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# Treatment of infections of the lumbar spine with single-staged posterior instrumentation, disc debridement and interbody fusion with titanium cages

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## SUMMARY

**Background.** The goal of this study is to compare the clinical and radiological results of a single-staged posterior instrumentation, disc debridement and interbody fusion with titanium cages for patients with pyogenic infections of the lumbar spine and patients with degenerative disc disease.

**Methods.** Posterior instrumentation, disc debridement and interbody fusion with titanium cages was performed on 35 patients affected by infections of the lumbar spine with compression of neural elements, neurological deficits or abscesses. At a minimum follow-up of one year, a functional and radiological evaluation was conducted, including a CT-scan of the operated segments to assess bony interbody fusion. A matched series of patients who underwent 360°-fusion with titanium interbody cages for the treatment of single-level degenerative disc disease was used as control group.

**Results.** Twenty-eight patients were available for evaluation. The median VAS improved notably after intervention, as did the questionnaires investigating function, activities of daily living and quality of life. These changes were comparable to those observed in the control group. A similar proportion of patients rated the results of surgical intervention as good or excellent in both groups. Bony interbody fusion was observed in 87.5% of the patients.

**Conclusion.** Posterior instrumentation, disc debridement and interbody fusion with titanium cages can effectively reduce pain and leads to an acceptable fusion rate. A substantial equivalence in terms of clinical results and subjective satisfaction is obtained in patients receiving this surgery for pyogenic infections with minimal anterior column disruption and for the treatment of degenerative disc disease.

## KEY WORDS

*spinal fusion; posterior instrumentation; single-stage; spinal infection; spondylodiscitis; titanium cage*

## INTRODUCTION

The term spondylodiscitis refers to an extradural spinal infection involving the intervertebral discs, the adjacent vertebral bodies and occasionally also the posterior elements of the spine (1). Infections of the spine can potentially be life-threatening conditions with possible dramatic sequelae, including deformity, neurological deficits and septic shock. Early recognition and appropriate treatment are therefore important to ensure a favourable outcome. The goals of treatment include infection eradication, pain reduction and preservation of the structure and function of the spine. For patients without spinal instability and neurological deficits, conservative treatment with antimicrobial drugs and immo-

bilization are considered an acceptable approach (2). Surgical treatment is indicated in the presence of spinal cord or nerve root compression, severe or progressive neurological deficits and epidural or paravertebral abscesses. In case of progression to a systemic disease with persistent positive blood cultures or with increasing pain despite targeted antibiotic therapy, surgical treatment is also indicated (3).
Older surgical techniques most commonly involved a single-staged anterior approach (4–6). Later on, reports documenting complications and late failures with this approach paved the way to the addition of a rigid internal fixation using posterior transpedicular screws (7–11). More recently, the experience acquired from treating degenerative disc disease lead to developing surgical techniques for the treatment of infective conditions by performing anterior debridement and interbody fusion using a single-staged posterior approach, mostly with interbody fusion with bone grafts (9,12–15). Since bone harvesting may lead to additional morbidity and during the graft resorption phase a loss of the sagittal profile is possible, some authors proposed the use of titanium cages during surgical treatment of spinal infections (16–18). Placing hardware in an infectious setting is a matter of discussion, since this may lead to biofilm formation and perpetuation of the infectious process (19,20). However, titanium implants did not appear to increase the risk of infection or relapse when used in anterior approaches (1,16,17,21–24). Titanium lacks porosity to this potentially offers an advantage over bone grafts, which may harbour bacteria. Moreover, animal studies reported, reported less biofilm formation on titanium rather than stainless steel or PMMA surfaces, which may lead to reduced infection rates when using this material (25,26).
For these reasons, the combination of the advantages of a single-staged procedure and a metallic interbody cage, already verified in the treatment of degenerative disc disease, appeared advantageous in treating patients affected by spinal infections with minimal anterior column disruption (27).
The goal of this study is to compare the clinical and radiological results of a single-staged Posterior Instrumentation, Disc Debridement and Interbody Fusion (PIDDIF) with titanium cages for patients with pyogenic infections of the lumbar spine and patients with degenerative disc disease.

## MATERIALS AND METHODS

This study was designed as a non-blinded, prospective, observational clinical trial with an historical cohort control group; the study protocol was approved by the Local Ethical Committee (Rheinische Friedrich-Wilhelms-Universität, Medizinische Fakultät, Ethik-Kommission, Lfd. Nr. 065/17-02/03). The primary goal of this trial was to evaluate the decrease in pain at mid-term follow-up single-staged PIDDIF with titanium cages for the treatment of pyogenic infections of the lumbar spine. Secondary goals were to evaluate bony interbody fusion at least one year after intervention and to compare the clinical and functional results with a cohort of patients who underwent single-staged PIDDIF with titanium cages for degenerative disc disease.

### Patient selection and preoperative evaluation

A total of 43 patients were assessed for eligibility and 35 of them were enrolled by two investigators (D.C., L.D). Patients with extended anterior bony defects not amenable for posterior interbody fusion were excluded. All patients underwent clinical examination prior to surgery. Blood samples and clinical scores were collected. The diagnosis of spinal infection was confirmed by magnetic resonance imaging (MRI) and computed tomography (CT) studies. Indication for surgical intervention was given in cases of imaging-confirmed spinal infection associated with progressive neurologic deficits, progressive deformity, spinal instability or bloodstream infection with impending septic shock (3).

