Applied nano-hydroxyapatite/polyamide 66 strut in anterior reconstructive surgery for lumbar spinal tuberculosis： a comparison with autogenous iliac bone graft.

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Article

Keywords: Spinal tuberculosis, Nano-hydroxyapatite/polyamide 66, Autogenous iliac bone graft

Posted Date: May 26th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1663546/v1

Abstract

This study aimed to compare the clinical efficacy of nano-hydroxyapatite/polyamide 66 strut （n-HA/PA66 group） with autogenous iliac bone grafts（AIBG group） in anterior reconstructive surgery for lumbar spinal tuberculosis（LSTB）. A total of 67 patients with LSTB who underwent one-stage combined anterior-posterior surgery using an n-HA/PA66 strut or an autogenous iliac bone graft were studied retrospectively at a mean follow-up of 33.8±7.0 months. The Data about erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), Orthopaedic Association (JOA) and Oswestry Disability Index (ODI)score, visual analog scale (VAS) score, American Spinal Injury Association（ASIA ）grade, and Cobb's angle were recorded and compared between the two groups before surgery, three months after surgery and at the last follow-up. At the last follow-up, both groups achieved satisfactory bony fusion without recurrence of tuberculosis, while ESR, CRP, VAS, ASIA grade, and Cobb angle were significantly improved at the last follow-up compared to the preoperative. The n-HA/PA66 group was superior in operation time($P < 0.05$), intraoperative blood loss ($P < 0.05$), VAS at 3 months after surgery ($P < 0.05$), and surgical complications as compared with the AIBG group. But the bone fusion time of the n-HA/PA66 group (8.4±1.3 months) was slightly longer than the TMC group (7.5±1.6 months)($P < 0.05$). The nano-hydroxyapatite/polyamide 66 strut can achieve good clinical efficacy comparable to autologous iliac bone grafts when treating tuberculosis of the lumbar spine. The less traumatic， lower incidence of complications， and similar excellent bony fusion indicated it could serve as a superior material in the anterior reconstructive surgery for lumbar spinal tuberculosis.

Introduction

The coronavirus (COVID-19) pandemic has caused enormous health, social and economic impacts on a global scale. According to the 2021 World Health Organization global tuberculosis report[1]: This is despite a decreasing trend in tuberculosis morbidity and mortality. However, due to the further aggravation of global population aging and the increase of drug-resistant tuberculosis, it is anticipated that tuberculosis will rank second as a cause of death from a single infectious agent, after COVID-19. China is still one of the high tuberculosis burden countries in the world[2].

AS common extrapulmonary tuberculosis, spinal tuberculosis (STB) is the most serious form of skeletal tuberculosis. Due to the insidious onset and poor awareness of the disease, most patients have severe disease with cold abscesses, bone destruction, posterior convexity deformity, and damage to the corresponding spinal nerve function leading to paraplegia[3][4]. Such severe STB requires surgical treatment, and one-stage posterior pedicle screw internal fixation combined with anterior lesion removal and bone graft fusion is a common procedure that can achieve satisfactory results[5]. Intraoperative repair of the vertebral defects left after complete removal of the lesion and reconstruction of spinal stability are the keys to successful surgery. More materials are currently used to reconstruct anterior spinal column support, such as titanium mesh cage, allogeneic bone, autologous iliac bone, and artificial vertebrae. Autologous iliac bone graft is a common clinical reconstruction method[6]. However, the high

incidence of complications at the autologous bone donor site and the use of additional surgical areas require much more attention[7][8].

The porous nano-hydroxyapatite/polyamide 66 (n-HA/PA66) bioactive strut is a novel biomedical bionic material whose composition structure and mechanical properties are similar to those of human cortical bone. it has been widely used in spinal reconstruction surgery due to the favorable biomechanical characteristics of the strut[9][10].

As far as we know, there are no relevant reports focused on the clinical efficacy of the n-HA/PA66 strut itself in reconstructive surgery for STB. The present study aimed to retrospectively analyze and evaluate the efficacy and safety of the n-HA/PA66 strut for lumbar spinal tuberculosis (LSTB)and provide a basis for selecting an appropriate method of spinal reconstruction.

