The role of lumbar disc replacement in the surgical management of low back pain

Spinal fusion has long been the standard surgical treatment for degenerative disorders of the spine, but clinical outcomes are often unpredictable. Lumbar disc replacement allows removal of the pain source while preserving motion. This article explores the role of lumbar disc replacement in the surgical management of low back pain.

Low back pain is one of the most prevalent health disorders in the industrialized world. At any given time 12–33% of the adult population is reported to have low back pain (Costa et al, 2009). Walker (2000) reported the 1-year prevalence of low back pain as between 22 and 65%, and the lifetime prevalence between 11 and 84%.

Natural history studies in large cohorts of patients with low back pain have established that many patients recover without surgical intervention. According to one study, 57% recover within 1 week, 90% over 6 weeks and 95% after 12 weeks. However, after 1 year, 1.2% remain disabled and out of work (Choler et al, 1985). For 3–7% of the population between 16–65 years of age, back problems will become a 'chronic sickness' that requires another approach to treatment (Clinical Standards Advisory Group, 1994).

While the genetic predisposition and pathological processes associated with disc degeneration are now better understood, these factors do not explain why certain individuals become symptomatic and others do not. Typically the complaint of low back pain is recurrent, intermittent and episodic; perhaps signalling that not all stages of disc degeneration are painful. The fluctuating severity of symptoms with the observation of spontaneous resolution in some makes the decision to offer surgical treatments for chronic low back pain all the more difficult.

For patients with chronic unremitting low back pain that is unresponsive to conservative measures including analgesic medication, exercise therapy, multidisciplinary pain treatment programmes or radiofrequency facet denervation, surgery can play an important role in management. Surgical options include spinal fusion and disc replacement.

This article discusses the indications and contraindications to disc replacement in the surgical management of back pain. Results of randomized controlled trials comparing spinal arthrodesis to lumbar disc replacement will be discussed, along with the latest developments in disc replacement technology.

Professor Brian JC Freeman *is Professor of Spinal Surgery in the University of Adelaide and Head of Spinal Services, Royal Adelaide Hospital, North Terrace, Adelaide, SA 5000, Australia (brian.freeman@health.sa.gov.au)*

Pathophysiology

Research indicates that heredity has a dominant role in disc degeneration, explaining 74% of the variance in adult populations (Battie et al, 2004). Environmental factors, such as mechanical loading and smoking, account for the remaining variance, although not all of the factors have yet been identified.

The process of disc degeneration has been defined as 'an aberrant cell-mediated response to progressive structural failure' by Adams and Roughley (2006). The structural changes appear after the age of 20 years and commence with circumferential tears in the annulus fibrosus and progress, through radial fissures, to the nucleus pulposus. Subsequent loss of proteoglycans and water content from the nucleus pulposus results in loss of disc height. These structural changes are now permanent because the adult disc is incapable of repair by virtue of its lack of blood supply and low metabolic rate. A biological cascade follows with high stress concentrations in the annulus fibrosus and reduced pressures in the nucleus pulposus leading to impaired proteoglycan production, further compounding the situation. Continued loss of disc height increases load on the facet joints initiating an inflammatory synovitis, followed by loss of articular cartilage, cyst and osteophyte formation. Ligamentous laxity in the capsule allows for increased movement, placing further stress on the disc. In advanced disc degeneration the entire three-joint complex (i.e. disc and both facet joints) will inevitably be involved.

Diagnosis

The diagnostic evaluation of chronic low back pain continues to be a significant challenge. History and examination are vitally important. Plain radiographs of the lumbar spine are often unhelpful. Occasionally, spondylolysis or spondylolisthesis may be identified on such radiographs, but it cannot be assumed that these entities are contributing to pain, particularly for individuals over the age of 25 years. Magnetic resonance imaging of the spine is the single most sensitive and specific investigation to identify disc herniation, tissue or neurological lesions, tumour or infection. However, for the assessment of degenerative low back conditions, it is too nonspecific to differentiate between patients with chronic low back pain and those without (Carragee and Hannibal,

2004). Furthermore studies in asymptomatic individuals have shown 'abnormal' magnetic resonance imaging scans in up to 30–40% of cases (Boden et al, 1990). Magnetic resonance imaging will not identify a pain source.