### Surgical technique

Surgery was performed under general anaesthesia, with the patient in a prone position on a Jackson-type frame, with the upper limbs kept at about 90° of abduction and 80° of flexion and the elbows at 90° flexion to prevent brachial plexus injuries.
A midline skin incision was performed over the spinous processes of the affected segments. The paravertebral muscles were bluntly detached from the spinous processes and retracted to expose the vertebral arcs. Polyaxial screws were inserted under fluoroscopic control in both pedicles of the vertebral bodies adjacent to the infected disc (WSI MX/PX Titan® Expertise System, Peter Brehm GmbH, Weisendorf, Germany). Subsequently, decompression was performed by laminectomy and partial removal of the facet joints, in order to visualize the nerve roots and the dural sac. If nerve root compression was present at the foraminal level, foraminotomy and nerve root decompression were performed. The intervertebral disc compartment was then opened, samples for microbiological investigation were routinely collected from the intervertebral disc and antibiotic prophylaxis was administrated as a single-shot dose after sample collection. Antibiotic choice was based on preoperative peripheral blood or urine cultures; if no aetiological agent could be identified preoperatively, empiric antibiotics were administrated according to local guidelines.
A debridement of the intervertebral disc space was performed by rinsing it with hydrogen peroxide and Ring-

er's solution. The vertebral baseplates were prepared and interbody fusion was performed with a metallic interbody spacer implant system (IBS-Titan®, Peter Brehm GmbH, Weisendorf, Germany). Additional bone grafting was not used to enhance interbody fusion. A pair of titanium rods was finally tightened to stabilize the fused segments in the proper lordosis. Local administration of antibiotics was not performed. The implant position and coronal and sagittal alignment were controlled by fluoroscopy.
After surgery early mobilization of the upper and lower limbs and full weight-bearing were encouraged; the heavy lifting of loads and carrying over 5 kilograms was discouraged for 6 weeks postoperatively. A staged physiotherapeutic exercise program was started immediately after surgery and continued under ambulatory setting. Postoperative antibiotic therapy was administrated for 6-12 weeks according to the microbiological culture results and local guidelines.

### Post-operative evaluations

Patients who underwent single-staged PIDDIF with titanium cages and had a minimum follow-up of one year were prospectively underwent a functional and radiological evaluation between March 2017 to September 2018. The following questionnaires were used to assess post- to pre-operative differences: the Visual Analogue Scale (VAS), the Oswestry Disability Index (ODI) (28), the Roland Morris Disability Questionnaire (RMDQ) (29), the SF-12 questionnaire (30) and the PainDETECT instrument (31). Each patient underwent also a CT-scan of the operated segments to assess bony interbody fusion using the protocol of Williams et al. (32). The sagittal alignment of the spine obtained immediately after surgery and at final follow-up were compared both for the fused segment, to assess implant loosening and fractures, and for the adjacent upper and lower segments, to quantify the progression of adjacent segment degeneration.

### Control group

As a control group a series of patients matched for smoking habits with the cohort of the current study was extracted from a previously collected database on clinical results of 360°-fusion with titanium interbody cages for the treatment of single-level degenerative disc disease was used (33). Indication for surgery in this group was lumbar degenerative disc disease or spondylolisthesis with corresponding lumbar spinal stenosis causing back- and/or leg-pain or neurological deficit, which did not respond to conservative treatment consistent in oral medical therapy, injection therapy and/or physiotherapy. In the control group with degenerative disc disease the same surgical technique was used, with the only difference that no samples for microbiological analysis were collected and antibiotic prophylaxis was administrated as a single-shot dose 30 minutes prior to skin incision (Cefuroxime 1.5g or Clindamycin 600mg if beta-lactam allergy). No post-operative therapy with antibiotics was given in this group. The peri-operative procedures and the post-operative rehabilitation protocol were the same as for the patients with infectious disease. Follow-up examination also occurred at least one year from surgery.

### Statistical analysis

A post-hoc analysis indicated that minimal sample size of 25 patients was considered sufficient to evaluate a difference in post- to pre-operative VAS greater than 0.5 SD units with a power >80% and significance level set at 5%. Statistical analysis was performed using validated statistic programs (REPORT V6.7 and TESTIMATE V6.5 from IDV data analysis and study planning). The differences between the groups of patients were evaluated with the Wilcoxon-Mann–Whitney-U test (two-sided) and the within group analysis were performed with the Wilcoxon-Pratt-test (two-sided). For all analyses, the significance level was set at p-value lower than 0.05. The results were not corrected due to multiple comparisons, so all results have to be interpreted descriptively.

