Imaging of intervertebral disc prostheses


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Abstract Disc arthroplasty is the replacement of a painful pathological intervertebral disc by a prosthesis, which, unlike spinal fixation, has the advantage of retaining vertebral mobility in the segment concerned. The success of the procedure is dictated by the indication. The radiologist must look for radiographic arguments indicating or contraindicating fitting an implant, and particularly for the presence of facet arthritis which will prompt the surgeon to choose an arthrodesis. Moreover, radiological information plays a major part in preparing for a surgical procedure, as far as access to the disc via the anterior approach is concerned and assessment by CT angiography of the risk of vascular complications. After insertion, radiological monitoring using dynamic X-ray images checks that the implant is correctly positioned and that mobility is restored. In the long term, it can detect complications related to the prosthesis and premature wear to other points of support such as adjacent discs and the facet joints.

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Arthroplasty consists of replacing the pathological disc responsible for the patient’s symptoms by a disc prosthesis inserted as an alternative to a more radical arthrodesis, which would completely neutralize the vertebral segment concerned, with loss of its mobility. This procedure has been in use since 1970.

Indications and contraindications for inserting a disc prosthesis

After eliminating the contraindications to arthroplasty, it is essential to confirm that the pain originates from the disc before finally deciding on this indication.
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Indications

Generally speaking, the best indication is considered to be a patient with a single Pfirrmann stage IV or V degenerative disc, with a Modic 1 inflammatory MRI signal and positive discography [1,2]. In these patients, the results are still better if the disc degeneration is primary, i.e. with no history of disc surgery exposing the patient to a risk of radiculopathy by postoperative stretching. This occurs in approximately 20 to 30% of cases but, more often than not, is reversible [3].

In April 2007, lumbar arthroplasty was evaluated by the French Haute Autorité de santé which considered the right indication to be disabling, chronic discogenic low back pain, refractory to medical treatment properly conducted for at least 6 months, in an adult subject less than 60 years old with symptomatic lumbar or lumbosacral disc degeneration. Only one pathological disc has to be replaced [4]. It may be a matter of alleviating a degenerated disc over-solicited because of a lumbosacral joint abnormality or of solving a compression problem due to hernia (a recurring root conflict or medial canal stenosis). The technique will be more readily favoured in a young patient for whom an arthrodesis is being considered.

Contraindications

Contraindications are as follows:

- fragile vertebral body: osteoporosis, osteogenesis, bone tumour;
- involvment of the posterior arch: developed arthritis of the zygapophyseal articlar facets of the level to be operated, marked asymmetry of the articular facets, a history of laminarhrectomy;
- difficulties concerning the approach: vascular disease (atheromatous plaque or malformation) making the approach to the disc dangerous, severe (BMI between 35 and 40) or morbid (BMI higher than 40) obesity;
- spinal deformation in the frontal plane (scoliosis responsible for inclination of the diseased disc) or the sagittal plane (spondylolisthesis > grade 1 or retrolisthesis which does not decrease in dynamic X-ray images);
- bony lumbar canal stenosis;
- a history of recent root deficit or excluded hernia, disc infection at the level concerned, recent vertebral trauma.

Pretherapeutic radiological investigations

Establishing the indication for arthroplasty and eliminating contraindications

As is the practice within our establishment, most centres performing this type of procedure require complete, precise radiological investigations to establish the indication for a disc prosthesis and eliminate contraindications. As the idea of instability is complex, a multimodal exhaustive investigation is required to provide the functional (via dynamic X-ray images) and anatomical (looking for contraindications) information.

Static X-rays

We take posterior-anterior and lateral images of the whole of the spine and pelvis under load. When doing this, the patient’s arms should not be held out in front nor the hands placed behind the head (when there is no corset).

The aim is to eliminate a non-discogenic aetiology wholly or partly responsible for the patient’s symptoms (non-degenerative lumbar causes: fractures, infection, neoplasm or extra-sinal causes) and to investigate the level concerned (disc degeneration, spondylolisthesis, joint abnormality, etc.).

These X-rays also provide useful information for preparing the surgical procedure:

- on the quality of the bone, the shape of the vertebral endplates, the orientation of the intervertebral spaces relative to the pubis, in order to anticipate approach difficulties;
- on disc collapse, bony foraminal stenosis (which cannot be treated via the anterior route in isolation);
- on the state of adjacent discs and the lumbopelvic-femoral complex.