Materials And Methods

Clinical information

Between January 2015 to December 2018, a series of 67 patients (38 males and 29 females) with LSTB underwent the surgery of one-stage posterior pedicle screw internal fixation combined with anterior lesion removal and bone grafting fusion performed by the same spine team were evaluated retrospectively. This retrospective study was approved by the Hangzhou Chest Hospital Affiliated with Zhejiang University Medical College. The methods used in this study were conducted in strict accordance with the Declaration of Helsinki and informed consent was obtained from all patients. The main clinical symptoms of patients include low back pain and typical TB toxicity symptoms, such as weakness low fever, night sweats and anorexia, while some patients showed neurological impairment. All patients had varying degrees of increased sedimentation (ESR) and C-reactive protein (CRP), indicating that the body was in the active phase of STB disease. In addition the imaging, laboratory examination, postoperative pathological examination, and bacterial culture of the patients met the diagnostic criteria for LSTB. Depending on the reconstructive material chosen during the anterior approach a total of 67 patients were divided into two groups: the n-HA/PA66 group n-HA/PA66 nano-hydroxyapatite/polyamide 66 strut:32 patients), and the AIBG group Autologous iliac bone graft:35 patients).

Preoperative examination and treatment

All 67 patients underwent preoperative radiographs X-ray, computed tomography (CT), and magnetic resonance imaging (MRI). The imaging examination suggested that there were different degrees of intervertebral space involvement, bone destruction, cold abscess formation, kyphotic deformity, or dural compression. Thus patients were required to be strictly bedridden to avoid the progression of the disease. A standard quadruple anti-tuberculosis regimen (HRZE) is administered on an individual basis for at least 2 weeks, including oral rifampicin, isoniazid, pyrazinamide, and ethambutol. Patients were provided intensive nutritional support to improve hypoproteinemia and anemia preoperatively. At the same time, the relevant departments will consult and assist in the treatment of patients with serious underlying

diseases. Surgery was performed when the patient's general nutritional status improved, CRP and ESR normalized or showed a significant downward trend, and relieved systemic symptoms.

Inclusion and exclusion criteria

The Indications for surgery in this study included：(1). Paraplegia or developing spinal cord nerve impairment caused by compression of a TB lesion;(2).Severe vertebral destruction with spinal instability; (3).Severe or progressive kyphotic deformity due to paraspinal abscess;（4）. Severe or persistent pain in the back or lumbar， inefficacious conservative treatment.

Inclusion criteria

（1）. Patients aged older than 25 years and less than 75;

（2）. Spinal tuberculosis in L1-L5 segments with surgical indications, and the destroyed segments were no more than 2 vertebral bodies;

（3）. Underwent surgical treatment with combined posterior-anterior approaches and complete follow-up data;

Exclusion criteria

（1）. The focus of tuberculosis lesions beyond the L1-5 segment;

（2）. Prior history of lumbar surgery and/or other spinal diseases that may affect postoperative evaluation, such as ankylosing spondylitis, severe scoliosis, etc;

（3）. Absence of complete follow-up data for any reason;

Surgical procedures

All the patients were treated with one-stage posterior pedicle screw fixation combined with anterior lesion removal and bone grafting fusion. After successful tracheal intubation with general anesthesia, the patient was first placed in the prone position and intraoperative neurophysiological monitoring was performed. C-arm machine fluoroscopy was used to locate the lesioned segment and mark it with a line. A posterior median incision is made with the diseased vertebrae as the center, the skin, subcutaneous tissue, and deep fascia are incised layer by layer, and the paravertebral muscle tissue such as the bilateral erector spinae interval is separated. Expose the superior and inferior responsible vertebral articular processes and laminae from the multifidus interval, mark the pedicle screw entry point with a needle, and implant bilateral pedicle screws in the corresponding responsible vertebrae after fluoroscopic clarification of accurate positioning. Final install appropriate length bilateral titanium rods and transverse joints. The incision was thoroughly cleaned with a flushing gun, the negative pressure drainage tube was placed and the wound was sutured.

After the posterior surgery is completed, the patient was changed to the lateral position for the mini-open anterior approach of focal cleaning(Fig.1). The length of the incision was determined according to the lesion segment and the size of the abscess of the psoas major muscle. Take the line between the tip of the 11th rib and the pubic symphysis and make an oblique incision along the mid-axillary line forward incision blunt separation along with the muscle fiber direction layer by layer was performed, including the external oblique abdominal muscle, internal oblique abdominal muscle, transverse abdominal muscle, posterior peritoneum, and lumbar major muscle, which was to fully reveal the diseased vertebrae and intervertebral disc. The lesion was adequately debrided through a curet and nucleus pulposus forceps. For patients with combined neurological dysfunction or compressive substances in the spinal canal, adequate decompression of the diseased segment is performed. The bone structure at the posterior margin of the diseased segment should be partially preserved, and the bone defect area was carefully trimmed using the piezosurgery device bone knife, and biting forceps to form a bone graft bed until there was petechial hemorrhage on the surface. At last, after measuring the length of the bone defect, hydrogen peroxide, povidone-iodine solution, saline, and isoniazid solution were repeatedly rinsed into the lesion area and the surgical area. Bone grafting and fusion are then performed.