## RESULTS

43 patients were assessed for eligibility and 35 of them were enrolled. A flow diagram illustrates the grouping and flow of patients in our clinical study (**Figure 1**). Four patients died during the follow-up period for reasons not related to the spinal pathology, whereas three developed cognitive deterioration and could not collaborate to the data collection.
Twenty-eight patients agreed to return to our institution for clinical and radiological evaluation. The median age was 65 [60 - 72.5] years. The male:female ratio was 0.85/0.15, while the smoker:non-smoker ratio was 0.39/0.61. The mean duration of surgery was 198.7 ± 56.5 minutes and the median length of hospital stay was 22.5 days [14 – 32.25]. Microbiological investigation could identify a pathogen in 67.86 % of the patients; Staphylococcus aureus was the most frequently identified pathogen (**Figure 2**).
The functional scores of the clinical assessment are reported in **Table I**. The median VAS improved notably after intervention, with a reduction in the median score by 70 mm. Half of the patients were not taking any painkillers at final follow-up, however only 35% of them declared to be completely pain free. Pain irradiation in the thigh was present in 21 % of the patients and irradiation in the calf or foot in 25%. The

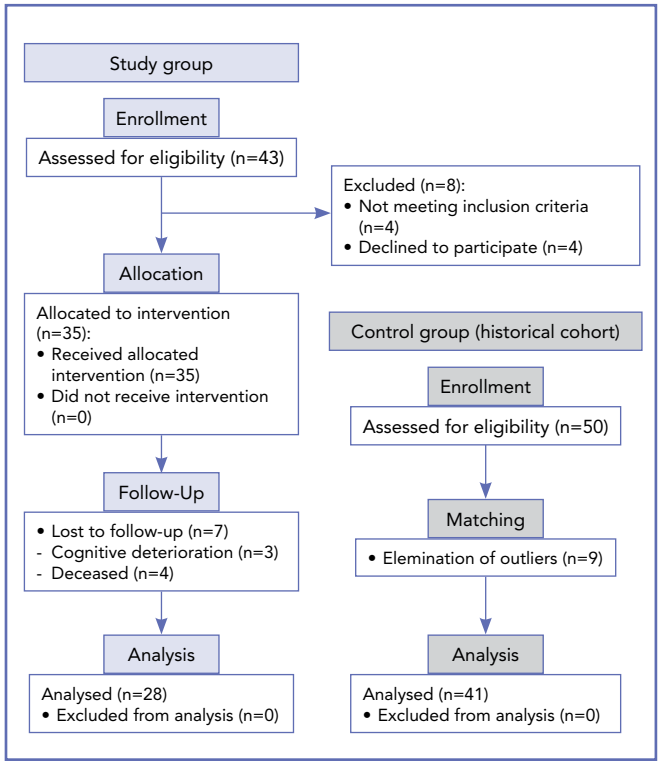


**Figure 1.** CONSORT flow diagram of the study.

scores obtained in the questionnaires investigating function, activities of daily living and quality of life improved notably after intervention. The PainDETECT score indicated a non-neuropathic type of pain in the pre-operative evaluation; pain level evaluated with this score also decreased after surgery, revealing the persistence of a non-neuropathic type of pain. The intensity of pain localized in the lower back also decreased after intervention. Pain irradiation in the lower limbs was reported pre-operatively by few patients only and was negligible after intervention. At final follow-up, all but one patient had normalization of the leukocyte count. The inflammatory marker C-reactive protein remained minimally elevated in five asymptomatic patients, four of which smokers, with no signs of infection and no radiographical signs of implant loosening or disease progression.

One relapse occurred: in this case, back pain persisted and inflammatory markers remained moderately elevated after L5-S1 instrumentation and fusion in an intravenous-drug-addicted, non-compliant patient. The follow-up CT revealed bony destruction of the L5 vertebral body, with mobilisation of screws and cages and progression of segmental kyphosis in the fused segment by 23°. Kyphosis progressed by 27° also in the adjacent L4-L5 segment. Revision surgery with posterior instrumentation from L4 to the Ilium was performed, and, in the same surgery, an

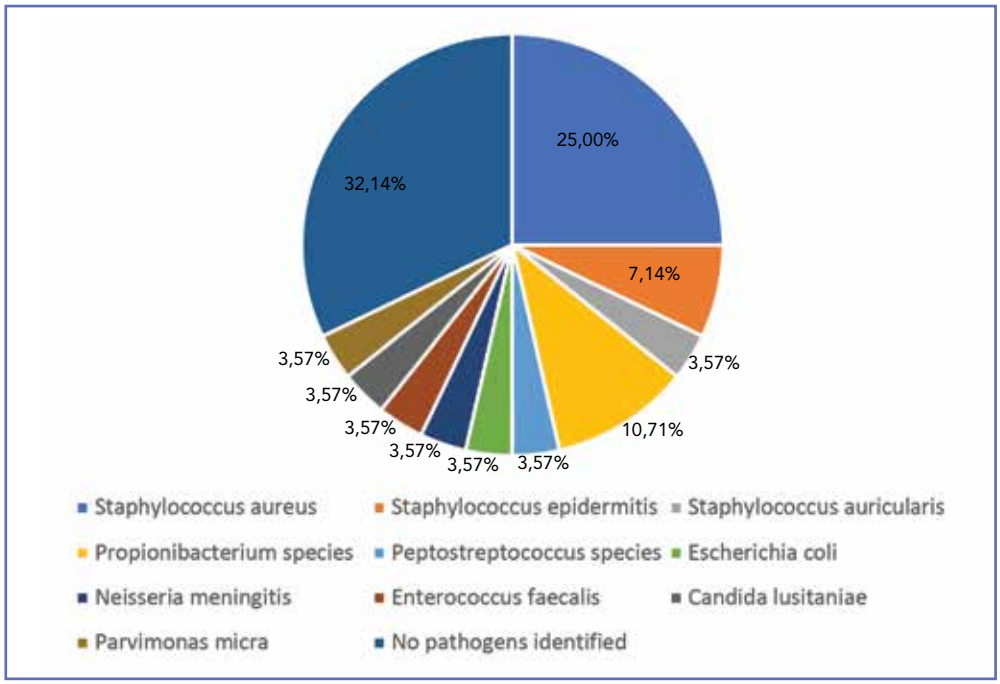


**Figure 2.** Graphic representation of the pathogens identified with microbiological investigation of the tissue sample collected during surgery.

