Asian Spine Journal
Clinical Study
Asian Spine J 2017;11(6):943-950 • https://doi.org/10.4184/asj.2017.11.6.943

Anterior Longitudinal Ligament Reconstruction to Reduce Hypermobility of Cervical and Lumbar Disc Arthroplasty

Ralph J. Mobbs[1,2], Jia Xi Julian Li[1,2], Kevin Phan[1,2,3]

[1]*Department of Neurosurgery, Prince of Wales Private Hospital, Neuro Spine Clinic, Sydney, Australia*
[2]*Department of Neurosurgery, Faculty of Medicine, University of New South Wales, Sydney, Australia*
[3]*Department of Neurospine Surgery Research Group (NSURG), Spine and Neurosurgery, Prince of Wales Private Hospital, Sydney, Australia*

Study Design: Retrospective case series

Purpose: This study aims to present the early clinical and radiological outcomes of anterior longitudinal ligament (ALL) reconstruction following disc arthroplasty.

Overview of Literature: Although cervical and lumbar disc arthroplasty have entered the clinical setting, there are still concerns regarding the short and long term complications arising from hypermobility of current prosthesis designs. Reconstruction of the ALL is a potential solution to disc arthroplasty hypermobility.

Methods: ALL reconstruction following disc arthroplasty have been performed by the senior author over a 24 month period. Ligament replacements used include allograft and synthetic, ligament advanced reinforcement system (LARS) ligaments. Methods of fixation used include titanium staples, bone anchors and suture fixation. Radiological follow-up pre- and postoperative Oswestry disability index, Neck Disability Index, Patient Satisfaction index scores were recorded on all patients.

Results: A total of 18 ALL reconstructions were performed. There have been no cases of early complications, revision surgery for recurrent symptoms or implant failure. Of the 6 patients receiving a minimum of 15 months follow-up, 4 patients received an allograft, 2 patients received the LARS ligament. Favourable, postoperative clinical and radiographic outcomes have been demonstrated.

Conclusions: ALL reconstruction following cervical and lumbar disc arthroplasty is a promising solution to addressing non-physiological kinematics of current disc arthroplasty devices. Randomized, controlled studies with larger study samples and long-term follow-up are required to establish these conclusions.

Keywords: Longitudinal ligaments; Lumbar vertebrae; Cervical vertebrae; Spondylosis; Arthroplasty

Introduction

Disc arthroplasty for discogenic pain has seen increasing use since its conception in the 1970s as a motion-preserving alternative to arthrodesis in the cervical and lumbar spine [1,2]. When suitably indicated, retaining motion in patients with degenerate disc pathology and normal facet kinematics aims to address the complications of adjacent segment degeneration associated with spinal fusion surgery [1,3-6].

Received Dec 11, 2016; Revised Feb 28, 2017; Accepted Mar 23, 2017
Corresponding author: Ralph J. Mobbs
Neurospine Surgery Research Group, Spine and Neurosurgery, Suite 7a, level 7, Prince of Wales Private Hospital, Barker street, Randwick NSW 2031, Australia
Tel: +61-02-9650-4766, Fax: +61-02 9650 4902+, E-mail: ralphmobbs@hotmail.com

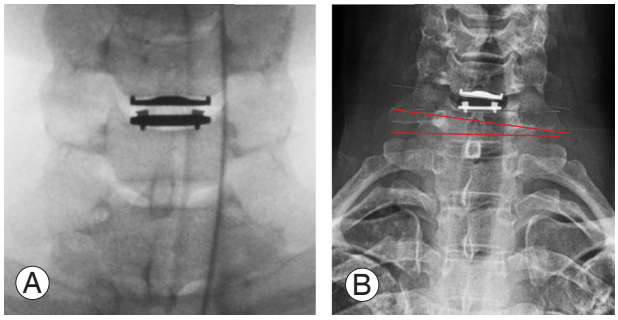

Fig. 1. (A) Standing neutral X-ray of cervical spine with prosthesis. **(B)** Coronal tilt of cervical disc prosthesis at 9 months.