In the n-HA/PA66 group Choose a suitable length of n-HA/PA66 strut according to the size of the bone defect area, and filled the middle of the strut cavity with the bone fragments removed during posterior fixation allogeneic bone can be added if necessary. Then implanted into the bone defect site(Fig.1).

In the AIBG group: An oblique incision of approximately 4 cm was made at the iliac crest site ipsilateral to the anterior incision. Depending on the size of the bone defect site, a suitable length of iliac bone is cut at about 1.5 cm from the anterior superior iliac spine and then implanted in the bone defect site after trimming.

After confirming the good position of the implanted material under fluoroscopy, the incision was thoroughly rinsed, and it was reconfirmed that there was no active bleeding, no foreign body residue, and no rupture of the posterior peritoneum in the incision, then gelatin sponge was wrapped with streptomycin and isoniazid was placed near the lesion, a drainage tube was placed and the wound was sutured layer by layer to complete the operation.

Postoperative management

The postoperative prophylactic broad-spectrum antibiotics to prevent infection and nutritional support therapy were routinely administered. The drainage tube was removed when drainage flow was less than 30 mL per 24 hours. Patients were bedridden for 2-3 weeks after surgery, during which they were encouraged to perform functional exercises of the limbs and muscles of the low back in bed and then they were permitted to start walking with the spinal protective brace after 4-6 weeks. And Patients with neurological impairment should receive neurorehabilitation timely under the guidance of the rehabilitation department. Strengthened quadruple anti-tuberculosis therapy with HRZE was administered for at least 3 months then the HRE chemotherapy was continued for 12 to 15 months. During this period, the blood biochemical parameters, as well as liver and kidney functions are regularly reviewed and evaluated.

Efficacy evaluation

The operative time, intraoperative bleeding, bone fusion time and the occurrence of postoperative complications were recorded in both groups. The Patient pain severity was evaluated using a visual analog scale（VAS, 0: no pain at all; 10: worst pain imaginable）. The Japanese Orthopaedic Association (JOA) and Oswestry Disability Index (ODI) were applied to evaluate lumbar spine dysfunction and quality of life. American Spinal Injury Association（ASIA ） impairment scale was applied to evaluate neurologic injury status. Regular postoperative Lumbar X-ray, CT, and MRI examinations were performed to evaluate the loosening and displacement of the internal fixation, as well as the fusion of the implant, and the Cobb angle of the lesioned segment. The VAS score, JOA, ODI, ASIA grade, and Cobb angle were recorded before surgery, three months after surgery, and at the last follow-up.

Statistical analysis

SPSS26.0 statistical software was used for statistical analysis. The clinical data between the two groups were compared by Student's t-test and χ^2 test. A paired t-test was used to compare the changes in indices between the groups before surgery, three months after surgery, and at the last follow-up. The rank-sum test was used to analyze any differences in the normal data distribution. P values <0.05 were considered statistically significant.

Results

Clinical assessments

The clinical data of patients in two groups are shown in Table 1. There was no significant difference in age, sex, disease duration, lesion location, or follow-up time between the two groups (all $P > 0.05$). The mean blood loss in the n-HA/PA66 group was 616.4 ± 107.3 mL which is lower compared to the AIBG group where the mean blood loss is 674.1 ± 114.2mL. And the surgery time was lower in the n-HA/PA66 group than in the AIBG group ($P < 0.05$).