**Table I.** Summary of the main clinical results of the study

| | Preoperative | Postoperative | p-value * |
|---|---|---|---|
| VAS (mm) | 90 [50-100] | 20 [0-40] | <0.0001 |
| ODI (points) | 61 [41.8-77] | 15 [6-32.7] | <0.0001 |
| RMDQ (points) | 15 [8.5 - 17] | 5 [0-9.5] | <0.0001 |
| SF-12 (points) | 34.5 [30.5 - 39.5] | 39 [36 – 44.5] | <0.0001 |
| PainDETECT (points) | 10 [3-15.5] | 4 [1-10.5] | 0.0039 |
| Low back pain (mm) | 90 [55-100] | 22.5 [0-55] | <0.0001 |
| Left thigh pain (mm) | 0 [0-55] | 0 [0-0] | 0.0059 |
| Right thigh pain (mm) | 0 [0-45] | 0 [0-0] | n.s. |
| Left calf pain (mm) | 0 [0-65] | 0 [0-0.5] | 0.0039 |
| Right calf pain (mm) | 0 [0-40] | 0 [0-0.5] | n.s. |

**: post- to pre-operative difference; **: between-group comparison; n.s.: not significant; ODI: Oswestry Disability Index; RMDQ: Roland Morris Disability Questionnaire; VAS: Visual Analogue Scale. Data are expressed as median with first and third quartiles [Q1-Q3].*

expandable titanium cage was implanted from the posterior approach to provide anterior column support. Candida lusitaniae was isolated from the intraoperative samples of the first intervention and Staphylococcus aureus from those of the revision surgery.

Adjacent segment degeneration with a progression of angular deformity in the sagittal plane greater than 3° was observed in further two cases, always in the upper adjacent segment. In the first case, a fracture of the anterior part of the adjacent baseplate was observed in the CT-scan, with an increase in segmental kyphosis by 13°. This patient could not recall any traumatic event and only complained about minor chronic low back pain and was satisfied with the intervention and with his present health state, so that no further therapy was required. In the second case, adjacent segment degeneration with an increase in segmental kyphosis by 8° was symptomatic; after one year of conservative treatment, revision surgery with extension of the instrumentation to the two upper segments was performed.

Four intra-operative complications occurred: in three cases the dural sac was injured during surgery, requiring direct repair, whereas in one case an accidental injury to the presacral venous plexus caused haemodynamically relevant bleeding, requiring massive blood transfusion and urgent vascular surgeon consultation to stop the bleeding. Wound healing problems requiring revision surgery complicated the postoperative course in five patients: in all cases, rinsing of the surgical site with hydrogen peroxide and Ringer's

**Table II.** Comparison of the main clinical results between the study population and a control group.

| Spinal infections | | | | Degenerative disc disease | | | p-value ** |
|---|---|---|---|---|---|---|---|
| | Preoperative | Postoperative | p-value * | Preoperative | Postoperative | p-value * | |
| VAS | 90 [50-100] | 20 [0-40] | <0.0001 | 88 [75-95] | 32 [14-64] | <0.0001 | n.s. |
| ODI | 61 [41.8-77] | 15 [6-32.7] | <0.0001 | 71 [60-80] | 24 [6-50] | <0.0001 | n.s. |
| Low back pain | 90 [55-100] | 22.5 [0-55] | <0.0001 | 88 [75-95] | 32 [14-64] | <0.0001 | n.s. |
| Left thigh pain | 0 [0-55] | 0 [0-0] | 0.0059 | 52 [0-83] | 12 [0-40] | <0.0001 | 0.0267 |
| Right thigh pain | 0 [0-45] | 0 [0-0] | n.s. | 57 [12-81] | 17 [0-48] | <0.0001 | n.s. |
| Left calf pain | 0 [0-65] | 0 [0-0.5] | 0.0039 | 57 [9-82] | 13 [0-39] | <0.0001 | n.s. |
| Right calf pain | 0 [0-40] | 0 [0-0.5] | n.s. | 69 [54-84] | 14 [0-44] | <0.0001 | n.s. |

**: post- to pre-operative difference; **: between-group comparison; n.s.: not significant; ODI: Oswestry Disability Index; VAS: Visual Analogue Scale. Data are expressed as median with first and third quartiles [Q1-Q3].*

solution was performed and the implants were left in place; in one case, the infection extended to the pleural space, so that an additional thoracotomy was performed to control the infection.

Forty-one patients were included in the control group. The comparison of clinical results between the two groups is reported in **Table II** and the distribution of patients' satisfaction in **Figure 3**. A similar pattern in VAS decrease was observed in both groups. An increase in function as documented in the ODI scale occurred in both groups with a mean improvement of 37.56 points in the spinal infection group and 40.61 points in the degenerative disc disease group. These changes were similar in the two groups. The intensity of pain localized in the low back decreased in a similar manner after intervention in both groups. Pain irradiation in the lower limbs was scarce in the spinal infection group, whereas it played a major role in the degenerative disc disease group and here it was dramatically reduced after intervention. A similar proportion of patients rated the results of surgical intervention as good or excellent in both groups (**Figure 2**).