Full spine

We take full spine PA and lateral static X-ray images on a large cassette, standing in the usual position with the arms crossed on an abdominal cushion.

Sagittal balance can thus be assessed and the absence of scoliosis of more than 20° confirmed. These images are always necessary for preoperative assessment because a candidate for a disc prosthesis is also a potential candidate for intervertebral arthrodesis, and this decision is sometimes taken peroperatively. If arthrodesis is required, this image is essential to the surgeon for planning the procedure.

Dynamic X-rays

We take dynamic X-rays of the lumbosacral spine, as follows (Fig. 1):

- lateral, in flexion then in extension, standing, then sitting on a chair completely relaxed;
- PA, in lateral flexion, standing.

They are always necessary except when particularly painful for the patient in order to assess the mobility of the healthy discs and the presumed pathological disc (as decreased, normal or exaggerated mobility suggests intervertebral mechanical instability).

The aim of dynamic images is to pick out abnormal movement between two vertebrae. The presence of abnormal movement combined with clinical symptoms could indicate intervertebral instability which should be fixed by an arthrodesis and not by arthroplasty. However, in the literature there is no consensus on the definition of abnormal movement.

CT scan

A CT scan clearly shows the damaged disc or discs as well as other possible sources of the pain and in particular assists in eliminating developed facet arthritis which would contraindicate the technique. It also shows canal or foraminal stenosis and ligament hypertrophy.
MRI
This is the standard examination, essential for assessing chronic low back pain by showing up the disc and/or abnormal vertebral endplates providing evidence for the pain being discogenic. It also provides information on the dimensions of the spinal canal and the appearance of the articular facets (although a CT scan is still better for the latter).

Modifications of the intervertebral disc
We use Pfirrmann’s criteria on the MRI T2 sequences to classify each disc in relation to its hydration and height [2] (Fig. 2). Pathological discs are usually dehydrated and more or less collapsed in stages III, IV and V.

A high intensity zone (HIZ) is sometimes visible behind the disc where tearing of the posterior fibrous ring may have occurred, but this is not a very reliable indicator, having relatively poor sensitivity [5].

Modification of the vertebral endplates
The classification described by Modic provides information on signal modifications on either side of the intervertebral disc [2] (Table 1).

A recent review of the literature showed a higher prevalence (6 to 43%) of these abnormalities in patients with lumbar or sciatic pain compared with patients without back symptoms. Some studies even observed a significant positive association between the pain and the modification of the vertebral endplates allowing an Odds ratio to be calculated [6].

A Modic I signal (a liquid signal considered to be inflammatory) is an excellent selection criterion for patients with low back pain of discogenic origin while a Modic II (fatty signal) is less sensitive (Fig. 3).

Work by Vital and Esposito has shown the efficacy of fusion in low back pain patients with a Modic I signal and even the possibility of progressing from Modic I to Modic II, indicating that the inflammatory signal has been quelled with progression towards a scar tissue stage [7,8]. For Esposito, Modic II is actually a contraindication to fusion surgery.

The rarer Modic III stage is a state of sclerosis and thus a sequela which does not require surgery.

Discography
This is only performed when a doubt remains after the MRI, to confirm that the suspected lesion is guilty of the pain by reproducing it identically on intradiscal injection.

Preoperative planning
The preoperative radiological examination is also essential for planning the procedure.

The sacral slope can be calculated from the lateral X-ray images of the lumbosacral spine, or at least its orientation relative to the pubis which may limit access to the disc, particularly if there is a lumbosacral joint abnormality. A sacral slope greater than 70° could well expel the polyethylene core when it is free, or reduce bone fixation (Fig. 4).

The operation can also be planned from the CT scan by using prosthesis template overlays to facilitate the choice of prostheses and by exploring the vascular relations of the retroperitoneum. CT angiography is systematically performed for planning the retroperitoneal approach since it is the most reproducible and reliable examination for careful analysis of the aorto-caval vascular relationships of the disc to be reached [9]. It is important to note the presence of aortic calcifications because they may contraindicate surgery via an anterior approach or at least necessitate considerable caution when retracting the aorta to avoid accidental embolisation. Young subjects often have thinner, supple and more mobile vessels while atheromatous subjects have rigid, voluminous, calcified vessels which are difficult to mobilise and sometimes to repair, not to mention the precariousness of the vascular bed.

The location of the bifurcation is only of relative interest anatomically since, except in a few rare cases of venous malformation, it gives no information on the possibility of
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Table 1  
Endplate modification according to Modic.