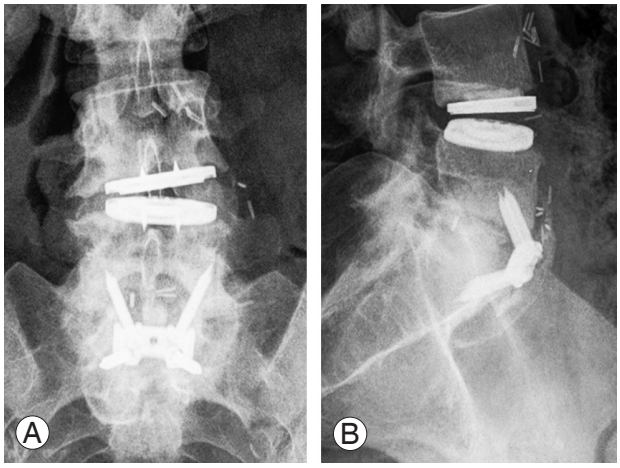

Fig. 2. (A, B) Standing neutral X-ray of lumbar spine with prosthesis. Note focal deformity with coronal tilt at L4/5 7 months post hybrid procedure. Design of prosthesis used: M6L (Spinal Kinetics, USA).

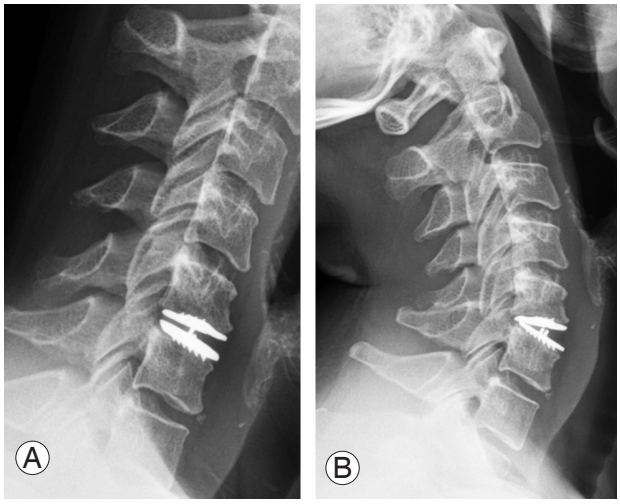

Fig. 3. X-ray of cervical spine with prosthesis in **(A)** flexion and **(B)** extension. Note hyperextension deformity with excessive opening, so called "fish-mouth" deformity, of the anterior aspect of the C5/C6 disc at 12 months post-surgery.

While the overall design principals of total disc replacement (TDR) prostheses have improved over the years, many available devices have semi- or non-constrained dynamics in an attempt to restore the normal range of motion [7]. This however comes with a risk of hypermobility in the motion segment, which combined with the inherent iatrogenic damage to the anterior longitudinal ligament (ALL) during insertion, disturbs the physiological kinematics of the spine [8-10]. These factors have been speculated to cause clinically significant secondary consequences to the operated spinal motion segment and adjacent segments in the short and long term [11-17]. Indeed, there have been several reports of anterior prosthesis migration following TDR, speculated to be a direct consequence of the disrupted ligamentous structures [12,15].

Although prosthesis design remains paramount in keeping with the original rationale behind disc arthroplasty of restoring physiological spinal kinematics, equal emphasis should also be placed on the stabilizing role of the ligamentous network in the spine [9,10]. As such we present a novel technical note and case series with preliminary results on ALL reconstruction following cervical and lumbar disc arthroplasty, in an attempt mitigate the disruption to the normal spinal motion segment.

Materials and Methods

1. Ethics and registry

Ethics for this study was approved by the South Eastern Sydney Local Health District (LNR/16/POWH/535). All patients signed informed consent for the operation and data access to their radiological outcomes and ongoing clinical evaluation.

The senior author (R.J.M.) has performed ALL replacements over a 24 month time period for lumbar and cervical pathologies receiving disc arthroplasty in an attempt to reduce potential coronal tilt (Figs. 1, 2), early implant expulsion and "fish-mouth" deformity (Fig. 3). Ligament replacements used include allograft (AusBiotech, Sydney, Australia) (Fig. 4) and synthetic, LARS ligaments (LARS, Arc-sur-Tille, France) (Fig. 5). Methods of fixation of the ligament replacement include titanium staples (Fig. 4C, D), bone anchors and suture fixation (Fig. 5C, D). All