Many surgeons use provocative lumbar discography to ascertain whether a specific disc is painful or not (*Figures 1a* and *b*). The target disc and an adjacent control disc are cannulated with a 22 gauge spinal needle. Radio-opaque contrast is injected into the disc. The patient is asked, if pain occurs, whether it is typical of the previously reported back pain. If so, the discogram is reported as positive. Discography can accurately define the internal architecture of the disc and has utility in defining the pain source (Manchikanti et al, 2009). However, others regard discography to be unreliable, particularly in chronic pain patients (Carragee, 2000). Pain may be arising from the zygapophysial or facet joints. X-ray-guided injections of these joints with local anaesthetic and steroid will shed light on the relative contribution of these joints to the patient's back pain.

Treatment

Many patients with low back pain respond to conservative measures including simple analgesics, non-steroidal anti-inflammatory medication, exercise therapy and multidisciplinary pain treatment programmes aimed at functional restoration (van Tulder et al, 1997). For patients experiencing predominant lumbar facet joint pain, short-term relief has been reported following radiofrequency facet denervation (van Kleef et al, 1999). For patients who fail to respond to conservative measures and who have high levels of disability, surgical intervention in the form of spinal fusion or disc replacement may be considered.

Spinal fusion

Spinal fusion addresses both the disc and the facet joint as potential sources of pain. The aim of surgery is to eliminate movement from the painful motion segment. Two well-conducted randomized controlled trials support the use of spinal fusion under such circumstances: Möller and Hedlund (2000) demonstrated posterolateral fusion to be an effective method of reducing pain and functional deficit in adult isthmic spondylolisthesis when compared to an exercise programme. Fritzell et al (2001) similarly were able to show that lumbar fusion, in a well-informed and selected group of patients with severe chronic low back pain, diminished pain and disability more efficiently than commonly used non-surgical treatments. By contrast two other randomized studies were not able to demonstrate superior outcomes following lumbar fusion when compared to those observed following structured rehabilitation programmes (Brox et al, 2003; Fairbank et al, 2005). This area remains controversial, particularly for the treatment of chronic discogenic low back.

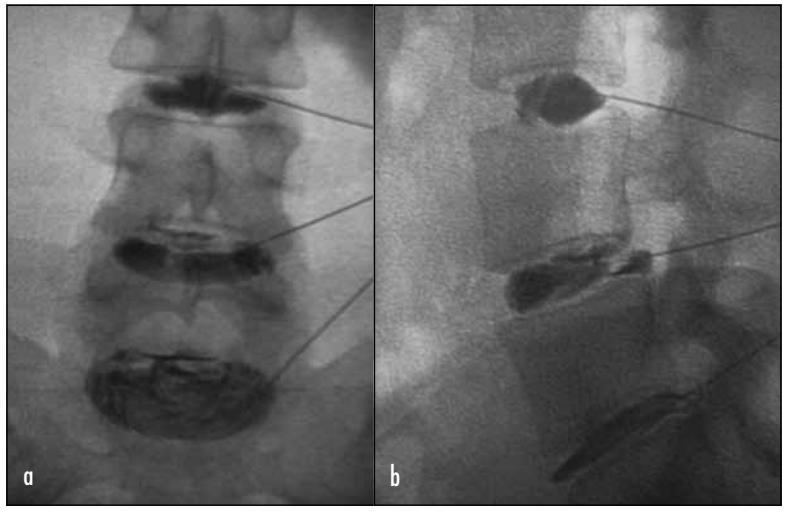


Figure 1. a. Anteroposterior and (b) lateral radiographs showing three-level lumbar discography. The patient experienced typical low back pain on injection of the lower two discs at L4/5 and L5/S1, but no pain on injection of the L3/4 disc.

Disc replacement

Spinal fusion has for many years been the standard surgical treatment for degenerative disorders of the spine. In much the same way that Charnley advanced from arthrodesis to arthroplasty of the hip for patients with painful arthritis, there has been a growing quest to develop motion-preserving technologies for the spine. Part of the stimulus for such technologies has been fuelled by the somewhat unpredictable results observed following spinal fusion, Wetzel et al (1994) reported satisfactory clinical outcomes in only 46% of cases compared to Thomsen et al (1997) who reported such outcomes in 82% of cases.