<table>
<thead>
<tr>
<th>Vertebral endplate signal modification</th>
<th>Signal in T1</th>
<th>Signal in T2</th>
<th>Histological appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 Oedema</td>
<td>Hyposignal</td>
<td>Hypersignal</td>
<td>Fibrovascular tissue and oedema</td>
</tr>
<tr>
<td>Type 2 Fat</td>
<td>Hypersignal</td>
<td>Hypersignal or intermediate</td>
<td>Adipose tissue</td>
</tr>
<tr>
<td>Type 3 Sclerosis</td>
<td>Hyposignal</td>
<td>Hyposignal</td>
<td>Dense fibrosis</td>
</tr>
</tbody>
</table>

A type I signal (oedematous signal considered to be inflammatory) is an excellent criterion for selecting patients with low back pain of discogenic origin, whereas a type II signal (fat) is less sensitive even if it seems to correlate with a set of symptoms. Type III (sclerotic signal) is a painless scar tissue state.
mobilising the large vessels peroperatively. Nevertheless, CT angiography can show anatomical variations and thus help avoid unpleasant surprises for the surgeon. Indeed, if the bifurcation of the vena cava is low, there is a danger for the L5-S1 approach because the medialised left common iliac vein reduces the operating window for access to the disc. Cappelades’ classification is used to estimate the operative risk for reaching the L5-S1 disc (Fig. 5) [9].

MR-angiography may also be used for vascular exploration.

**Types of disc prosthesis**

They generally consist of two metal vertebral endplates, fixed to the subjacent and superjacent vertebrae, and an insert between these two plates permitting mobility in several planes. The different implants can be classified according to several parameters.

![Figure 5. Illustration of the classification proposed by Cappelades concerning iliocaval relationships during L5-S1 disc surgery via the anterior approach: a: axial view centred on the L5-S1 disc. Anatomical variations in the position of the left common iliac vein on which the operating window for access to the L5-S1 disc depends; b: anatomical variations in the height of the iliocalval junction. The higher the iliocaval junction the more the left common iliac vein is lateralised and the wider the disc-operating window. On the other hand, patients with a low junction have a risk of vascular complications.](image)
The means of fixation

There are two groups of prostheses (Fig. 6):
- with keel: the keel must be placed in the middle of the superior and inferior vertebrae. It is a means of anchorage giving good primary stability;
- without keel: the other means of fixation are represented by small metal teeth or more anatomical prosthetic endplates i.e. convex to marry the shape of the vertebral endplates. Secondary fixation is obtained by treating the surface of the endplates to encourage regrowth of bone at the bone-implant interface [10].

Biomechanics

A normal disc has six degrees of freedom: three translational and three rotational degrees of freedom.

Prostheses are separated by convention into two groups depending on the number of degrees of freedom they allow:
- unconstrained prostheses or those with very few constraints that offer five to six degrees of freedom (Mobidisc and SB Charité). They have a flexible interface between the two prosthetic endplates which allows movement in compression. It is a polyethylene core that sometimes has radiopaque markers;
- semi-constrained prostheses providing three degrees of freedom (Prodisc® and Maverick®). They have a fixed spherical nucleus.

No definitive conclusion concerning the superiority of one or other of these prosthetic designs can be drawn from the current data. In terms of biomechanical and kinematic restoration, both types should allow near normal mobility.

Whatever the type of prosthesis, centring is the most important point for ensuring the functional biomechanics [11]. Implants positioned too far forward lose mobility in flexion and extension and have poor dynamics in lateral bending and rotation. Positioning errors can explain poor clinical results.

There has not yet been any formal evaluation in implanted prostheses of the clinical implications of the lack or excess of prosthetic mobility that can sometimes be observed [12].

Fitting disc prostheses requires good preoperative analysis of the images obtained and a precise placement technique that complies with the biomechanics of the implant used, to ensure a good clinical outcome.

Operating technique

The surgical approach

The approach is anterior and retroperitoneal (Fig. 7). The surgeon can pass to the right or the left for L5-S1, but will prefer to pass to the left for superjacent levels because of the fragility of the lateral side of the vena cava.

The transperitoneal approach is less and less used since Sasso’s work which showed a high incidence of retrograde ejaculation with it compared with a retroperitoneal approach (10% against 0.8%) [13]. Nevertheless, it is a feasible surgical approach in cases of revision surgery or if the retroperitoneal approach is not possible.