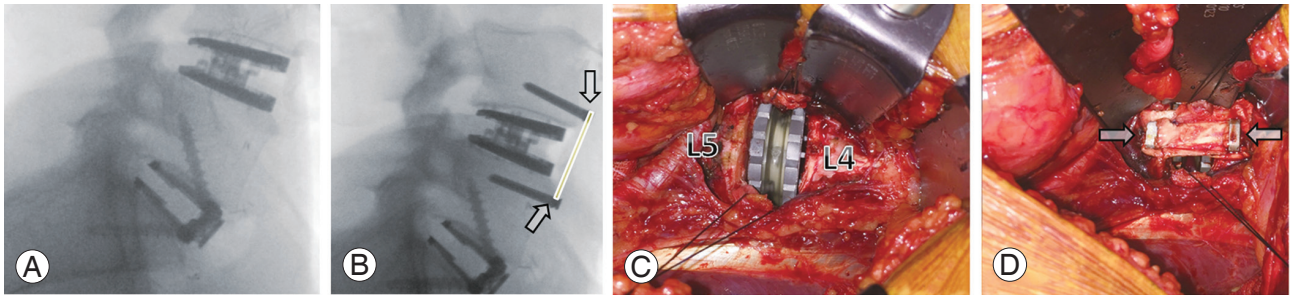

Fig. 4. (A-D) Anterior longitudinal ligament replacement using allograft ligament and staple bone fixation in a hybrid L4/5 total disc replacement and L5/S1 anterior fusion procedure. Arrows in **(B)** indicate attachment point of allograft ligament to bone fixation staple on X-ray. Arrows in **(C)** equivalent point of attachment of Allograft/Staple to Anterior vertebral body.

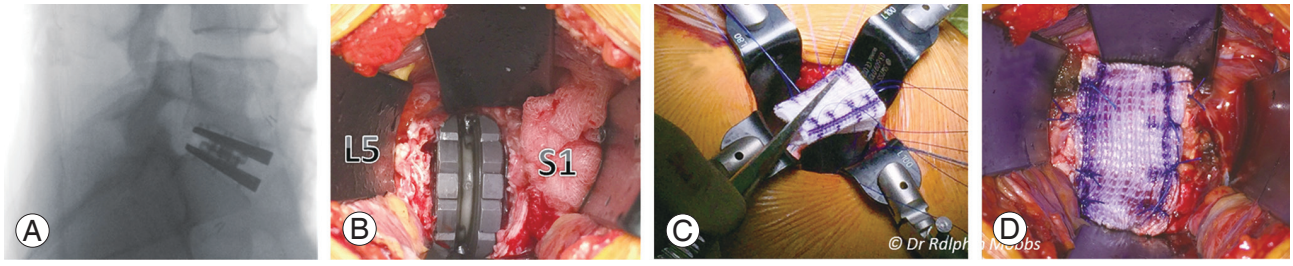

Fig. 5. (A-D) Anterior longitudinal ligament (ALL) replacement using synthetic ligament and suture fixation to adjacent ALL in a L5/S1 proceedure.

patients with disc arthroplasty were routinely followed up with standing X-ray at day 1 and 6 weeks postoperative, with flexion/extension X-rays at 3 months, 12 months, then at yearly follow-up. Computed tomography or magnetic resonance imaging is performed only if concerns regarding recurrent mechanical or neurological symptoms develop. Pre- and postoperative Oswestry disability index, neck disability index for cervical pathologies, and patient satisfaction index scores were recorded on all patients with data collection and retrospectively analysed by a research nurse. Feasibility of technique, safety and potential complications, and radiological outcomes were also assessed.

2. Surgical technique

The ALL reconstruction was performed following the TDR procedure, which was completed in a standard fashion. The decision to use an ALL replacement ligament was performed in combination with informed consent with the patient, and discussion on the potential benefits of the technique. The choice of ligament used was based on availability of an Allograft ligament. If no Allograft ligament was available, a synthetic ligament advanced reinforcement system (LARS) ligament was used. The ALL ligament was 'cut to size' so that firm attachment to the vertebral body or ALL above and below the disc replacement prosthesis was achievable using available attachment methods. As the ALL ligament takes load in extension and lateral bending, the motion segment was positioned 'neutral' at the time of ligament attachment. This allowed for a "no-tension" technique to mirror the normal mechanics of the structure in the neutral position.