Spinal arthrodesis may have unintended consequences by creating abnormal biomechanics in the segment adjacent to the spinal fusion, leading to adjacent level disc degeneration. Gillet (2003) reported a 20% re-operation rate for symptomatic lumbar adjacent-level degenerative disc disease in 106 lumbar fusion patients.

Indications for disc replacement

The ideal candidate for disc replacement should have painful disc degeneration, as proven by provocative discography, at one or two lumbar segments. The facet joints should be normal or have only mild degenerative change. Up to 5% of patients undergoing lumbar discectomy for sciatica will develop disabling low back pain within 2 years of the original discectomy. These patients may be suitable for total disc replacement, provided the posterior elements of the spine are largely intact.

Contraindications to lumbar disc replacement

Contraindications to lumbar disc replacement are many (*Table 1*) and may be placed into one of two categories:

1. Those diagnoses that may compromise the long-term stability of the disc replacement

Table 1. Contraindications to lumbar disc replacement

Reason	Contraindication
May compromise the long-term stability of the disc	Spondylolysis
	Spondylolisthesis (> grade 1)
	Spinal deformity
	Post-surgical instability
	Osteoporosis
	Obesity
Painful conditions not corrected by disc replacement	Facet arthrosis
	Spinal stenosis (central and lateral)
	Lumbar disc herniation with radiculopathy

2. Those painful conditions that are not corrected by disc replacement.

Huang et al (2004) reported on the prevalence of contraindications to total disc replacement in a cohort of patients undergoing lumbar surgery from one surgeon's practice. Only 5% of patients in this cohort were regarded as possible candidates for lumbar disc replacement.

Types of lumbar disc replacement

Nucleus pulposus replacement: As the disc degenerates, the nucleus pulposus loses its ability to attract and maintain water leading to a loss of disc height and a loss of tension in the fibres of the annulus fibrosus. By replacing the diseased nucleus pulposus with such a device, the aim is to restore disc height, maintain joint space between adjacent vertebrae and place the retained annular fibres under tension, thereby restoring stability to the affected motion segment.

The first partial disc replacement to be implanted in the lumbar spine was the Fernström endoprosthesis in the late 1950s (Fernström, 1966). Indeed it is rumoured that John F Kennedy had such a device inserted for degenerative disease of the lumbar spine (Hart, 2006). More recent examples include the polymer-based devices: the Aquarelle (Stryker Spine, Allendale, NJ, USA) and the Prosthetic Disc Nucleus (Raymedica Inc, Bloomingtom, MN, USA). The Aquarelle is a hydrogel pellet implanted in a minimally-invasive fashion through a small annulotomy. High extrusion rates (20–33%) have been reported in cadaveric studies when using the posterolateral or anterior approaches respectively (Allen et al, 2004). However, when fully hydrated, extrusion only occurred when the disc space was placed under loads well above what is expected in vivo. Clinical trials in Europe are ongoing. The Prosthetic Disc Nucleus contains a hydrogel core composed of polyacrylamide and polyacrylonitrite. These co-polymers have hydrophilic and non-hydrophilic properties allowing the hydrogel to absorb and release water dependent on the load applied. Klara and Ray (2002) reported favourably on 480 completed procedures with increase in disc height and overall reduction of pain.

