Brain and Spine 2 (2022) 101186

Contents lists available at ScienceDirect

Brain and Spine

journal homepage: www.journals.elsevier.com/brain-and-spine

PMMA-cement anterior column reconstruction in surgical treatment of spondylodiscitis

X. Banse [a,*], L. Kaminski [a], N. Irda [a], C. Briquet [b], O. Cornu [a], J.-C. Yombi [c]

[a] Department of Orthopaedic and Trauma Surgery, Cliniques Universitaires Saint-Luc, Avenue Hippocrate 10, 1200, Brussels, Belgium
[b] Pharmacy Department, Cliniques Universitaires Saint-Luc, Avenue Hippocrate 10, 1200, Brussels, Belgium
[c] Department of Internal Medicine and Infectious Diseases, Cliniques Universitaires Saint-Luc, Avenue Hippocrate 10, 1200, Brussels, Belgium

ARTICLE INFO

Keywords:
Spondylodiscitis
Vertebral osteomyelitis
Spine surgery
PMMA cement

ABSTRACT

Introduction: and research question: This paper explains how antibiotic loaded cement can be used in surgical treatment of spondylodiscitis to reconstruct the anterior column of the spine.
Material and methods: 35 consecutive surgical procedures performed for spondylodiscitis were collected over a 11-year period and charts were reviewed. Most infections were caused mainly by *staphylococcus spp (n = 16), streptococcus spp (n = 8) and pseudomonas spp (n = 4)*. Most patients had long standing but unsuccessful antibiotic therapy (median 42 days). Other indications included instability, neurologic deficit, abscess, and patients were generally in very poor medical condition.
Results: Anterior debridement was followed by a partial cavity filling with surgical high viscosity PMMA cement in all cases. Cement was a high viscosity gentamycin loaded cement, that was placed in the cavity created by debridement under the direct eye control. In 25 cases, a part of the cavity was filled with freeze dried cancellous bone allograft rehydrated in rifampicin. Spine was further stabilized with an anterior plate in 15 cases, with short (+1/+1) posterior instrumentation in 5 cases, and a long ($\geq$ +2/+2) posterior instrumentation in 11 cases. In four patients, spine was left un-instrumented. Immediate, unrestricted mobilization was always authorized after surgery. None of the patients were reoperated neither for mechanical failure nor for infection relapse.
Conclusion: This report supports the idea that surgical bone cement is an efficient gap filler when used through anterior approach. For small as well as for large defects, it can help to reconstruct the anterior column and locally control the infection in combination with additional stabilization and optimal intravenous and oral antibiotic treatment.

1. Introduction

Spondylodiscitis (also called vertebral osteomyelitis) is an infection of the spine characterized by a destruction of the disc and vertebral bodies (Zimmerli, 2010). While most agents are pyogenic germs, some infections are caused by mycobacteria, parasites or fungi. With aging population, increasing number of patients with immunosuppression, and intravenous lines (dialysis, cancer treatment …), the incidence of pyogenic spondylodiscitis tends to rise along with that of bacteriemia episodes (Conan et al., 2021).

Conservative treatment with bed rest and long-term (6-12 weeks) antibiotics is certainly the standard of care (Bernard et al., 2015). However, in some situations it is not sufficient, and surgery is indicated (Rutges et al., 2016). Good indications for surgery include neurological deficit (with canal compromise, i.e. related to epidural abscess), spinal instability (most often related to bone destruction and progressive kyphosis), failure of conservative treatment (i.e. with persisting bacteremia, or poor clinical and biological evolution). In some cases, surgery is indicated specifically for drainage of paravertebral abscess or identification of the causative pathogen.

Depending on the published series, surgery is required in 15-40% of the cases, with a realistic estimate to 28% in a recent epidemiological study (Conan et al., 2021). When surgery is performed the objectives are: to decompress the canal (1), to align and stabilize the spine (2) and to do an aggressive debridement (3) (Duarte and Vaccaro, 2013). This usually results in rapid pain reduction, increased mobility and improved infection control.

Anatomically, spondylodiscitis leads in a variable but sometimes very

* Corresponding author. Service de chirurgie orthopédique et de traumatologie de l'appareil locomoteur, Cliniques Universitaires Saint-Luc, Avenue Hippocrate, 10, 1200 Bruxelles, Belgium.
E-mail address: xavier.banse@uclouvain.be (X. Banse).

https://doi.org/10.1016/j.bas.2022.101186
Received 15 May 2022; Received in revised form 19 August 2022; Accepted 2 September 2022
Available online 17 September 2022

important destruction of the anterior column of the spine. If debridement is properly performed, removing pus, disc debris, bone sequestrum and dead bone, it leaves a cavity of variable size. In combination with spine instrumentation, different materials have been used to reconstruct the anterior column. The gold standard material is a structural iliac crest tricortical autograft (Wu et al., 2021). Alternatively, structural bone allografts or more commonly titanium cages can be used (Liljenqvist et al., 2003; Martínez-Gutiérrez et al., 2021).

There is a long-standing experience in the orthopedic community with antibiotic loaded PMMA cement when dealing with chronic osteomyelitis of the appendicular skeleton: either as temporary spacer or as definitive spacer (Bor et al., 2022). Accordingly, high viscosity PMMA cement is a good candidate as a reconstruction material for vertebral osteomyelitis. It has many theoretical advantages: it will cure in the cavity under visual control of the surgeon within minutes, it can fill the cavity with complex shape resulting a large surface of contact, it locally diffuses antibiotics, and it is always available and cheap. It has already been used in palliative vertebral metastatic patients (Cahill and Kumar, 1999).