CT evaluation revealed bony fusion in 87% of the cases; bony fusion appeared to correlate with superior VAS and ODI improvement in the non-smoker population (Pearson.r < 0.6453, p < 0.0141). Pre-and post-operative imaging results of an explanatory case are illustrated in **Figure 4**.

## DISCUSSION

The main finding of this study is that a single-staged PIDDIF with titanium cages can effectively reduce pain, leading to good clinical and functional results and a high rate of satisfaction. These results are comparable with those obtained using the same technique for the treatment of degenerative disc disease.

Spinal infections are classified based on their localisation in the rare intra-dural infections and the more frequent extradural infections. These can be further divided in discitis, spondylitis and epidural abscesses, depending on the extent of soft tissue involvement. The term spondylodiscitis refers to an extradural spinal infection involving the intervertebral discs, the adjacent vertebral bodies and occasionally also the posterior elements of the spine (1). Spondylodiscitis is the most common presentation of spinal infectious disease in the adult patient. A male predominance and a two-peak distribution have been described and the frequency of these infections is reported as increasing. The lumbar spine is the most frequently involved, followed by the thoracic and the cervical spine (34,35). Pyogenic infections are the most frequent types of spinal infections, and mainly occur in the area of the thoracic and lumbar spine (36). Haematogenous spread, external inoculation or involvement from adjacent tissue are the three main contamination routes (1). In most cases, however, the inflammatory process has progressed so

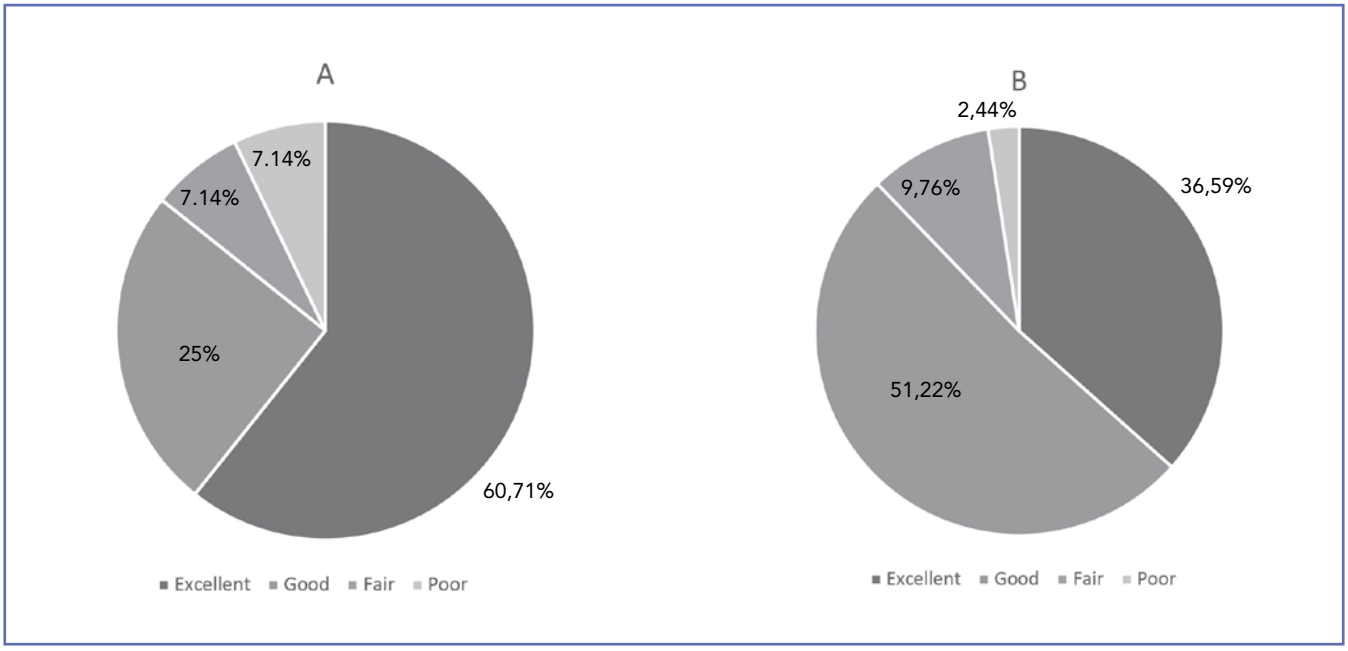


**Figure 3.** Comparison of the distribution of patients' satisfaction between the study population and a control group. A. Study population. B. Control group