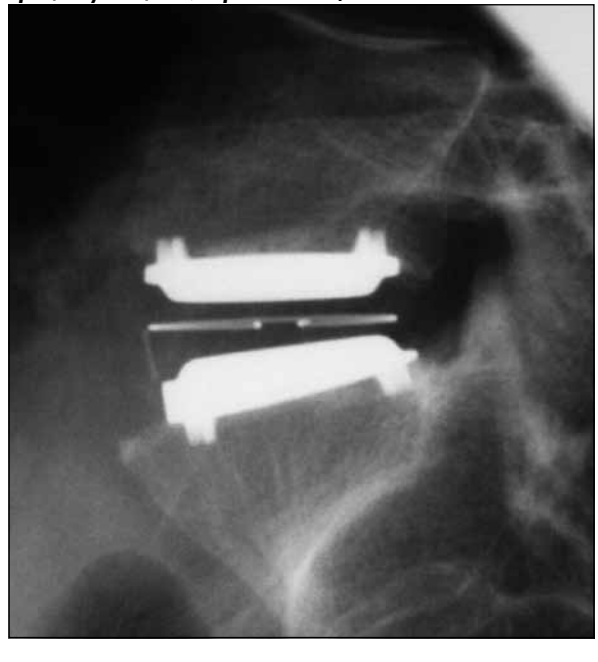
Total disc replacements: The first total disc replacement (Link SB Charité, Waldemar Link GmbH & Co., Hamburg, Germany) was implanted in 1984 (Link, 2002). The aims of total disc replacement include the elimination of the discogenic pain source, restoration of disc height and canal volume, retention of the facet joints and restoration of the kinematic and load-sharing properties of the motion segment. When compared to spinal fusion, total disc replacement may eliminate the unsatisfactory results observed following pseudarthrosis, donor site morbidity, adjacent level disc degeneration and posterior spinal muscle damage produced by posterior spinal fusions.

There are two main types of total disc replacement:

1. Low friction total disc replacement, e.g. Charité artificial disc (DePuy Spine Inc, Raynham, MA), ProDisc-L (Synthes Spine, West Chester, PA), FlexiCore inter-vertebral disc (Stryker Spine, Allendale, NJ)
2. Compliant total disc replacements, e.g. AcroFlex lumbar disc replacement (DePuy Spine Inc, Raynham, MA), CAdisc (Ranier Technology Ltd, Cambridge, UK).

***Low friction total disc replacements*:** The articulating surfaces for these devices are either metal on polyethylene or metal on metal. The Charité artificial disc (*Figure 2*) comprises two cobalt chromium alloy end plates and an ultra-high molecular weight polyethylene sliding core. The ProDisc-L total disc replacement (*Figures 3a* and *b*) comprises two cobalt-chromium molybdenum alloy end plates with central keels and ultra-high molecular weight

Figure 2. Lateral radiograph showing Charité artificial disc (DePuy Spine, Raynham, MA) implanted at L5/S1.



polyethylene convex inlay, which slides into the inferior end plate and articulates with the superior end plate. The FlexiCore intervertebral disc is a metal-on-metal artificial lumbar total disc replacement composed of a retained ball and socket device positioned between two base plates.

There have been three published randomized controlled trials and 16 prospective cohort studies relating to total disc replacement (van den Eerenbeemt et al, 2010). Blumenthal et al (2005) published the first prospective randomized multicentre study comparing lumbar total disc replacement to lumbar fusion after 2 years. This study involved 304 patients randomized in a 2:1 ratio to treatment with the Charité artificial disc or the control group which received an instrumented anterior lumbar interbody fusion. The study demonstrated clinical outcomes following lumbar total disc replacement to be at least as equivalent to those observed following anterior lumbar interbody fusion. Guyer et al (2009) subsequently reported the 5-year follow up of the same study where no statistically significant differences in clinical outcomes were identified between groups.

Zigler et al (2007) published a prospective randomized multicentre study of the ProDisc-L total disc replacement compared to circumferential fusion for the treatment of one-level degenerative disc disease, followed up for 2 years. In this study, the ProDisc-L total disc replacement was found to be safe and efficacious. In properly chosen patients, the disc replacement group had superior outcomes using a composite measure of 'clinical success' when compared to the circumferential fusion group. Others, however, have criticized this study because of its high risk of bias (van den Eerenbeemt et al, 2010). Moreover, there were no statistically significant differences noted in mean pain and physical function scores between the two groups.

Sasso et al (2008) reported the 2-year preliminary results of a prospective randomized trial of metal-on-metal artificial lumbar total disc replacement compared to circumferential fusion. The authors demonstrated the FlexiCore lumbar total disc replacement compared favourably to circumferential fusion for the treatment of lumbar degenerative disc disease.