A very recent study has presented the option of PMMA cement as a good solution when deployed in a PLIF mode (Deml et al., 2022). Authors reported 73 patients with lumbar spondylodiscitis. The disc and bony erosions debridement were always carried out form posterior approach, and PMMA cement (also loaded with gentamycin) was used to fill the cavity. The results with this technique were very good.

We report here almost exclusively anterior debridement and reconstruction using PMMA cement.

Our hypothesis is that a spacer of high viscosity PMMA is a reliable, efficient and durable way to reconstruct anterior column in spondylodiscitis. The primary outcome was no revision surgery or demonstrated sepsis relapse within 2 years after surgery.

2. Material and methods

Database from the hospital were explored from 2010 to 2021. We reviewed the surgical programs to track spondylodiscitis and the pharmacy administrative record, looking for any surgical cement or antibiotic locally implanted in the spine. Spine tango register extract (only available 2012–2017) was used to cross-check the information.

Charts were reviewed to include all cases operated by one single surgeon (X.B.) for spondylodiscitis, vertebral osteomyelitis, epidural, or paravertebral abscess. All cases where surgery was performed and where disc or vertebral body was infected were considered. Accordingly, isolated facet joint infection or isolated posterior implant infection were excluded. All patients where polymethylmethacrylate antibiotic loaded cement thereafter called cement or PMMA cement was used for anterior column reconstruction were included in this series.Medical charts and available images were reviewed. Cases were classified according to the indication, medical condition, causative micro-organism, and type of reconstruction performed. Surgical protocol and hospitalization notes allowed us to analyze the indications for surgery. Six indications were considered: neurologic deficit, instability, epidural abscess, intractable pain, uncontrolled sepsis, other abscesses and diagnostic purpose. In most cases two or more reasons for surgery were explicitly mentioned. One was classified as the ‘main indication’, other were classified as ‘additional indication’. Preoperative and postoperative CT-scan and Magnetic Resonance Imaging (MRI) were also reviewed to follow the evolution of hardware, bone cement and bone graft aspect. Gap height was measured as the largest diameter (from proximal to distal, mm) of the PMMA cement, as measured on a follow up CT-scan or more rarely X-ray (see Fig. 1). We also searched for episode of sepsis relapse (clinically, biologically or accessible imaging), implant failure (breakage, loosening) or revision surgery.

This study was approved by the university hospital ethic committee (reference number: B403201523492).

3. Results

3.1. Indication

Over the 11-year review period, among 49 patients operated for spondylodiscitis, 34 were operated using PMMA cement to fill the cavity left by debridement of the infection. As one of these 34 patients (or case) was operated on the same day in the thoracic spine and in the lumbar spine (two spondyodiscitis, one in T9-T10 and one in L3-L4), the actual number of surgical procedures included in this review is 35.

Median age was 66 (47–84). Indications for surgery as well as some preoperative parameters are reported in Table 1. Most patients had some kind of uncontrolled sepsis (i.e. ongoing bacteremia, poor biological or poor clinical evolution; n = 25) and this was the main indication for 10 cases. Spine instability was found in 20 cases and reported as the main indication for surgery in 14 cases. Six patients had neurological deficit, and this always came as the main indication; 2 had epidural abscess (without neurologic deficit), and it was mentioned as the main indication in 2 cases (see Table 1).

3.2. Preoperative medical condition

Antibiotics were administrated preoperatively in 29/34 patients preoperatively and often for a long period (>30 days in 23 patients). Median preop antibiotic treatment duration was 42 days (0–365). Antibiotherapy duration was longer in the group of patients with uncontrolled sepsis as main indication, compared to the other (108 versus 51 days).

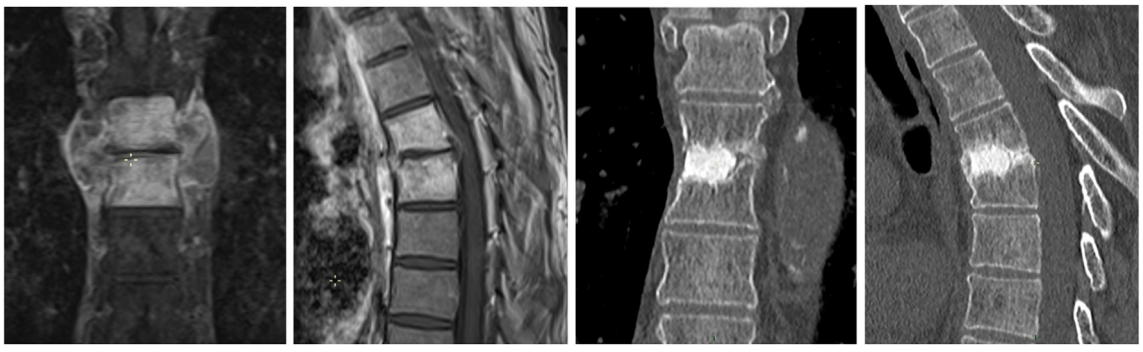

Fig. 1. Example of spondylodiscitis (T5-T6) in a 61-year-old man who had liver transplant. After 7 days of antibiotherapy it was decided to operate, because of uncontrolled sepsis and immunosuppression. Right mini thoracotomy was done, abscesses were drained, and disc space was debrided. Cavity was filled with PMMA-cement and some bone chips. MRSA was identified in the surgical biopsies. Preop MRI on the left showing paravertebral and epidural abscesses, and postop CT at 2 years on the right showing solid fusion and good tolerance of the cement. Gap height was 12 mm. This is one of the 3 cases over 35 that was not instrumented.

Table 1
Indications for surgery and duration of preoperative antibiotherapy.