Results

Over our 11 year experience with cevical and lumbar disc arthroplasty, the surgeon has identified a cohort of patients that have a postoperative supraphysiological range of motion (ROM) that may result in excessive loading of the facet joints and abnormal mechanics of the motion segment, and may benefit from reconstruction of ALL. A total of 18 ALL replacements were performed over a 24 month period. There have been no cases of early expulsion of implants, and no patient has required revision surgery for recurrent symptoms or implant failure. However a patient with an L3/4 TDR has received no benefit from the TDR implant with minimal movement on follow-up flexion/extension X-rays. Within the total cohort of 18 patients, 6 patients received a minimum of 15 months

follow-up, the details of which are summarised in Table 1. These 6 patients comprise 4 elastic spine pad (ESP) implants (FH Orthopaedics, Mulhouse, France) and 2 M6C implants (Spinal Kinetics, Sunnyvale, CA, USA). The ESP is a one-piece deformable implant providing 6-degrees of freedom about 3 axes. The M6-C artificial disc incorporates an artificial nucleus and annulus, also allowing range of motion in all 6 degrees of freedom. Of these patients, ALL replacement materials used include Allograft (4/6 patients) and LARS Synthetic ligament (2/6 patients). At a mean follow-up of 18 months, favourable, postoperative radiographic outcomes have been demonstrated in flexion and extension in both lumbar and cervical TDR with the exception of the patient who received an L3/4 implant. The other 12 patients were excluded from the present study due to short follow-up available, but comprise of 7 Allograft cases and 5 LARS ligament reconstruction cases.

Discussion

Cervical and lumbar interbody fusion techniques have become a routine surgical approach to effectively manage various degenerative pathologies of the spine including discogenic back and neck pain, spondylosis, segmental instability and deformity [18]. However, adjacent segment degeneration is an established long-term complication of cervical and lumbar fusion [1,4,5]. Immobilization of a spinal motion segment transfers increased loading and biomechanical stress to the adjacent motion segments, thereby accelerating the degenerative process.

Consequently disc arthroplasty has garnered increasing interest since their conception in the 1970s as a motion-preserving alternative to arthrodesis in patients with degenerate disc pathology but normal facet kinematics [1,3-5]. When suitably indicated, there is increasing evidence in the literature on cervical and lumbar disc arthroplasty achieving clinical and functional outcomes comparable with fusion surgery in IDE and randomised controlled trials [19-23]. Additionally, the risk of developing adjacent segment degeneration and requiring subsequent revision surgery with disc arthroplasty has been shown to be lower than spinal fusion in randomized controlled trials and multiple meta-analyses [4,5,19-23]. However, the results of these studies are limited by the relatively short follow-up, while emerging studies with longer follow-up have reached less definitive conclusions on the advantages of disc arthroplasty in the long term [24,25]. These issues are

Table 1. Operation details and outcomes of patients with minimum 15 months follow-up

No.	Age/Sex	Level of pathology	Prosthesis	Preop ODI (%)	Postop ODI (%)	PSI	Replacement ligament	ROM (flexion/extension) (°)	Ligament fixation	Follow-up (mo)
1	43/Male	Lumbar L4/L5	ESP[a]	46	8	1	Allograft	10.9 (5.9/16.8)	Staple fixation	15
2	46/Male	Lumbar L4/L5	ESP	34	18	2	Allograft	7.1 (7.2/14.1)	Suture fixation	16
3	48/Male	Cervical C6/C7	M6C[b]	NDI 42	NDI 4	1	Allograft	18.1 (–6.0/12.1)	Suture fixation	18
4	32/Male	Lumbar L5/S1	ESP	52	34	2	LARS ligament	9.4 (9.2/19.6)	Suture fixation	15
5	38/Female	Lumbar L3/L4	M6C	28	26	3	Allograft	2.6 (9.5/12.1)	Staple fixation	20
6	53/Female	Lumbar L4/L5	ESP	38	12	1	LARS ligament	9.6 (0.5/10.1)	Suture fixation	24

Preop, preoperative; ODI, Oswestry disability index; Postop, postoperative; PSI, patient satisfaction index (1=excellent outcome, 2=good, 3=fair, 4=poor); ROM, ranges of motion; NDI, neck disability index; ESP, elastic spine pad; LARS, ligament advanced reinforcement system.
[a]ESP, ESP lumbar arthroplasty/FH Orthopaedics, France; [b]M6C/M6L, Spinal Kinetics (USA).

reflected in a recent study by Hart et al. [26] on the perceptions of US-based spine surgeons in which over 50% of respondents were concerned with the potential long-term complications and technical difficulties of subsequent revision associated with lumbar TDR. This potentially reflects the inadequacy of current disc arthroplasty techniques and prosthesis design in replicating the normal kinematics of the cervical and lumbar spine [9,14,15,27].