Compliant total disc replacements: The AcroFlex elastomeric total disc replacement (*Figures 4a* and *b*) consists of two titanium end plates bound together by a hexane-based polyolefin rubber core and was designed to replicate the elasticity of the normal human intervertebral disc. Extensive biomechanical testing predicted at least 10 years of in-vivo use. Fraser et al (2004) reviewed the AcroFlex design and clinical results in 28 patients in whom the device was implanted between 1998 and 1999. Significant improvements in the Oswestry Disability Index (23 points) and the Low Back Outcome Score (22 points) were reported 2 years following surgery. Complications included one auto-fusion and one partial disc expulsion. However, of particular concern was the

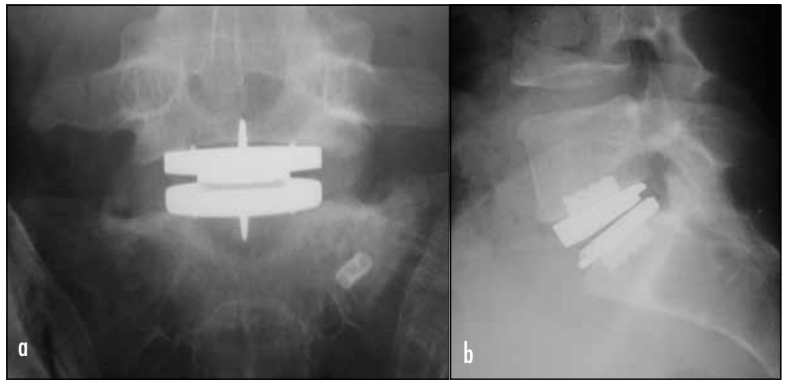


Figure 3. a. Antero-posterior and (b) lateral radiograph showing ProDisc-L lumbar disc replacement (Synthes Spine, West Chester, PA) implanted at L5/S1.

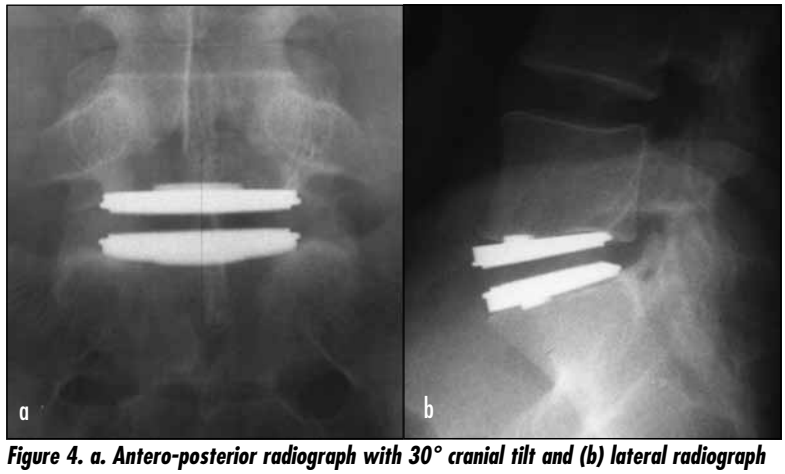


Figure 4. a. Antero-posterior radiograph with 30° cranial tilt and (b) lateral radiograph showing AcroFlex lumbar disc replacement (DePuy Spine Inc, Raynham, MA) (now discontinued) implanted at L5/S1.

observation on fine-cut computed tomography of rubber tears in 10/28 (36%) of patients. The majority were mid-substance antero-inferior peripheral tears. Subsequent imaging revealed osteolysis and peri-annular ossification. At a mean of 9 years and 8 months following surgery, the cumulative implant survival was only 60.7%, with 11 out of 28 (39.3%) patients having undergone revision surgery for device failure in seven and disabling pain in four (Fraser et al, 2011). This study highlighted the potential for wear particle formation with resultant osteolysis and also the development of peri-annular ossification leading to auto-fusion. As a result of disruption of the polyolefin rubber and associated osteolysis, the AcroFlex lumbar total disc replacement was never released to general market (Freeman and Davenport, 2006).