Situation	n patients where situation was the main indication[a]	n patients where situation was main or additional indication	Preop days of antibiotherapy (mean)	n patients >30 days of antibiotherapy
Neurlogic deficit	6	6	64	3
Instability	14	20	67	11
Epidural abcess	2	6	30	2
Uncontrolled sepsis	10	25	108	7
Psoas, or paravertebral abcess	1	5	0	0
Diagnostic	1	1	21	0
Overall	34	NA	71	23

[a] When patients had more than one indication for surgery, one of thes was identified as the main indication and other(s) were labeled as additional.

Overall, most patients were in very poor medical condition at the time of surgery. Ten out of 34 had diabetes and 3 were in dialysis. Six were considered as immunosuppressed, and 5 were treated for cancer. One was drug abuser, and another alcoholic. Another had received liver transplantation. Four had recent heart surgery (3 valve repair or replacement for concomitant endocarditis). In only three cases out of the 34, anterior infection was clearly iatrogenic (1 times post discectomy, 2 others after arthrodesis procedures). Four patients had previous surgical attempt to treat the infection and were transferred to our department for medical and surgical failure. Eleven patients were 75 or older.

3.3. Microbiology

In all cases, the microbiological identification could be performed (Table 2). It was known before surgery in 17/35 (48.6%) surgeries (blood culture n = 16 or CT-scan biopsy n = 1). Culture of various tissue fragments coming from surgical field was always performed, but it only allowed microbial identification in 24/35 (68.6%) surgeries since, as mentioned above, most patients received long standing antibiotics before surgery. Among the 5 patients that did not receive antibiotics before surgery, perioperative culture was always positive. The most common infecting agent was a *staphylococcus spp* (*aureus* n = 12, 8 Methicillin-sensitive (MSSA) and 4 Methicillin-resistant (MRSA), *coagulase negative* (CN n = 4, 3 MR and 1 MS) and *streptococcus spp* (n = 8).

3.4. Infection location and extension

Six patients had main site of infection in the cervical spine, 6 in the thoracic spine (T2-T10), 12 at the thoracolumbar junction (T11-L2) and 11 in the lumbar spine. Abscesses requiring drainage were noted in the paravertebral/paraspinal area in 6 cases, and in the peridural area in 5 cases as well.

Table 2
Microbiology.

Microbiological identification			Microbiological diagnosis	
Staphylococcus aureos	12	MSSA 8, MRSA 4	Pre-op blood culture (but not perop culture)	10
Coagulase-negative Staphylococcus	4	MRSE 3, MSSE 1	Pre-op CT biopsy	1
Streptococcus	8		Only perioperative surgical biopsy	18
Pseudomonas Aeruginosa	4		Pre-op blood culture and perioperative biopsy	6
Klebsiella pneumoniae	1			
Escherichia Coli	2		Total	35
Enterobacter	1		Known preoperatively	17
Mycobacterium tuberculosis	2			
Candida albicans	2			
Total	36[a]			

[a] One patient had two microbes identified.

3.5. Surgical approach and instrumentation

Surgical approach and technique were always adapted to the location and local extension of the infection. Regarding the stabilization/instrumentation technique, bone destruction guided the choices (Table 3).

Surgical debridement of the infected anterior column was performed through anterior approach (one exception). Only three cases were left un-instrumented (2 cervical and one high thoracic spine, Fig. 1). In many cases (15 procedures) this anterior approach was also used to stabilize the spine with anterior cervical, thoracic or lumbar plating (anterior short instrumentation, +1/+1, Fig. 2 and Fig. 3).

For 17 surgical procedures, bone destruction was more extensive, and a combination of anterior and posterior approach was performed. In most surgeries, appropriate posterior instrumentation was performed first, followed by an extensive anterior debridement and anterior reconstruction. In this group of posterior then anterior approach, 11 stabilizations were performed using a long posterior instrumentation (+2/+2 or more levels, Figs. 4 and 5), and 4 with short posterior instrumentation (+1/+1). The choice between long and short posterior instrumentation depended on the degree of instability, bone quality and accessible bone structures. Only one patient with extensive destruction, previously operated 4 times, could not be re-instrumented. Posterior alone surgery with PMMA cement placed from posterior approach was done in only one case.

3.6. Gap height

Height of the reconstructed gap varied from 7 mm to 58 mm depending on the extension of the discal and bone destruction. Mean gap height was 21,3 with standard deviation being 12,0 mm. Mean gap height was logically smaller in the cervical spine (n = 6; 9,1 mm) than in the thoracic spine (n = 6; 19,1 mm). Bigger gaps were found in the thoraco-lumbar (n = 12) and lumbar (n = 11) spondylodiscitis (mean gap size respectively 26,9 and 26,1 mm).

This had some influence on the stabilization technique (Table 3). When a long instrumentation was used (+2/+2 or more posterior instrumentation) mean gap size was bigger (29,7 mm) than when a short instrumentation was chosen (17,6 mm for anterior plate reconstruction, and 21,0 for posterior reconstruction). In the 3 un-instrumented cases, mean gap size was quite small (9,7 mm).

Over 35 reconstruction procedures, 19 gaps were bigger or equal to 20 mm in height, and 9 were bigger than 30 mm.

Table 3
Surgical approach, type of instrumentation and gap size.