While the overall design principals of disc replacement prostheses have changed over the years, many currently used designs have semi-constrained or non-constrained dynamics including the Bryan (Medtronic, Memphis, MA, USA), Mobi-C (LDR, Troyes, France), ProDisc-C (DePuy Synthes), M6-C (Spinal Kinetics) and Synergy disc (Synergy Disc Replacement Inc., Toronto, ON Canada) for the cervical spine, and the SB Charite III (DePuy Acromed, Raynham, USA), ProDisc II (Synthes Inc., West Chester, MA, USA), and Maverick (Medtronic) [7-9]. Semi- or unconstrained designs theoretically allows for greater freedom of movement in the implanted device, and consequently closer restoration of the normal range of motion in the spinal motion segment [7-9,14]. However, this carries the risk of greater than physiological range of motion in the operated motion segment and significantly less stability, which may be reflected in radiological findings including coronal tilt and fish-mouth deformity at the operated spinal segment (Figs. 1–3). In contrast, implant constraint can be a contributing factor to the complications and outcomes of TDR.

Restoring the physiological kinematics of a spine motion segment requires consideration of the role of spinal ligaments in stabilizing and regulating the motion of the tri-joint complex, which are often compromised during surgical dissection. The ALL has been demonstrated to be an important stabilizer of the motion segment during extension and lateral bending but at the same time, is routinely divided during anterior discectomy and prosthesis insertion [10]. The non-physiological kinematics introduced by current prosthesis designs in conjunction with loss of the ALL is speculated to cause clinically significant hypermobility, especially in extension, of the operated segment and excessive loading of the facet joints and implanted device [11,15,27,28]. There has been speculation on the use of the lateral approach for TDR, but this has not been well explored and there is the theoretical risk of lumbosacral plexus injury with this approach.

1. Short term complications of TDR

In the short-term, anterior migration and explantation of lumbar TDR prostheses have been reported by McAfee et al. [13] and Stieber and Donald [14] following a hyperextension motion. In both instances, the prostheses were positioned sub-optimally, with the centre of rotation of the devices placed too anteriorly to the individual's physiological centre of rotation, such that non-physiological compressive forces were sustained. Consequently, the device was fixed in extension and created a wedge which was significantly more vulnerable to anterior migration and explantation [14]. In a separate study Gragnaniello et al. [12] reported 2 cases of anterior migration within the first 2 weeks following lumbar disc arthroplasty with the same preceding event of spine hyperextension but in the absence of a sub-optimally positioned prosthesis. The authors speculated that inadequate release of the posterior longitudinal ligament during discectomy may have contributed by sustaining excessive lordosis of the operated segment intra- and postoperatively [12]. Without the ALL counteracting the posterior longitudinal ligament, this may replicate the situation of fixed extension and wedging as described by Stieber and Donald [14] such that excessive compressive loads render the prostheses more susceptible to anterior migration.

2. Long term complications of TDR

Long term secondary consequences of facet degeneration in the operated and adjacent levels due to segmental hypermobility following disc arthroplasty have also been described. van Ooij et al. [15] reported 11 cases of facet joint arthrosis following lumbar disc arthroplasty with pain aggravated in extension. Though the authors acknowledge that this facet arthrosis could be pre-existing, they speculate abnormal segmental kinematics from the Charite disc prosthesis, even in the absence of device subsidence or sub-optimal placement may introduce or accelerate facet degeneration. In the same study, 3 cases of excessive lordosis at the operated segment demonstrated opening of the superior aspect of the facet joint and compression of the inferior aspect [15]. In studies on lumbar TDR failures, Pettine [17] reported that 50% of failures were attributed to facet pathology while Rosen et al. [16] reported 100% of failures involved a facet aetiology [27]. In the cervical spine, Gautschi et al. [11] reported a case

of failed disc arthroplasty due to segmental hypermobility which resulted in persisting axial neck pain worsening under motion. These studies describe sagittal imbalance and subsequent concentration of stresses to the posterior elements, especially the facet joints, as mechanisms of clinically significant facet degeneration.