Table 1

Comparison of general information between the two group

Item	n-HA/PA66 group(N = 32)	AIBG group(N = 35)	P value
Gender m/f	17/15	21/14	P = 0.570
Age (years)	55.6 ± 10.7	52.1 ± 12.8	P = 0.227
Disease duration (months)	8.3 ± 2.9	7.9 ± 2.7	P = 0.534
Operation time(min)	238.3 ± 11.6	263.6 ± 10.3	P < 0.01
Blood loss (ml)	616.4 ± 107.3	674.1 ± 114.2	P = 0.037
Lesion location			
L1-2	9	8	
L2-3	10	9	
L3-4	8	11	
L4-5	5	7	
Bone fusion time(month)	8.4 ± 1.3	7.5 ± 1.6	P = 0.018
Duration of follow-up (months)	34.1 ± 6.6	33.5 ± 7.5	P = 0.753

The mean follow-up times were 34.1 ± 6.6 months and 33.5 ± 7.5 months(P > 0.05). The evaluation of pain and functional impairment is shown in Table 2. The VAS, JOA score, and ODI improved in both groups at 3 months after surgery and the final follow-up compared to the preoperative period(P < 0.05). At the 3 months after surgery, the VAS scores in the AIBG group were significantly higher than n-HA/PA66 group (P < 0.05). But the rest of the differences between the two groups were not statistically significant(P > 0.05).

Table 2

Changes in VAS and JOA and ODI before and after the operation.

	n-HA/PA66 group (N = 32)	AIBG group (N = 35)	P value
VAS			
Pre	7.1 ± 1.3	7.3 ± 1.6	0.650
TMP	2.9 ± 1.2*	3.9 ± 1.3*	0.03
FFU	1.3 ± 1.1*	1.5 ± 1.2*	0.314
JOA			
Pre	11.4 ± 4.6	12.1 ± 4.2	0.507
TMP	18.3 ± 3.8*	16.9 ± 3.6*	0.124
FFU	25.4 ± 3.7*	24.5 ± 4.1*	0.351
ODI			
Pre	41.7 ± 6.2	40.7 ± 7.4	0.575
TMP	22.4 ± 5.6*	21.8 ± 4.9*	0.637
FFU	8.9 ± 4.2*	8.2 ± 3.5*	0.455
*compare with preoperation P < 0.05.			
VAS Visual Analogue Scale, Japanese Orthopaedic Association, ODI Oswestry Disability Index, Pre preoperative, TMP 3 months postoperative, FFU final follow-up.			

Follow-up results

At the final follow-up, no recurrence of tuberculosis, loosening or fracture of the internal fixation device, or displacement of the bone graft material occurred in all patients. Bone fusion was confirmed in 67 patients according to radiographic and/or CT assessment during the follow-up. But the bone fusion time in n-HA/PA66 group was longer than in the AIBG group (P < 0.05)(Table 1). ESR and CRP were achieved to a normal level for all patients and no significant difference in ESR or CRP was found at any time point between the two groups(Table 3). At the last follow-up, the Cobb angle of kyphosis was statistically significant (P < 0.05) in both two groups compared with that before surgery, but there was no significant difference between the two groups（Table 3）. The preoperative and postoperative imaging data of typical cases of the n-HA/PA66 group are shown in Figs. 2, 3, 4, and the AIBG group in Figs. 5, 6, 7.

The neurological function is evaluated by the ASIA impairment scale. At the final follow-up, patients combined with neurological impairment showed varying degrees of improvement compared with that before the operation in both groups(Table 4).

Table 3

Changes of ESR and CRP and Cobb angle before and after the operation.

	n-HA/PA66 group (N = 32)	AIBG group (N = 35)	P value
ESR			
Pre	52.8 ± 16.8	50.2 ± 14.9	0.492
TMP	16.6 ± 5.8*	15.7 ± 5.3*	0.519
FFU	5.7 ± 4.3*	4.9 ± 3.9*	0.406
CRP			
Pre	37.5 ± 16.7	38.1 ± 20.5	0.898
TMP	5.4 ± 3.5*	5.7 ± 2.9*	0.647
FFU	2.6 ± 1.7*	3.1 ± 1.6*	0.242
Cobb angle (°)			
Pre	25.5 ± 8.1	24.7 ± 7.8	0.696
TMP	8.2 ± 4.1*	7.3 ± 4.2*	0.385
FFU	11.6 ± 3.8*	10.7 ± 4.7*	0.393

*compare with preoperation $P < 0.05$.

ESR erythrocyte sedimentation rate, CRP C-reactive protein, Pre preoperative, TMP 3 months postoperative, FFU final follow-up.