Approach	Instrumentation	n	Gap size mean (SD), mm
Anterior	no instrumentation	3	9,7 (2,1)
Anterior	Short anterior	15	17,6 (8,9)
Posterior then anterior	Short posterior	4	21,0 (7,8)
Posterior then anterior	Long posterior	11	29,7 (9,5)
Posterior then anterior	no instrumentation	1	56
Posterior	Short posterior	1	19
	Total	35	21,3 (12,0)

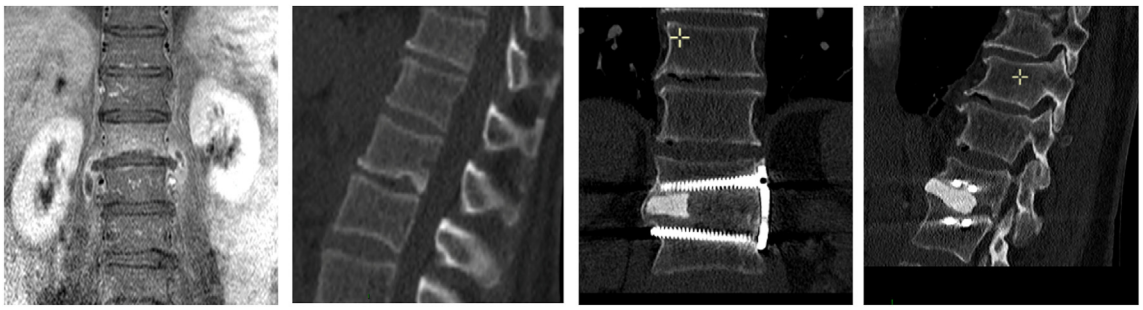

Fig. 2. 81 y old man hospitalized for L1-L2 spondylodiscitis. MSSA was identified on blood culture. Early surgery was indicated here because of untractable pain (a rare indication). Goal was to speed up recovery in this frail patient. Limited lombotomy, debridement and reconstruction with cement and grafts. Gap height was 12 mm. Pain stopped after surgery, allowed to walk without any brace. Patient was discharged one week after surgery. On the right side, CT scan at 5 years postop, showing fusion and good tolerance of the PMMA cement.

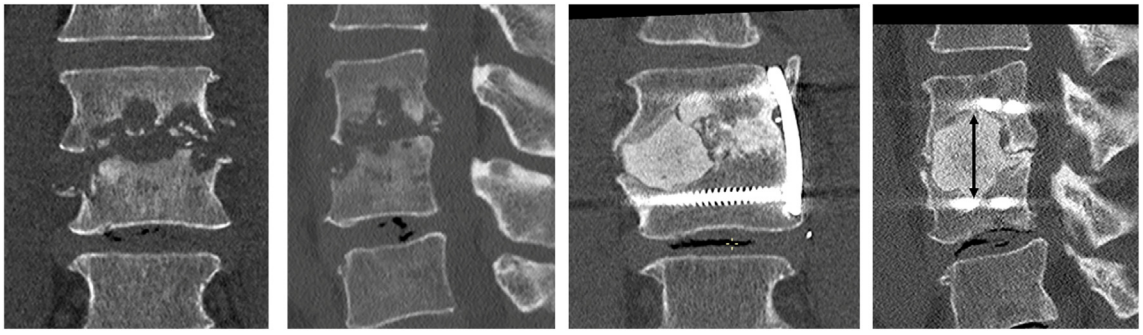

Fig. 3. 58 y old patient with spondylodiscitis of L3-L4 and presenting with limited motor deficit. Generous debridement was preformed through left lumbotomy, creating a large cavity (gap height measured 29 mm, indicated by black arrow). Reconstruction was performed with PMMA-cement (right half) and cancellous bone chips rehydrated with rifampicin (left half), and hort instrumentation (L3-L4, anterior plating). Streptococcus gallolyticus was found in the samples. Patients recovered rapidly. At 5 years (on the right), solid fusion. Gap height measured 29 mm here is indicated by the vertical black arrow.

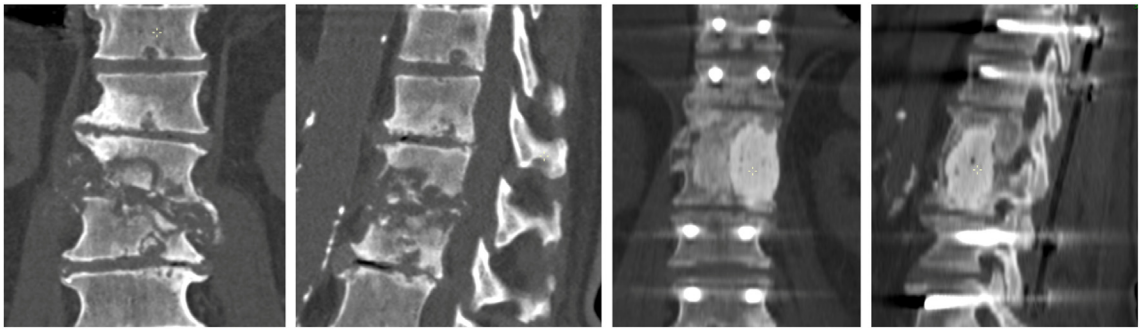

Fig. 4. Example of spinal instability (L1-L2) and conservative treatment failure. This 80-year-old man had diabetes and was treated conservatively during 42 days before going to surgery. A posterior approach was performed to stabilize the spine, then lombotomy was used to remove infected tissue. This left a large gap, that was filled with bone chips (right side) and cement (left side), as on the CT scan at 8 months. Gap height was 46 mm. Patient improved but died one year later of renal insufficiency.

3.7. Gap filling material

In the 35 procedures reported here, anterior column reconstruction and support was partially or totally performed using PMMA (polymethyl methacrylate) cement. Gentamycin loaded cement was used in all cases. Biomet Refobacin cement® (Zimmer Biomet) and Palacos R + G® 20g or 40g (Zimmer). The concentration of gentamycin was 0.5g/40g of cement for the two cements. Depending on the case, 20g or 40g of cement was used. For one patient with candida infection in the L5 vertebral body, cement was additionally loaded with amphotericin B.