The compliant artificial lumbar disc replacement (CAdisc-L) is a polyurethane-polycarbonate graduated modulus disc replacement designed to mimic the biomechanical properties of the natural lumbar disc (*Figures 5a* and *b*). The device demonstrates a lower modulus nucleus surrounded by a higher modulus annulus with end plates that allow primary and secondary fixation (Gwynne and Cameron, 2010). Theoretically the graduated interface between the annulus and the nucleus should reduce the risk of long-term fatigue failure. The device has been

Figure 5. a. Antero-posterior radiograph and (b) lateral radiograph showing CAdisc-L lumbar disc replacement implanted at L4/5. The device is radiolucent apart from six tantalum markers which define the implant position.

tested in an animal model and demonstrated good in-vivo implant stability and subsequent osseointegration (Steffen et al, 2011). A prospective non-randomized multicentre clinical trial is underway in Europe and has demonstrated good clinical outcomes 12 months following surgery, with no device-related adverse events (Freeman et al, 2011). Clearly this cohort of patients will require careful long-term follow up with the perceived advantages on device longevity and protection of the adjacent disc taking some years to realize.

***Complications of total disc replacement*:** van den Eerenbeemt et al (2010) reported a wide range (1–91%) of complications in various cohort studies following total disc replacement; however, the majority of studies report a narrower range (10–40%). It is interesting to note the reported complication rates from the three aforementioned randomized controlled trials (Zigler et al, 2007; Sasso et al, 2008; Guyer et al, 2009); the overall complication rate was 7.2–28.6% for the total disc replacement group *vs* 6.6–50.2% for the fusion group, and the re-operation rate at index level was 3.7–11.4% for the total disc replacement group *vs* 5.4–26.1% for the fusion group.

Complications may be categorized as follows:

1. Related to the surgical approach (range from 2.1 to 18.7%), e.g. vascular injury, nerve root damage, retrograde ejaculation, inadvertent sympathectomy, deep venous thrombosis, injuries to bowel, ureter or bladder, rectus sheath hernia
2. Related to the prosthesis (range from 2.0 to 39.3%), e.g. malposition, subsidence, migration, implant displacement, implant failure, end plate fracture, fracture of the pars interarticularis, failure to osseointegrate, osteolysis, facet joint arthrosis, heterotopic ossification, spontaneous fusion, adjacent level degeneration, periprosthetic tissue reaction deranged range of motion
3. Related to the treatment (range from 1.9 to 62%), e.g. wound, pain, neuromusculoskeletal (van den Eerenbeemt et al, 2010).

Conclusions

Low back pain is an extremely common condition affecting the majority of the population at some point in their lifetime. Fortunately most acute episodes settle quickly, but for 3–7% of the population, back problems will continue as a chronic relapsing condition that will require another approach to treatment. The natural history of low back pain is unpredictable with fluctuating severity of symptoms, making decisions about surgical intervention difficult.

Patients with disabling low back pain who have failed at least 6 months of conservative treatment may be considered as surgical candidates. Great efforts should be made to define the pain source as accurately as possible. Surgery in the form of spinal arthrodesis for spondylolysis and spondylolisthesis has good support in the literature. However, the results of fusion for discogenic low back pain are less favourable.

Total disc replacement was introduced to remove the discogenic pain source and restore the kinematic and load-sharing properties of the motion segment. It was anticipated that this treatment may protect the adjacent segment from undergoing degenerative change. This has yet to be proven. Patients must undergo careful selection for disc replacement as there are many more contraindications to disc replacement than there are for spinal fusion.

Three randomized clinical trials comparing lumbar disc replacement to spinal arthrodesis have demonstrated at least equivalent clinical outcome, and in some cases superior outcomes following disc replacement when compared to spinal fusion (Zigler et al, 2007; Sasso et al, 2008; Guyer et al, 2009). Emergence of the next generation of compliant artificial disc replacements offers theoretical advantages in that they should more closely replicate normal motion segment kinematics, and thereby reduce further the load on the adjacent segment. Close observation will be required to ascertain whether these perceived advantages translate into superior clinical outcomes that patients can appreciate. Similarly long-term follow up to ensure biocompatibility and implant survival will be extremely important for this device group.

