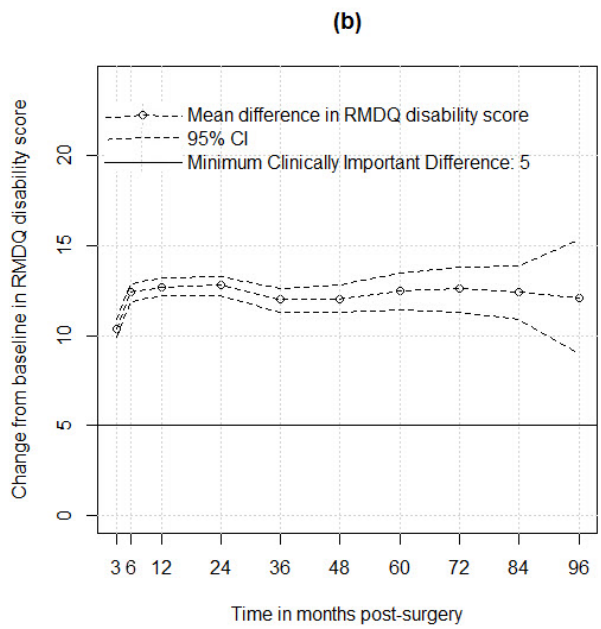
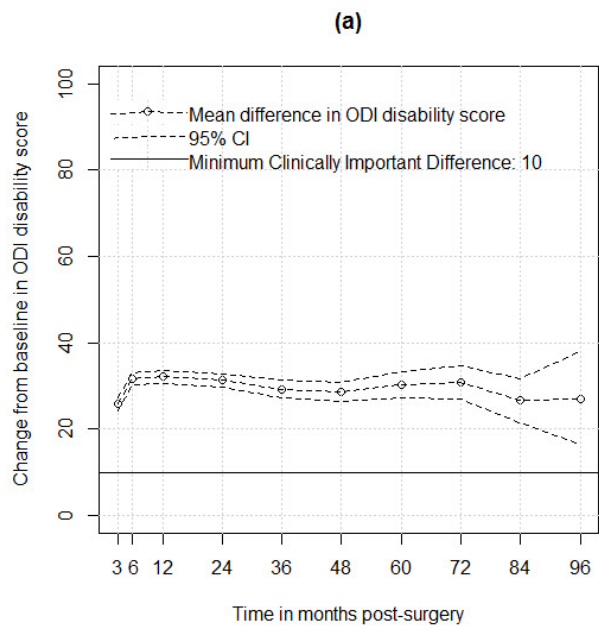
**Table 3: Summary statistics for patient satisfaction ratings (Excellent/Good) over time**

<b>Time (months) post-surgery</b>	<b>Total <i>n</i></b>	<b>Excellent/Good <i>n</i> (%)</b>
<b>3</b>	572	506 (88.4)
<b>6</b>	561	512 (91.3)
<b>12</b>	555	501 (90.3)
<b>24</b>	436	394 (90.4)
<b>36</b>	344	299 (87.0)
<b>48</b>	270	244 (90.4)
<b>60</b>	170	153 (90.0)
<b>72</b>	108	101 (93.5)
<b>84</b>	75	68 (90.6)
<b>96</b>	32	30 (93.7)
<b>108</b>	11	10 (90.9)
<b>120</b>	9	6 (66.7)

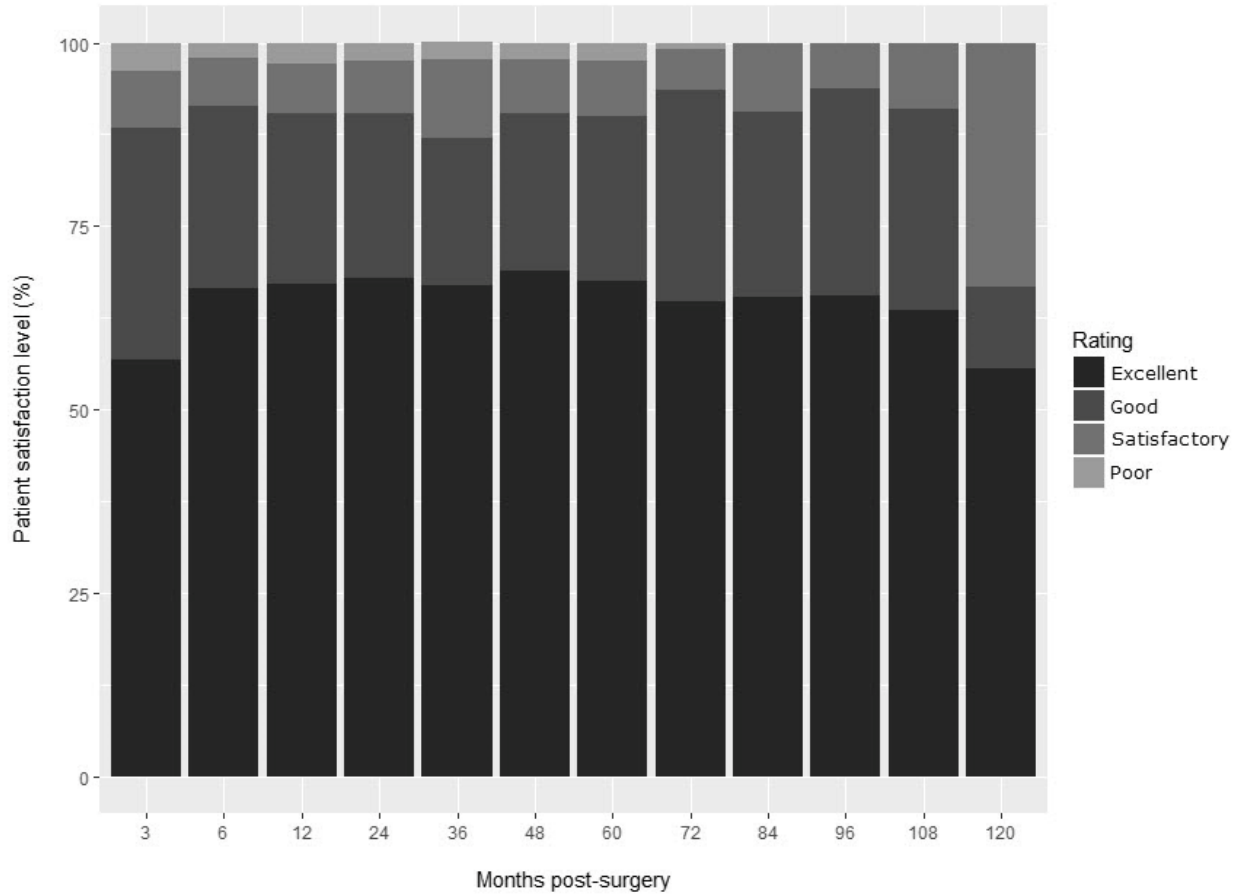
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372 **FIGURES**

373 **Figure 1: Profile of median difference between pre- and post- surgery over time, and 95%**  
 374 **confidence intervals for VAS back (a) and leg pain (b) scores in 617 patients.**

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376 **Figure 2: Profile of mean difference between pre- and post- surgery over time, and 95%**  
 377 **confidence intervals for ODI (a) and RMDQ disability scores (b) in 617 patients.**

378

379 **Figure 3: Results of the patient satisfaction questionnaire over the duration of follow up**  
 380 **(N=617).**

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