Preparation of the disc space

Once the disc is exposed an H-shaped incision is made with two lateral flaps. Discectomy should be complete, removing the entire nucleus and the annulus fibrosis using a curette. It is preferable to retain the posterior longitudinal ligament to avoid injuring the epidural veins.

The subchondral bone of the vertebral endplates is retained in order to avoid subsidence of implants into the vertebral endplates.

Selecting and fitting the implant

Once discectomy has been completed, the desired height and anteroposterior and mediolateral dimensions of the prosthesis are chosen using prosthetic templates.
Figure 7. The various operative stages during L5-S1 disc arthroplasty: a: retroperitoneal approach with vascular structures retracted; b: exposure then an H-shaped incision in the disc; c: total discectomy and choice of the prosthesis using a template; d: centring the prosthesis.

The implants should not be too high but they must fill the disc space to rest on the cortical periphery of the vertebra. The volume of the interbody implant determines the possible dynamics of the facet joints.

The most suitable prosthesis is then inserted using the instrumentation provided for this purpose.

**Postoperative radiological assessment**

To understand this assessment, one must keep in mind what is expected of the disc prosthesis (Table 2):
- it must replace the painful intervertebral disc, restore its height and preserve physiological movement while maintaining correct alignment of the vertebral column in both planes;
- it must protect the column of facet joints and the adjacent discs from premature wear and must not undergo secondary displacement or wear before time.

Monitoring is via standard X-ray PA and lateral images and dynamic images, from which the following is assessed:
- the quality of the disc reconstruction compared with the superjacent disc;
- this consists of measuring the intervertebral height of the prosthetic level at three points on the lateral X-ray: posteriorly, corresponding to the posterior wall, in the middle of the superior vertebral endplate and as anteriorly as possible. These measurements are compared with those of a non-pathological level to compare the quality of the recovery of disc height (Fig. 8);
- the position and size of the implant in the intervertebral space: anterior-posterior positioning is assessed by measuring the position of each prosthetic endplate (inferior and superior) on the lateral X-ray image, relative to the posterior vertebral wall. Its symmetry or asymmetry relative to the midline is assessed on the PA image (Fig. 9). Coverage of the implant relative to the anteroposterior and mediolateral dimensions of the vertebral endplates should also be measured on the PA and lateral images, to
Table 2  Short-term and long-term objectives of disc arthroplasty.

<table>
<thead>
<tr>
<th>Short-term objectives</th>
<th>Long-term objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement of the disc responsible for the pain</td>
<td>Protection of adjacent physiological structures from excess load which could result in</td>
</tr>
<tr>
<td></td>
<td>accelerated degeneration: adjacent intervertebral discs, posterior articular column,</td>
</tr>
<tr>
<td></td>
<td>ligaments</td>
</tr>
<tr>
<td>Restoration of disc height</td>
<td>Preserving good spinal alignment</td>
</tr>
<tr>
<td>Decompression of the root and articular facets</td>
<td>Stable lasting implant</td>
</tr>
<tr>
<td>Restoration of the biomechanics and the normal kinematics of the spine</td>
<td></td>
</tr>
<tr>
<td>Stabilisation of the intervertebral segment</td>
<td></td>
</tr>
</tbody>
</table>

ascertain the suitability of the size of the implant selected by the surgeon for the size of the vertebrae;
• the mobility of the implant and the lordosis angle in the neutral position: the range of movement between flexion and extension is measured on the lateral images. It is measured in right and left lateral bending on the PA image and is assessed to be greater or less than 5° (Fig. 10). The lordosis angle of the prosthesis, standing, under load, and impaction of the superior prosthetic endplate into the superjacent vertebra can also be assessed.

Complications

There are three types (Table 3):
• osseous:
  ○ fractures: of the vertebral body, the pedicles (Fig. 11),
  ○ adjacent disc disease,
  ○ facet arthritis;
• prosthetic (Figs. 12–14):
  ○ migration of the prosthesis or impaction into the vertebra,
  ○ luxation of the prosthesis,
  ○ dislocation of the prosthesis (extrusion of the polyethylene nucleus),
  ○ oxidation and wear of the material with loss of range of movement;
• vascular:
  ○ vascular lesion,
  ○ postoperative thrombosis.

Figure 8. Lateral X-ray centred on the L5-S1 prosthetic disc. The height of the disc has been restored. Comparison made at three points with the superjacent disc.