The shift from arthrodesis to arthroplasty in the spine has not nearly been as smooth as the transition that Charnley brought about in 1962 when the low friction arthroplasty was introduced for painful arthritis of the hip. It is still regarded by many as the gold standard primary hip replacement well over 40 years later. It is clear that evolution of lumbar disc replacement has some way to go to reach this gold standard. **BJHM**

Figures 2, 3 *and* 4 *are reproduced by kind permission of Springer from Freeman and Davenport (2006).*

Conflict of interest: Professor BJC Freeman has a consultancy agreement with Ranier Technology Ltd, Cambridge, UK. In this capacity, he serves as an advisor and member of its scientific advisory board. He has an option agreement with the right to purchase shares in the event of a listing.

Adams MA, Roughley PJ (2006) What is intervertebral disc degeneration, and what causes it? *Spine* **31**(18): 2151–61
Allen MJ, Schoonmaker JE, Bauer TW, Williams PF, Higham PA, Yuan HA (2004) Preclinical evaluation of a poly (vinyl alcohol) hydrogel implant as a replacement for the nucleus pulposus. *Spine* **29**(5): 515–23
Battie MC, Videman T, Parent E (2004) Lumbar disc degeneration: epidemiology and genetic influences. *Spine* **29**(23): 2679–90
Blumenthal S, McAfee PC, Guyer RD et al (2005) 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* **30**(14): 1565–75; discussion E1387-1591
Boden SD, Davis DO, Dina TS, Patronas NJ, Wiesel SW (1990) Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. *J Bone Joint Surg Am* **72**(3): 403–8
Brox JI, Sorensen R, Friis A et al (2003) Randomised clinical trial of lumbar instrumented fusion and cognitive intervention and exercises in patients with chronic low back pain and disc degeneration. *Spine* **28**(17): 1913–21
Carragee EJ (2000) Is lumbar discography a determinate of discogenic low back pain; provocative discography reconsidered. *Curr Rev Pain* **4**(4): 301–8
Carragee EJ, Hannibal M (2004) Diagnostic evaluation of low back pain. *Orthop Clin North Am* **35**(1): 7–16
Choler U, Larsson R, Nachemson A, Peterson LE (1985) Back Pain [in Swedish]. SPRI Report No. 188, Stockholm
Clinical Standards Advisory Group (1994) *Epidemiology review. The epidemiology and cost of back pain.* HMSO, London
Costa L da C, Maher CG, McAuley JH et al (2009) Prognosis for patients with chronic low back pain: inception cohort study. *BMJ* **339:** b3829
Fairbank J, Frost, Wilson-MacDonald J et al (2005) Randomised controlled trial to compare surgical stabilization of the lumbar spine with an intensive rehabilitation programme for patients with chronic low back pain: The MRC spine stabilisation trial. *BMJ* **330:** 1233–8
Fernström U (1966) Arthroplasty with intercorporal endoprothesis in herniated disc and in painful disc. *Acta Chir Scand* **357**(Suppl) 154–9
Fraser RD, Ross ER, Lowery GL, Freeman BJ, Dolan M (2004) AcroFlex design and results. *Spine J* **4**(6 Suppl): 245S–51S
Fraser RD, Freeman BJC, Meir AR, Fowler S (2011) Prospective 10 year follow up of the AcroFlex lumbar disc replacement. Podium presentation at Spine Society of Australia, Melbourne, Australia, 15–17 April
Freeman BJC, Davenport J (2006) Total disc replacement in the lumbar spine: a systematic review of the literature. *Eur Spine J* **15**(Suppl 3): S439–447
Freeman BJC, Quirk I, Bertagnoli R et al (2011) Early clinical performance of the CAdisc-L total disc replacement. A Prospective non-randomised multicentre clinical trial. Podium presentation at Spine Society of Australia, Melbourne, Australia, April 2011
Fritzell P, Hagg O, Wessberg P, Nordwall A (2001) 2001 Volvo Award Winner in Clinical Studies: Lumbar fusion versus non-surgical treatment for chronic low back pain: a multicenter randomized controlled trial from the Swedish Lumbar Spine Study Group. *Spine* **26**(23): 2521–32; discussion 2532–4
Gillet P (2003) The fate of the adjacent motion segments after lumbar fusion. *J Spinal Disord Tech* **16**(4): 338–45
Guyer RD, McAfee PC, Banco RJ et al (2009) Prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: five-year follow-up. *Spine J* **9**(5): 374–86