Given the above complications, it is clear current techniques of disc arthroplasty are still inadequate in replicating the normal kinematics of the operated spinal segment, which include normal facet joint movement and loading [15]. In order to address the current limitations outlined above, emphasis should be directed towards restoring important components of the ligamentous network [28]. The senior author of the current study describes a novel technique of ALL reconstruction following cervical and lumbar disc replacement. It is speculated reconstruction of the ALL may mitigate the issues associated with current prosthesis designs including hypermobility especially in extension, non-physiological kinematics and potential secondary complications. This may provide spinal surgeons greater confidence in performing disc arthroplasty.

3. Discussion of ALL reconstruction technique

Positive and promising radiological outcomes have been demonstrated following cervical/lumbar TDR with ALL reconstruction, with no intraoperative and postoperative complications. The use of allograft and LARS synthetic ligament in combination with either titanium staples or sutures in the reconstruction of the ALL are viable options. Synthetic ligaments may have a future role with ALL reconstruction [29].Technical issues encountered include precise sizing of the ALL implant and difficulty in attachment of the ligament in cases of poor quality ALL with suture attachment, and determining tension of the implant at the time of insertion. Staple fixation is a technically smoother procedure, however there are no commercially available staples that are manufactured for this indication.

Though we present a small sample size, the novelty of this surgical intervention and the prospective results we describe warrants extensive future research. Randomized and controlled prospective studies with long-term follow-up are needed to establish the radiological and clinical advantages of ALL reconstruction with disc arthroplasty, as well as determining patients most likely to benefit from this intervention. Biomechanical studies should aim to further elucidate the physiological kinematics of the spine and its ligamentous supporting structure to establish the ideal ligament material and tension, as well as the strength properties of anchoring techniques for ALL reconstruction.

Conclusions

Early clinical and radiological outcomes of ALL reconstruction following disc arthroplasty are positive and promising. There may be a role for ALL replacement techniques to provide confidence for spine surgeons that the complications profile and early failure of these devices can be reduced. Further research is required to establish the advantages of ALL reconstruction and the optimal technique of reconstruction.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

Ms Kelly Denning, Practice Nurse, NeuroSpineClinic.
Mr Simon Berry, AusBiotechnologies, Sydney, Australia.

References

1. Uschold TD, Fusco D, Germain R, Tumialan LM, Chang SW. Cervical and lumbar spinal arthroplasty: clinical review. AJNR Am J Neuroradiol 2012;33:1631-41.
2. Radhakrishnan K, Litchy WJ, O'Fallon WM, Kurland LT. Epidemiology of cervical radiculopathy: a population-based study from Rochester, Minnesota, 1976 through 1990. Brain 1994;117 (Pt 2):325-35.
3. Lackey A, Phan K, Mobbs R. A systematic review and meta-analysis of outcomes in hybrid constructs for multi-level lumbar degenerative disc disease. J Clin Neurosci 2016;34:23-9.
4. Pan A, Hai Y, Yang J, Zhou L, Chen X, Guo H. Adjacent segment degeneration after lumbar spinal fusion compared with motion-preservation procedures: a meta-analysis. Eur Spine J 2016;25:1522-32.
5. Zhu Y, Zhang B, Liu H, Wu Y, Zhu Q. Cervical disc arthroplasty versus anterior cervical discectomy