Generally (25 procedures out of 35), while one 50-60% of the volume of the cavity was filled with cement, the rest was filled with freeze-dried cancellous bone allografts rehydrated in rifampicin (see later for detailed technical description). This was the most common solution. The rationale behind this was to obtain maximal gap filling, immediate stability with cement *and later fusion* thanks to the allografts (Figs. 2, 4 and 5).

Going through the 10 cases where these bone chips were not used, it appeared that, in six cases the reconstruction followed anterior cervical spine debridement where the available space was considered not sufficient to put both cement and allografts. In four other cases, preoperative microbiological analysis indicated that rifampicin would be inefficient (three were gram negative bacteria, and one candida infection).

3.8. Intravenous (IV) antibiotics and local antibiotics

Retrospectively we checked the antibiogram to know whether

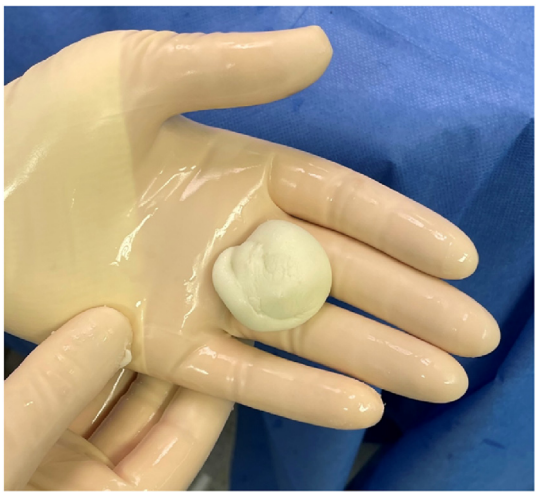

Fig. 5. PMMA cement ready for implantation. This is high viscosity cement, 4 min after mixing. Consistency is ideal for safe implantation in the cavity left by debridement.

antibiotics that was used locally (either gentamycin in the cement, or rifampicin in the allografts chips) were active or not on the causative micro-organism.

When an antibiogram testing gentamycin was accessible, it turned out that 25/26 time the gentamycin was explicitly mentioned as active. In only one occurrence was it found as resistant. Regarding the rifampicin, the micro-organism was susceptible in 17/18. As for gentamycin, resistance to rifampicin was found in only one case.

Postoperatively all patients received initial intravenous antibiotherapy, with oral switch after one or two weeks (Cheung and Luk, 2011; Li et al., 2019). Antibiotic treatment was carried on during 6–12 weeks (Bernard et al., 2015).

3.9. Follow up

No patient died during surgery and no cement complications were observed. In postoperative care all patients were allowed to mobilize freely the day after surgery without any external support (no brace, no corset), since reconstruction technique was always adapted to stabilize the spine. Post-operative CT scan was revised in 28/35 procedures and showed no technical issues.

The delay between surgery and CT scan was not standardized, but it was more than six months in 14/28 and less than six months in 14/18. All late CT scan (>6 months) showed solid interbody fusion defined as bridging bone spanning from one level to the other. The degree of integration and remodeling of the allograft bone chips depended on the delay between surgery and CT (see Figs. 2, 3 and 7 for extensive remodeling and very good integration and Fig. 4 for incomplete remodeling at 8 months).

No patient was reoperated. *Cement was never removed in any patients* for any type of mechanical failure or septic relapse.

Majority of patients (26/34, 74.3%) achieved the primary endpoint that was a two years follow up without any mechanical failure or septic relapse. Six patients died before two years. Cause of death was cancer in four patients, heart failure in one patient who had valve surgery, and one patient who died of renal failure (consecutive to the severe infection) after months in dialysis. Three patients had a follow up of less than two years but are doing well, so far.

4. Discussion

This report shows that using antibiotic loaded PMMA cement to reconstruct the anterior column after debridement of a spondylodiscitis is a good option. After systematic revision, it was found to be sufficiently reliable, efficient and durable to be reported here.

4.1. Good indication for surgery

Even if medical treatment is efficient for many patients (Zimmerli, 2010; Bernard et al., 2015) there is no debate that surgery is necessary for a substantial part of patients. In some situations, surgery is indicated very early, for example in case of neurologic deficit. In other situations, conservative treatment is initiated, but it can become difficult to manage or simply fail. After weeks of medical treatment, the situation may deteriorate for many reasons. Bone erosions may cause kyphosis and instability, pain can be very difficult to manage, and some patients are forced to stay in bed. In addition, in some cases, there may be evidence of fever, high CRP or even bacteremia. Like other authors, we made our best to identify the indication (or main indication) for surgery, trying to sort it in six categories (see above). However, our data point that in most cases, one will find more than one reason to go for surgery (22 patients over 34). This is logical, since progressive instability and medical treatment failure are linked, one way or another. The idea of reporting multiple indications was not found in previous papers and may require further work, seeking for more standardized definition of the different indications. However, regarding the indication, we consider that the case mix reported here is in line with other series (Rutges et al., 2016; Duarte and Vaccaro, 2013; Valancius et al., 2013). Maybe our patients had longer preoperative medical treatment, and some were referred extremely late after months of conservative treatment. We also briefly report here the preoperative medical condition of our patients. Mainly to recall that these patients are very often in poor condition, with significant comorbidities. The case-mix of microbiological agent found in our series is grossly comparable to that of other series, with a dominance of gram-positive bacteria (Bernard et al., 2015; Li et al., 2019; Valancius et al., 2013).

Fig. 6. Preparation of freeze-dried cancellous bone chips (left), rifampicin (middle), and rehydration of the chips with pure rifampicin solution. These grafts are also antibiotic carriers.