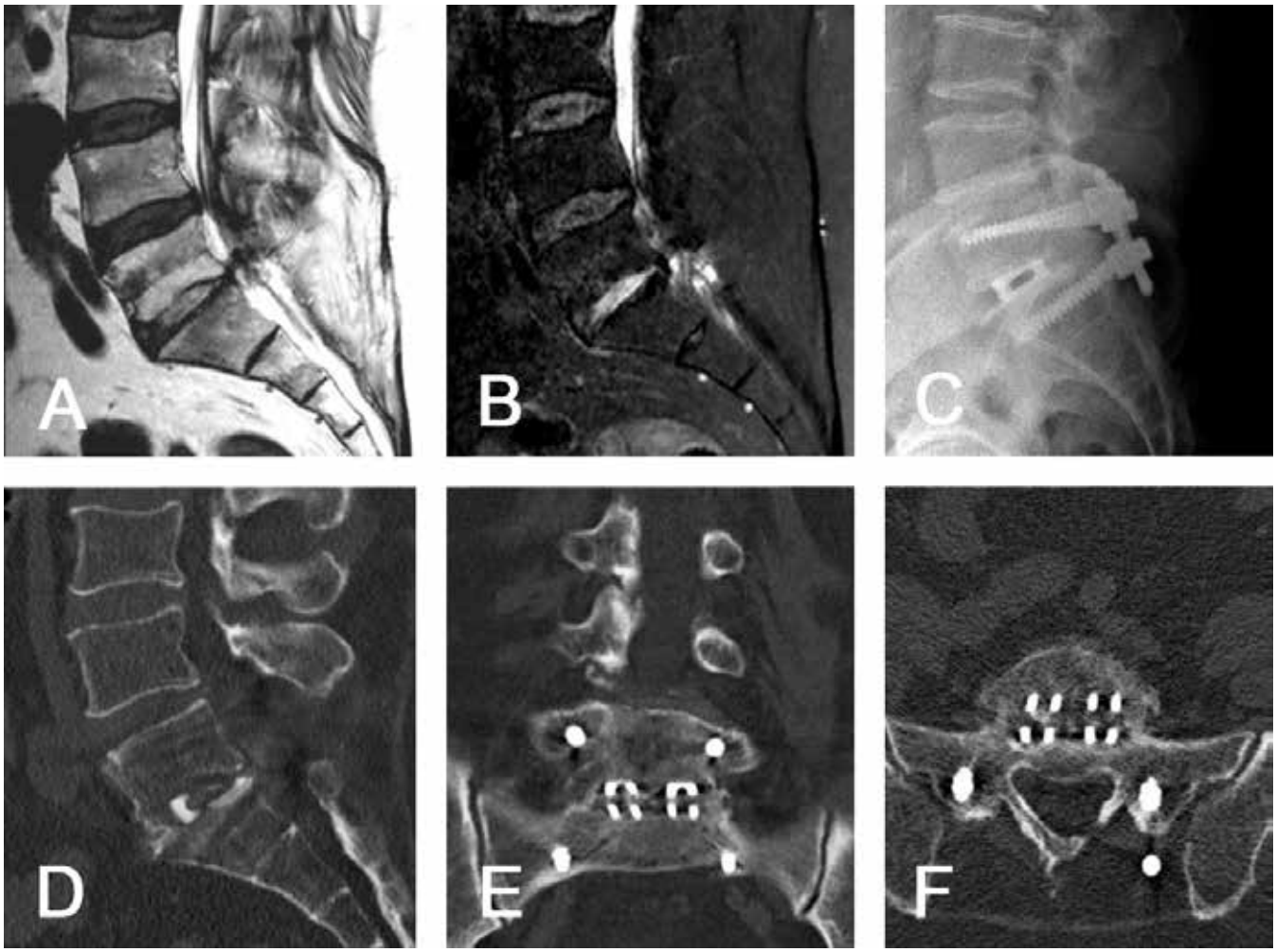


**Figure 4.** Pre-operative MRI scans in T2 weighted images (A) and Short Tau Inversion Recovery sequences (STIR, B) showing an infection in the intervertebral disc segment L5–S1, with epidural abscess in the spinal canal and in the left L5–S1 neural foramen, causing symptomatic compression of the left S1 root.
Post-operative plain radiography in lateral, weight bearing projection (C) showing restoration of the sagittal alignment. Post-operative CT scan sagittal (D), coronal (E) and axial (F) reconstructions showing interbody fusion and bony ingrowth around and within the titanium cages.

far at the moment of the first diagnosis, that the primary process can no longer be determined (37).
Clinical presentation can vary from a chronic onset, characterized by aspecific back pain to a fulminant septic shock (38,39). The diagnostic workflow includes blood tests and collection of urine samples and blood samples for microbiological analysis to target antibiotic therapy (38,40). A definitive diagnosis can be obtained with imaging studies: standard radiographs belong to the initial workup; magnetic resonance is considered the gold standard in the diagnostic. CT scan and nuclear medicine studies can help defining the extension of the bony involvement or substitute MR in cases of contraindications to this diagnostic technique (36). Early recognition is very important, because specific treatment can lead to a significant improvement of morbidity and mortality (41). Patients without spinal instability and neurological deficits can be treated conservatively with antibiotics and immobilization which can lead to disease remission, satisfying clinical results and may achieve a solid fusion in 65–79% of cases (1,2). A single study compared patients' conservative and surgical treatment for single-level spondylidiscitis, suggesting that surgery (posterior percutaneous spinal instrumentation) can be a safe, feasible, and effective procedure in reliev-

ing pain, preventing deformity and preventing neurologic compromise in patients affected by noncomplicated lower thoracic or lumbar spondylidiscitis (42).