and fusion for incidence of symptomatic adjacent segment disease: a meta-analysis of prospective randomized controlled trials. Spine (Phila Pa 1976) 2016;41:1493-502.
6. Maharaj MM, Mobbs RJ, Hogan J, Zhao DF, Rao PJ, Phan K. Anterior cervical disc arthroplasty (ACDA) versus anterior cervical discectomy and fusion (ACDF): a systematic review and meta-analysis. J Spine Surg 2015;1:72-85.
7. Galbusera F, Bellini CM, Zweig T, et al. Design concepts in lumbar total disc arthroplasty. Eur Spine J 2008;17:1635-50.
8. Delecrin J, Allain J, Beaurain J, et al. Effects of lumbar artificial disc design on intervertebral mobility: in vivo comparison between mobile-core and fixed-core. Eur Spine J 2012;21 Suppl 5:S630-40.
9. Lazaro BC, Yucesoy K, Yuksel KZ, et al. Effect of arthroplasty design on cervical spine kinematics: analysis of the Bryan Disc, ProDisc-C, and Synergy disc. Neurosurg Focus 2010;28:E6.
10. Panjabi MM, Goel VK, Takata K. Physiologic strains in the lumbar spinal ligaments: an in vitro biomechanical study 1981 Volvo Award in Biomechanics. Spine (Phila Pa 1976) 1982;7:192-203.
11. Gautschi OP, Corniola MV, Stienen MN, Smoll NR, Cadosch D. Postoperative segmental hypermobility after cervical arthroplasty: a possible pathomechanism for outcome failure. J Clin Neurosci 2015;22:1194-6.
12. Gragnaniello C, Seex KA, Eisermann LG, Claydon MH, Malham GM. Early postoperative dislocation of the anterior Maverick lumbar disc prosthesis: report of 2 cases. J Neurosurg Spine 2013;19:191-6.
13. McAfee PC, Geisler FH, Saiedy SS, et al. Revisability of the CHARITE artificial disc replacement: analysis of 688 patients enrolled in the U.S. IDE study of the CHARITE Artificial Disc. Spine (Phila Pa 1976) 2006;31:1217-26.
14. Stieber JR, Donald GD 3rd. Early failure of lumbar disc replacement: case report and review of the literature. J Spinal Disord Tech 2006;19:55-60.
15. van Ooij A, Oner FC, Verbout AJ. Complications of artificial disc replacement: a report of 27 patients with the SB Charite disc. J Spinal Disord Tech 2003;16:369-83.
16. Rosen C, Kiester PD, Lee TQ. Lumbar disk replacement failures: review of 29 patients and rationale for revision. Orthopedics 2009;32:pii:orthosupersite.com/view.asp?rID=41919.
17. Pettine K. Clinical significance of hypermobility in cervical artificial disc replacements. Spine J 2011;11 (Suppl):S106.
18. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 2015;1:2-18.
19. Blumenthal S, McAfee PC, Guyer RD, et al. A prospective, randomized, multicenter Food and Drug Administration investigational device exemptions study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: part I: evaluation of clinical outcomes. Spine (Phila Pa 1976) 2005;30:1565-75.
20. Heller JG, Sasso RC, Papadopoulos SM, et al. Comparison of BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion: clinical and radiographic results of a randomized, controlled, clinical trial. Spine (Phila Pa 1976) 2009;34:101-7.
21. McAfee PC, Cunningham B, Holsapple G, et al. A prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: part II: evaluation of radiographic outcomes and correlation of surgical technique accuracy with clinical outcomes. Spine (Phila Pa 1976) 2005;30:1576-83.
22. Murrey D, Janssen M, Delamarter R, et al. Results of the prospective, randomized, controlled multicenter Food and Drug Administration investigational device exemption study of the ProDisc-C total disc replacement versus anterior discectomy and fusion for the treatment of 1-level symptomatic cervical disc disease. Spine J 2009;9:275-86.
23. Zigler J, Delamarter R, Spivak JM, et al. Results of the prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of the ProDisc-L total disc replacement versus circumferential fusion for the treatment of 1-level degenerative disc disease. Spine (Phila Pa 1976) 2007;32:1155-62.
24. Burkus JK, Traynelis VC, Haid RW Jr, Mummaneni PV. Clinical and radiographic analysis of an artificial cervical disc: 7-year follow-up from the Prestige pro-

spective randomized controlled clinical trial: clinical article. J Neurosurg Spine 2014;21:516-28.
25. Ding F, Jia Z, Zhao Z, et al. Total disc replacement versus fusion for lumbar degenerative disc disease: a systematic review of overlapping meta-analyses. Eur Spine J 2017;26:806-15.
26. Hart RA, DePasse JM, Daniels AH. Failure to launch: what the rejection of lumbar total disk replacement tells us about American spine surgery. Clin Spine Surg 2017;30:E759-E64.
27. Pettine K, Ryu R, Techy F. Why Lumbar Artificial Disk Replacements (LADRs) Fail. Clin Spine Surg 2017;30:E743-E7.
28. Dooris AP, Goel VK, Grosland NM, Gilbertson LG, Wilder DG. Load-sharing between anterior and posterior elements in a lumbar motion segment implanted with an artificial disc. Spine (Phila Pa 1976) 2001;26:E122-9.
29. Chen T, Jiang J, Chen S. Status and headway of the clinical application of artificial ligaments. Asia Pac J Sports Med Arthrosc Rehabil Technol 2015;2:15-26.