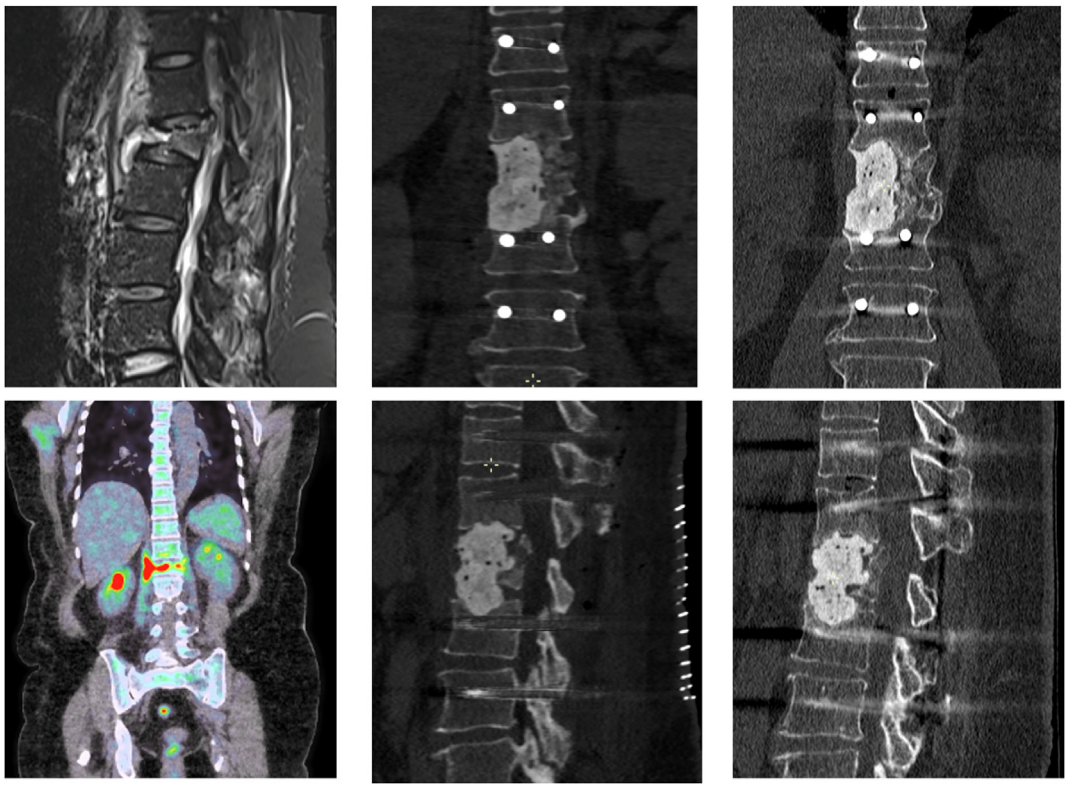

Fig. 7. PMMA Cement was also used to reconstruct large defects. This 58-year-old woman had a streptococcus pyogenes septicemia with secondary spondylitis of L1, as diagnosed on the MRI (left, up) et PET-scan (left bottom). It was not possible to determine if the fracture happened before or after the infection. After one month of antibiotic treatment, surgery was performed for spinal instability. Posterior instrumentation was placed first, followed by anterior reconstruction with cement and grafts (middle up and bottom). At 2 years postoperatively, fusion is obtained, and cement is well tolerated. In coronal view, cement (right top) and in sagittal view (right down), bone can be seen very close to the cement and bone chips integration was very correct.

4.2. Anterior column destruction and gap height

The size and extent of bone and soft tissue destruction in the anterior column is rarely reported in the literature. Bone erosions may appear in any part of the vertebral bodies adjacent to the infected disc and will generally lead to local kyphosis. Kyphosis closes the cavity created by the infection. Consequently, the shape and size of the cavity is variable and difficult to estimate preoperatively, and some authors report the degree of kyphosis.

In this series, our basic strategy was to do an anterior approach and perform a relatively aggressive debridement. As cavity was filled with PMMA cement and, in many cases, additional grafts, we could measure the gap height as an interesting parameter. Bigger gap means more instability. In our series most gaps (19/35) were bigger than 20 mm, and 9 were bigger than 30 mm, corresponding generally to a vertebrectomy indication (Figs. 4 and 7).

4.3. Technical tricks: debridement

Debridement is a very important step of the surgical technique. It is never as extensive through a posterior approach than through an anterior approach. For thoracolumbar approach long instruments are necessary. Segmental vessels are very difficult to find in the infection and should be cauterize or clipped and divided. After removal of the disc remnants with pituitary rongeurs, curettes are used to remove dead bone fragments. Generally, such debridement lasts 1 h and leaves a bleeding round shaped cavity. Its walls are generally concave, with various cavities. It is not necessary to remove the vascularized capsule of the infection, except on the side where you created a window to access the cavity.

4.4. Comparing the reconstruction materials

For large anterior column reconstruction (>30 mm), many technical solutions exist. The gold standard is still tricortical iliac crest autograft (Wu et al., 2021; Eysel et al., 1997; Tong et al., 2019), with a tendency to replace it with titanium cages or mesh cages (Liljenqvist et al., 2003; D'Aliberti et al., 2012; Zhang et al., 2021). Structural allograft is also an alternative (Martínez-Gutiérrez et al., 2021; Munting, 2001). Exhaustive review can be found elsewhere (Rutges et al., 2016).

4.4.1. Mechanical considerations

From the mechanical perspective, all solutions offer good mechanical strength, although tricortical autograft is probably the weakest. The main difference is the inevitable point-contact that one will observe with cages, allograft and even tricortical autograft. Indeed, it is very difficult to obtain a flat solid surface to accommodate any cage, if not though an increase in bone sacrifice, extending the resection to the next vertebra to position the implant on the next endplate. Compared to this, the contact obtained with cement has much larger surface contact, *reducing the stress shielding* at the contact point. Consequently, we consider cement as a bone preserving strategy for anterior column reconstruction.