Although the majority of patients can be treated successfully with an appropriate antimicrobial therapy, some may require surgery during or after antibiotic treatment (43). Indications for surgery include the development of neurologic deficits, symptoms of spinal cord compression and evidence of progression or recurrence despite proper antimicrobial therapy (3). Spinal instability with bone destruction and severe kyphosis are also considered indications for surgery (2). In these cases, additional therapeutic goals are to be considered: mechanical debridement and removal of the infectious focus, collection of specimens for microbiological testing and histopathological examination, decompression of the spinal canal to address any progressive neurological deficit, stabilisation and subsequent bony fusion if the spine is unstable (44,45). Surgical treatment of spinal infections gained popularity in the middle of the last century as radical treatment of vertebral tuberculosis (46). In these early ages, a single-staged anterior approach with debridement and autogenous strut-graft fusion combined with antibiotic coverage, without instrumentation, was the most commonly adopted strategy, and a number of reports were published, showing satisfying results (4–6). Later on, however, studies suggested that anterior-only approaches bear a relevant rate of intra- and peri-operative complications and could lead to late failures caused by pseudoartrosis or bone graft mobilisation, with subsequent kyphotic deformity (10,11). Therefore, the addition of a rigid internal fixation using posterior pedicle screws to anterior fusion was introduced, showing earlier ambulation and facilitated rehabilitation (7–9).

Nowadays, anterior, posterior or combined approaches in single- or two-staged procedures are used, each of which presents advantages and disadvantages (9,13,14,47–51). The selection of anterior or posterior approach is still a matter of debate. Since the pathology of pyogenic vertebral osteomyelitis mainly affects the vertebral bodies and disc spaces, the anterior approach is adopted by many surgeons, because it allows direct access to the infected focus and is convenient for debridement and anterior column reconstruction (4,5,45), although complications such as injuries of gastrointestinal or urinary tracts and compromise of the lung function by thoracotomy are possible (48,52). However, if debridement without internal fixation is conducted through an anterior approach, long-term bed rest or a body cast is required, unless surgery via an additional posterior approach is performed (52). Graft or vertebral body collapse that can lead to kyphotic spine are further possible complications of classical single-staged anterior approaches (10,48,53). The main advantage of adding a dorsal instrumentation to the anterior fusion is the maintenance of the structure and stability of the spine, even if decompression of the spinal canal is performed. Moreover, additional instrumentation of the involved segment allows earlier mobilization, which can lead to lower rates of postoperative complications (47) and spinal stability; this is believed to contribute to a more rapid suppression of infections (54,55).

More recently, single-staged posterior approaches with PIDDIF have been proposed. These approaches apply concepts derived from the experience gained in treating degenerative disc disease to infection treatment. A wide variety of different treatment modalities have been proposed to treat degenerative disc disease, and numerous publications report satisfactory results at short- and medium-term follow-up evaluation (9,13,47,50,56–60). For this reason, it appeared sensate to extend the use of single-staged techniques to patients affected by spinal infections with minimal anterior column disruption. The combination of radical debridement and instrumentation through a single approach has, in fact, some theoretical advantages, such as reduction of blood loss, operative time and bed rest period (12,55,61,62). Von der Hoeh et al. demonstrated that a single-stage operation is as effective as a 2-stage operation, but with shorter operative time and less blood loss, although a better reconstruction of the sagittal profile and less loss of reduction, not affecting the clinical outcome, was achieved in the two-stage posterior-anterior treated group (12). Rath et al. analyzed retrospectively the results of single-staged debridement, autologous bone grafting and transpedicular posterior instrumentation, presenting good clinical outcomes and no additional risk of persistence or recurrence of the infection (13). These results were confirmed by Przybylski et al., Lee et al. and Gonzalvo et al., who reported that a single-staged operation using iliac autograft is an effective procedure for the treatment of infection and the stabilization of the spine, with sufficient pain reduction and facilitation of early mobilization (9,14,62). Most recently, Zhang et al. also presented satisfactory outcomes in terms of fusion rate and quality of life (15).

The current study adds a component of innovation to the articles discussed, introducing the use of titanium interbody cages for anterior column support in a single-staged posterior operation and showing favourable results of this technique. The use of metal implants has been debated in infection treatment in spine surgery: the fear of a possible colonisation of the implant, with subsequent persistence or relapse of an infection or pseudoarthrosis, initially dominated, so that many surgeons preferred to use autologous bone grafts to promote interbody fusion, combined with antibiotic coverage and without instrumentation (4–6,14,15,41,63,64). The idea of using metallic implants originated to avoid the morbidity of tricortical bone harvesting and prevent the

possible loss of strength for vertical support during the graft resorption phase. Interbody cages were first introduced to provide early anterior support to compression forces exerted by the vertebrae above and below and showed satisfactory clinical and radiological results, without increasing the risk of infection relapse (1,16,17,21–24). The use of posterior instrumentation in treating spinal infections was also demonstrated not to increase the recurrence or primary failure rate (65). A possible explanation for this finding is that posterior instrumentation traverses relatively healthy cancellous bone with abundant blood flow, where bacterial growth is expected to be inhibited (21,52). The spine appears to provide a unique environment that permits the use of metal implants in the setting of infection, so that their use is nowadays considered safe and acceptable especially when using implants which promote osteointegration and appear resistant to microbial adhesion (66,67).