Gwynne JH, Cameron RE (2010) Using small angle X-ray scattering to investigate the variation in composition across a graduated region within an intervertebral disc prosthesis. *J Mater Sci Mater Med* **21**(2): 787–95
Hart RA (2006) Failed spine surgery syndrome in the life and career of John Fitzgerald Kennedy. *J Bone J Surg (Am)* **88**(5): 1141–8
Huang R, Lim MR, Gerardi FP, Cammisa FP (2004) The prevalence of contraindications to total disc replacement in a cohort of lumbar surgical patients. *Spine* **29**(22): 2538–41
Klara PM, Ray CD (2002) Artificial nucleus replacement: clinical experience. *Spine* **27**(12): 1374–7
Link HD (2002) History, design and biomechanics of the LINK SB Charite artificial disc. *Eur Spine J* **11**(Suppl 2): S98–S105
Manchikanti L, Glaser SE, Wolfer L, Derby R, Cohen SP (2009) Systematic review of lumbar discography as a diagnostic test for chronic low back pain. *Pain Physician* **12**(3): 541–59
Möller H, Hedlund R (2000) Surgery versus conservative management in adult isthmic spondylolisthesis: A prospective randomized study: Part 1. *Spine* **25**(13): 1711–15
Sasso RC, Foulk DM, Hahn M (2008) Prospective, randomized trial of metal-on-metal artificial lumbar disc replacement: initial results for treatment of discogenic pain. *Spine* **33**(2): 123–31
Steffen T, Freeman BJC, Aebi M (2011) Compliant artificial disc replacement: in vivo implant stability and osseointegration in an animal model. *Eur Spine J* **20**(Suppl 4): S439
Thomsen K, Christensen FB, Eiskjaer SP, Hansen ES, Fruensgaard S, Bunger CE (1997) 1997 Volvo Award winner in clinical studies. The effect of pedicle screw instrumentation on functional outcome and fusion rates in posterolateral lumbar spinal fusion: a prospective, randomized clinical study. *Spine* **22**(24): 2813–22
van Kleef M, Barendse GA, Kessels A, Voets HM, Weber WE, de Lange S (1999) Randomized trial of radiofrequency lumbar facet denervation for chronic low back pain. *Spine* **24**(18): 1937–42
van den Eerenbeemt KD, Ostelo RW, van Royen BJ, Peul WC, van Tulder MW (2010) Total disc replacement surgery for symptomatic degenerative lumbar disc disease: a systematic review of the literature. *Eur Spine J* **19**(8): 1262–80
van Tulder MW, Koes BW, Bouter LM (1997) Conservative treatment of acute and chronic non-specific low back pain. A systematic review of randomized controlled trials of the most common interventions. *Spine* **22**(18): 2128–56
Walker BF (2000) The prevalence of low back pain: a systematic review of the literature from 1966 to 1998. *J Spinal Disord* **13**(3): 205–17
Wetzel FT, LaRocca SH, Lowery GL, Aprill CN (1994) The treatment of lumbar spinal pain syndromes diagnosed by discography. Lumbar arthrodesis. *Spine* **19**(7): 792–800
Zigler J, Delamarter R, Spivak JM et al (2007) 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* **32**(11): 1155–62; discussion 1163

KEY POINTS

- Spinal fusion has to date been considered the gold standard for the surgical treatment of chronic low back pain.
- Results following spinal fusion are not universally successful, prompting the innovation of lumbar disc replacement.
- Lumbar disc replacement allows removal of the discogenic pain source and restoration of the kinematic and load sharing properties of the motion segment.
- Three published prospective randomized clinical trials of current total disc replacements have demonstrated moderate success after 2–5-year follow up when compared to spinal fusion.
- Not all candidates for spinal fusion are candidates for disc replacement. Contraindications include conditions that may compromise the long-term stability of the disc replacement (such as spondylolysis, spondylolisthesis and osteoporosis) and painful conditions (such as facet joint arthropathy, spinal stenosis and radiculopathy) that will not be corrected by disc replacement.
- The next generation of compliant artificial disc replacements offer exciting possibilities, but will demand close scrutiny both in terms of osseointegration and biodevice longevity.