Furthermore, cement will logically follow irregular -most often concave-surface of the upper and lower limits of the cavity. Combined with the fact that it is good practice to retain the capsule of the infected site, these properties will increase immediate stability and prevent toggle or dislodgement of the cement spacer (Fig. 7). Although it is very difficult to demonstrate, it is our opinion that relatively shorter instrumentation could be used (Fig. 3), taking benefit of an efficient anterior column reconstruction.

4.4.2. Biologically: local antibiotic delivery

At the bone-cement interface we could regularly observe some type of 'bone growth', that would strongly encapsulate the cement. One can also postulate that the use of local antibiotics (released by the cement, gentamycin) would help to obtain local healing. This is very consistent with the observation of Deml et al. (2022). In our series gentamycin was tested active against the microbiological agent in most of the cases (25/35 procedures compared to 56/73 procedures in their series). Even if it seems very reasonable and logical, we cannot demonstrate that local release had a significant influence on infection healing. Our opinion is that it may, at least, induce a better tolerance of the spacer. In some cases, we observed a real bone growth around the cement (Figs. 2, 3 and 7).

Our data also support the fact that gentamycin remains a very good empirical choice to load the cement in spondylodiskitis. Indeed, considering the 26 antibiograms where gentamycin was tested, germ was sensitive 25/26 times and resistant only one time.

Even if the titanium cages have proven to be efficient and shown no problem (Liljenqvist et al., 2003), in this series of 35 procedures two procedures were performed to remove infected titanium cages (placed for spondylodiscitis) and reconstruction with PMMA antibiotic loaded cement (gap height 36 and 58 mm). These two patients were in very bad situation and finally did well.

4.5. Technical tricks: cement use through open the anterior approach

Using the cement to *openly* fill anterior column cavity is quite simple and straightforward, but completely different compared to vertebroplasty or screw augmentation. First, a high viscosity cement must be selected (not the low viscosity cement that is too liquid). This is the most common form of surgical cement. If curing time is generally 14 min, operator must wait 4–5 min after mixing, before manipulating the cement and putting it in the cavity (Fig. 5). The goal is to have the consistency of a chewing gum to allow reasonable control of the positioning of the cement. Cement is always positioned in the cavity under control of the eye. It may be inserted step by step, controlling the contact with bone at the top and bottom of the cavity (i.e. see Fig. 4, right side). This has a very good hemostatic effect. If the debridement exposes the spinal canal operator should gently push it few mm away with a cobb elevator or any other tool. During curing, cement will heat, and some saline may be poured to cool it, but generally it is not mandatory.

4.6. Additional value of the bone chips

It is very difficult to measure the added value of rifampicin loaded cancellous allograft, it has been demonstrated as an efficient antibiotic carrier (Witsø et al., 2000). If posterior instrumentation and fusion is performed, additional anterior grafts may not be useful. In our series 15 patients had no posterior instrumentation and we considered that adding anterior grafts was useful. The best way (in our opinion) to reduce the risk of graft infection was to load them with antibiotic (Fig. 6). Note that autograft is a reasonable alternative.

4.7. Technical tricks: bone chips

To load the allografts with maximum amount of rifampicin, we proceeded as follows: Freeze dried irradiated cancellous bone chips are prepared before any rehydration. Sometimes, the bone bank can deliver it directly in a vial filled with cancellous bone chips, sometimes one must fragment a block of cancellous bone to obtain 5-10 ml of fragments roughly 4 mm in diameter. Rifampicin powder (600 mg) is mixed with the 10 ml water in a seringue (normal preparation), poured over the bone chips in a cup containing the bone chips. After 5 min a substantial part of the antibiotics is absorbed by the grafts, that become brown-red color. Rifampicin loaded bone chips are ready to be compacted in the cavity left by debridement, and not yet filled with cement.

If a combination of cement and bone graft is used, operator may choose to put the bone graft in the left or right half and the cement in the other half. Per-operative fluoroscopy is recommended.

4.8. Recent papers on PLIF technique

When finishing the redaction of this paper, Deml et al. published a series of 73 lumbar spondylodiskitis operated with a PLIF-cement technique (Deml et al., 2022). Their results reinforce the idea that antibiotic loaded cement is a good solution to reconstruct anterior column. They report good results, local healing, bone growth around the cement plug.

Few months earlier, Slavnic et al. published the mini-invasive variant of this procedure (Slavnic et al., 2021). They reported on 62 patients with spondylodiscitis where discal debridement was mostly performed through tubular mini-invasive approach, PMMA was introduced through the same route. Finally, the spine was percutaneously stabilized. They obtained consistent fusion and observed good tolerance of the PMMA cement.

Our results add some relevant information. As we preferred anterior approach for cement application, we could go for cervical surgeries. Additionally, Deml et al. excluded cases that would be indication for vertebrectomy, while we did not hesitate to go for large reconstructions. These studies support each-other, showing that high viscosity PMMA-cement is well tolerated and efficient in anterior column reconstruction.

4.9. Practical considerations

PMMA cement is available in almost every hospital across the world. You do not need delivery of special implants, there is no instrumentation to prepare or position the implant. Putting aside the iliac crest tricortical autograft, it is clearly the cheapest available reconstruction material.

4.10. Study limitations

This study carries all the limitations and weaknesses of a retrospective study (i.e. heterogeneity of the included patients, single center, missing data and lost at the follow up). Consequently, this paper must be considered as a preliminary report, even if it is encouraging.