This study was designed to evaluate the clinical outcomes of a surgical technique, therefore long-term results on relapse are not available; however, as some previous authors already suggested, in the short term the use of metallic implants was safe and did not lead to persistence or recurrence of infection (41,60,67,68). To our knowledge, reports describing single-staged PIDDIF with titanium cages are extremely limited, and mainly describe the use of these implants as part of case series in which different materials are used to provide anterior support (61,69–71). In this context, our study adds more solid evidence to the series presented by Gorensek et al., who performed single-staged PIDDIF with different types of anterior column supports and reported no cases of re-infection and 88% of bony fusion (61). Previously, Lu et al. also presented a mixed case series of 36 patients, of which some received single-staged PIDDIF with expandable titanium cages, reporting no cases of implant failure but an infection recurrence rate of 5.5% (70). Schomacher et al. investigated patients undergoing single-staged PIDDIF and application of titanium- or PEEK-cages, reporting that the use of synthetic materials does not appear to influence the radiological outcome or risk of reinfection, neither does the extent of disc removal in this clinical subset. In this series, however, only 7 patients were treated with titanium cages, so that conclusions of limited evidence could be derived for this specific technique (69). Finally, Shetty et al. recently retrospectively reviewed the radiological results of 27 patients treated for pyogenic spondylosicitis with posterior instrumentation and transforaminal lumbar interbody fusion, 14 of which using titanium cages, showing satisfactory deformity correction (71). The studies described present encouraging results, consistent with our findings; however, no subgroup analysis is performed to distinguish results obtained using cages in titanium. As a single exception, Zaveri et al. presented a consistent series of 15 patients affected by spinal tuberculosis and all treated by transforaminal lumbar interbody fusion with a titanium cage and posterior instrumentation, reporting satisfying improvement in terms of pain and neurological function and suggesting this as a simple, safe, and effective procedure (27).

The use of metallic interbody cages is not the sole possibility to perform a single-stage procedure without the additional morbidity of an autologous graft. Allografts have also been proposed for patients with poor general condition (52) and the use of PEEK was presented in several publications with satisfying results (12,61,69,72,73). The latter has however been recently associated to allergic reactions which deserve further safety investigation (74,75). This considered, our conclusions are in agreement with the findings of Schomacher et al., who suggested that debridement and fixation with anterior column support in combination with an antibiotic therapy appear to be the key points for successful treatment of spondylodiscitis, independently of the material used for anterior column support (69). Furthermore, this study first reports a substantial equivalence in terms of clinical results and subjective satisfaction for patients undergoing single-staged PIDDIF with titanium cages for pyogenic infections with minimal anterior column disruption and patients receiving surgery in the same technique for the treatment of degenerative disc disease, although the origin of pain from a primary degenerative disease is different from bacterial acute inflammation, especially taking into account the structural and biochemical changes of receptors, neurogenic structures and chronic functional deficit.

This study has some limitations. First of all, patients' age and comorbidities, route of infection, causative microorganism, and sensitivity of pathogens differ across the study population: these factors all play a role both in the success of surgical and medical therapy and may affect fusion rate. The location of the infection at different levels of the lumbar spine may also influence outcomes, especially those regarding bony fusion and adjacent segment degeneration. However, the low incidence of this disease allows to restrict the inclusion criteria or to perform subgroup analyses only in the setting of a larger, multicentre study (34,35). In facts, the number of patients included in this study is limited and a control group is lacking. The enrolment of a control group of conservatively treated patients was not considered, since different indications are nowadays accepted for conservative and surgical treatment (3). A control group of patients operated with a different surgical technique for the same indication was not available in the institution where the study was performed. During surgery for spinal infections, prospective, controlled and randomized clinical studies comparing the different

methods are difficult to conduct because of the rareness of the disease, the apparently comparable results of different operative therapies, and the individual preferences of spinal surgeons when choosing the operative technique, a change of which implies a steep learning curve with the possibility of reduced results (41). Therefore, the best way to treat spondylodiscitis remains unknown and the results of this study only add a low level of evidence for a single technique, albeit offering a comparison with a widespread and established technique. However, to our knowledge, there are no large comparative cohort studies to give either level one or level two evidences on the most effective treatments, so that case series and prospective cohort studies still remain the best available evidence for the treatment of this rare disease (45).

## CONCLUSION

Single-staged posterior instrumentation, disc debridement and interbody fusion with titanium cages can effectively reduce pain with good clinical and functional results and a high rate of satisfaction in patients affected by pyogenic spinal infections with minimal anterior column disruption. Therefore, it can be added to the portfolio of surgical options available to the spine surgeon to handle this pathology. The results of the described technique applied in the setting of an active infection are similar to those obtained using the same technique in the established and more widespread setting of the treatment of degenerative disc disease.

### Authors' contributions

DC contributed to study design, clinical evaluation of enrolled patients, original draft preparation; LD contributed to the clinical evaluation of enrolled patients and radiological evaluation of reported cases; AK, MG and DCW contributed to manuscript correction; YR contributed to surgical procedures; RB contributed to the preparation of the study protocol and the correspondence with the local ethic committee; RP contributed to study design and to surgical procedures.

### Conflict of interest

The authors declare that they have no conflicts of interest relevant to this study.

### Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

### Informed consent

Informed consent was obtained from all individual participants included in the study.

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