Figure 9. Lateral and PA X-ray centred on the L5-S1 prosthetic disc. The centring of the prosthesis is assessed relative to the posterior vertebral wall on the lateral X-ray (C = D) and relative to the midline axis on the PA image (C = D). The size of implant selected (B must be suitable for the size of the vertebral endplate A).
Figure 10. Postoperative lateral (a) and PA (b) dynamic X-ray images. The prosthetic intervertebral angle is determined in flexion then extension and in right and left lateral bending. The delta calculated gives the amplitude of the prosthesis.

Table 3 Complications of lumbar arthroplasty described in the literature.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Patient</th>
<th>Postoperative time</th>
<th>Clinical symptoms</th>
<th>Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stieber 2006</td>
<td>1 M 45 years</td>
<td>J21</td>
<td>Lumbar and root pain</td>
<td>Migration of the implant and L iliac vein occlusion</td>
</tr>
<tr>
<td>Shim 2005</td>
<td>2 M 40 years</td>
<td>J1</td>
<td>Lumbar pain</td>
<td>Fracture of L4 and L5 vertebral bodies</td>
</tr>
<tr>
<td>Mathew 2005</td>
<td>1 M 30 years</td>
<td>5 months</td>
<td>Lumbar pain</td>
<td>Fracture of L5 pedicles</td>
</tr>
<tr>
<td>Bertagnoli 2005</td>
<td>1 F 53 years</td>
<td>6 days</td>
<td>Lumbar pain</td>
<td>Fracture of L5 vertebral body</td>
</tr>
<tr>
<td>Kurtz 2005</td>
<td>1 F 49 years</td>
<td>1.6 years</td>
<td>Lumbar and root pain</td>
<td>Posterior facet arthritis and migration of the implant = fusion</td>
</tr>
<tr>
<td>David 2005</td>
<td>1 F 42 years</td>
<td>9.5 years</td>
<td>Dorsal and root pain</td>
<td>Oxidation of the material</td>
</tr>
<tr>
<td>Van Ooij 2003</td>
<td>12 M 15 F 30–67 years</td>
<td>Between 1 year and 10 years</td>
<td>Lumbar and root pain 4 abdominal haematomas 1 erection problem 1 retrograde ejaculation 1 leg ischaemia</td>
<td>27 with postoperative facet arthritis 1 dislocation of prosthesis 14 adjacent degenerations 2 anterior luxations of the prosthesis (iliac compression) 1 polyethylene wear</td>
</tr>
</tbody>
</table>
Figure 11. Axial section CT scan in ventral decubitus passing through the L5 pedicle in a patient with an L5-S1 disc implant and recurrent pain. A fracture can be seen in the right pedicle (arrow).

Figure 12. Standard lateral X-ray centred on the disc prosthesis: a: luxation of the prosthesis combined with anterior migration of the inferior endplate of the implant. Note the X-ray marker corresponding to the polyethylene core still within the prosthesis; b: implant luxation.
Figure 13. Sagittal X-ray of the cervical spine in a 50-year-old woman: a, b: postoperative dynamic images exploring the amplitude of the C5-C6 and C6-C7 arthroplasties; c: static image at 21 months showing subsidence into the inferior endplate of C5.

Figure 14. Sagittal X-ray of the lumbosacral spine in a 57-year-old man with an L5-S1 arthroplasty. Posterior-superior intravertebral subsidence of the implant can be seen.

There are very few long-term studies on the fate of the prosthesis after 10 years. Preliminary data on the effectiveness of the prosthesis (the maintenance of function at the operated level, the absence of physiological degeneration in adjacent structures) and complications related to it are positive. The surgical revision rate is low compared with data known for arthrodesis [14,15].

Conclusion

Arthroplasty is an alternative to arthrodesis in the treatment of disc degeneration refractory to medical treatment. Preliminary results of short-term evaluation are satisfactory for cases where the indication for surgery was correctly determined, strictly observing the contraindications. The radiologist plays a fundamental role in this preoperative assessment by demonstrating single segment damage and the absence of developed facet arthritis.

In addition, he or she contributes to planning the surgery by identifying potential technical difficulties related to the patient’s morphology.

Postoperatively, radiological monitoring checks the position of the prosthesis and detects any complications. It is especially useful in cases of pain recurring for incriminating the prosthesis in the cause of the symptoms, or otherwise.
Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