4.11. General conclusion

Further fundamental research on the local behavior of antibiotic carrier should be performed as well as multicenter studies to compare different surgical techniques. This report supports the idea that surgical bone cement is an efficient gap filler when used through anterior approach. It appeared to be well tolerated on the long term, and consequently it can help to reconstruct the anterior column and locally control the infection in combination with additional stabilization and optimal intravenous and oral antibiotic treatment.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Bernard, L., Dinh, A., Ghout, I., Simo, D., Zeller, V., Issartel, B., et al., 2015. Antibiotic treatment for 6 weeks versus 12 weeks in patients with pyogenic vertebral osteomyelitis: an open-label, non-inferiority, randomised, controlled trial. Lancet Lond Engl 385, 875–882.

Bor, N., Dujovny, E., Rinat, B., Rozen, N., Rubin, G., 2022. Treatment of chronic osteomyelitis with antibiotic-impregnated polymethyl methacrylate (PMMA) – the Cierny approach: is the second stage necessary? BMC Muscoskel. Disord. 23, 38.

Cahill, D.W., Kumar, R., 1999. Palliative subtotal vertebrectomy with anterior and posterior reconstruction via a single posterior approach. J. Neurosurg. 90 (1 Suppl. l), 42–47.

Cheung, W.Y., Luk, K.D.K., 2011. Pyogenic spondylitis. Int. Orthop. 36, 397–404.

Conan, Y., Laurent, E., Belin, Y., Lacasse, M., Amelot, A., Mulleman, D., et al., 2021. Large increase of vertebral osteomyelitis in France: a 2010–2019 cross-sectional study. Epidemiol. Infect. 149, e227.
Deml, M.C., Cattaneo, E.N., Bigdon, S.F., Sebald, H.-J., Hoppe, S., Heini, P., et al., 2022. PMMA-Cement-PLIF is safe and effective as a single-stage posterior procedure in treating pyogenic erosive lumbar spondylodiscitis—a single-center retrospective study of 73 cases. Bioengineering 9, 73.
Duarte, R.M., Vaccaro, A.R., 2013. Spinal infection: state of the art and management algorithm. Eur. Spine J. 22, 2787–2799.
D'Aliberti, G., Talamonti, G., Villa, F., Debernardi, A., 2012. The anterior stand-alone approach (ASAA) during the acute phase of spondylodiscitis: results in 40 consecutively treated patients. Eur Spine J. Off Publ Eur. Spine Soc. Eur Spinal Deform Soc. Eur Sect Cerv Spine Res. Soc. 21 (Suppl. 1), S75–S82.
Eysel, P., Hopf, C., Vogel, I., Rompe, J.-D., 1997. Primary stable anterior instrumentation or dorsoventral spondylodesis in spondylodiscitis? Eur. Spine J. 6, 152–157.
Li, H.-K., Rombach, I., Zambellas, R., Walker, A.S., McNally, M.A., Atkins, B.L., et al., 2019. Oral versus intravenous antibiotics for bone and joint infection. N. Engl. J. Med. 380, 425–436.
Liljenqvist, U., Lerner, T., Bullmann, V., Hackenberg, L., Halm, H., Winkelmann, W., 2003. Titanium cages in the surgical treatment of severe vertebral osteomyelitis. Eur. Spine J. 12, 606–612.
Martínez-Gutiérrez, O., Peña-Martínez, V., Camacho-Ortiz, A., Vilchez-Cavazos, F., Simental-Mendía, M., Tamez-Mata, Y., et al., 2021. Spondylodiscitis treated with freeze-dried bone allograft alone or combined with autograft: a randomized and blinded trial. J. Orthop. Surg. 29, 23094990211019100.
Munting, E.A.F.E.M., 2001. Vertebral reconstruction with cortical allograft: long-term evaluation. Eur. Spine J. 10, S153–S157.
Rutges, J.P.H.J., Kempen, D.H., van Dijk, M., Oner, F.C., 2016. Outcome of conservative and surgical treatment of pyogenic spondylodiscitis: a systematic literature review. Eur. Spine J. 25, 983–999.
Slavnic, D., Tong, D., Anton, G., Bashiti, R., Carr, D., Hanson, C., et al., 2021. Efficacy and safety with the use of Antibiotic-impregnated Poly-methyl methacrylate (AI-PMMA) for thoracolumbar spinal reconstruction in pyogenic Spondylodiscitis: retrospective cohort study. Interdiscip Neurosurg 26, 101324.
Tong, Y., Liu, J., Fan, S., Zhao, F., 2019. One-stage debridement via oblique lateral interbody fusion corridor combined with posterior pedicle screw fixation in treating spontaneous lumbar infectious spondylodiscitis: a case series. Orthop. Surg. 11, 1109–1119.
Valancius, K., Hansen, E.S., Høy, K., Helmig, P., Niedermann, B., Bünger, C., 2013. Failure modes in conservative and surgical management of infectious spondylodiscitis. Eur. Spine J. 22, 1837–1844.
Witsø, E., Persen, L., Løseth, K., Benum, P., Bergh, K., 2000. Cancellous bone as an antibiotic carrier. Acta Orthop. Scand. 71, 80–84.
Wu, S., Lin, B., Li, X., Chen, S., Zhang, H., Wu, Z., et al., 2021. Single-stage debridement via autogenous iliac bone graft through the OLIF corridor and lateral fixation in treating spontaneous single-level lumbar pyogenic spondylodiscitis. BMC Muscoskel. Disord. 22, 947.
Zhang, S., Wang, S., Wang, Q., Yang, J., Xu, S., 2021. Debridement and corpectomy via single posterior approach to treat pyogenic spondylitis after vertebral augmentation. BMC Muscoskel. Disord. 22, 591.
Zimmerli, W., 2010. Clinical practice. Vertebral osteomyelitis. N. Engl. J. Med. 362, 1022–1029.