Table 4

The condition of nerve functional restoration

Grades	n-HA/PA66 group (N = 32)						AIBG group (N = 35)					
	Pre	FUU					Pre	FUU				
		A	B	C	D	E		A	B	C	D	E
A	0						0					
B	2			1	1		4			2	1	1
C	5				2	3	7			1	3	3
D	10				3	7	12				3	9
E	15					15	12					12

ASIA American Spinal Injury Association, Pre preoperative, FFU final follow-up.

Complications

In the n-HA/PA66 group, abscess of the psoas due to the self withdrawal of anti-tuberculosis drugs in a patient, cured by a conventional chemotherapy regimen combined with CT-guided percutaneous abscess drainage. postoperative incision superficial infection occurred in two patients, which improved with anti-infection treatment and incision dressing change. A patient presented with subcutaneous fluid accumulation in the wound, which was cured by puncture and aspiration.

In the AIBG group, thirteen patients developed chronic pain and discomfort in the iliac bone donor area during the follow-up period, with symptoms lasting from 1 to 6 months; A patient occurred with a fissure fracture in the iliac bone area. and one patient suffered postoperative wound infection. Complications of all patients recovered after symptomatic treatment.

Discussion

The primary goals of surgical treatment for STB are to eliminate the necrotic tissue from the vertebral lesions, release the spinal nerve compression, correct the kyphosis and rebuild the stability of the spine[11].

At present, the main surgical approaches to LSTB include anterior-only, posterior-only, and combined anterior-posterior[12], but the optimal surgical procedure remains controversial. Anterior-only approach can remove lesions and decompress orthopedics more thoroughly[13]. But the stability of anterior internal fixation may not be as strong as posterior, or it is prone to damage important organs and blood vessels due to the complex anatomy and limited exposure to the operative field. Compared to the anterior approach, Posterior surgery allows for adequate decompression directly from the posterior and can

effectively correct severe kyphotic deformities, which seems to be more advantageous[14][15]. However, “thorough debridement” is the key to surgical treatment of STB, the cardinal pathological destruction of STB is in the anterior-middle column of the vertebrae, and" thorough debridement" is difficult to achieve by posterior-only approach[16]. Meanwhile, the Intraoperative disruption to the normal structures of the posterior column leading to medically induced instability of the spine is also a matter of concern[5]. The combined anterior-posterior approaches might compensate for the anterior-only or posterior-only approach defects, which can achieve excellent orthopedic fixation and thorough debridement[17]. But the traditional view is that the combined anterior-posterior approaches require multiple incisions and have the drawbacks of large trauma, high blood loss, high surgical risk, and long operation time.

Our study used the mini-open anterior approach of focal cleaning (Fig. 1)combined with posterior internal fixation, which has the advantages of short operation time and low operational risk[18]. Fully exposing the diseased vertebrae through blunt separation, avoids the direct dissection of the abdominal wall muscle layer in the traditional anterior approach, resulting in less damage to the abdominal wall muscle and surrounding blood vessels[19].

It is well known that “Good anterior reconstruction” is the cornerstone of successful surgical treatment of STB. Autologous bone grafting has been considered the “gold standard” for bone defect repairs[20]. The iliac crest is the most preferred autogenous bone graft harvesting donor site for spinal reconstruction because of its richness in cancellous bone and the characteristics of three-sided cortical bone, which brings adequate support strength, less immune rejection, and optimal fusion rate[12]. However, the use of autologous iliac bone grafting possesses significant disadvantages[8][21][22]: (1) the poor quality of autologous iliac bone in the elderly patients provides limited support strength and tends to cause loss of vertebral height in the long term; (2) the limited amount of bone retrieved cannot accommodate multi-segmental vertebrae and severe bone defects; (3) additional surgical bone retrieval is required, which increases surgical time and trauma as well as the risk of infection. (4) high incidence of related complications, such as persistent postoperative donor area pain, gait disturbance, sacroiliac joint injury, avulsion fracture, deep infection, etc. In the present study, patients in the AIBG group showed a high incidence of complications at the iliac donor site, which should be of concern to the surgeon.

The n-HA/PA66 bioactive strut is a neotype bionic non-metallic implant synthesized from nano-hydroxyapatite and polyamide66 with nano-scale particle diameter by thermal pressing and injection molding technique[23]. Nano-hydroxyapatite (n-HA) is the main inorganic component of bones and teeth and plays a scaffolding role for calcium salt deposition during bone metabolism while inducing new bone formation[24][25]. PA66 is an organic polymer material with a chemical structure similar to that of bone collagen, easy to process, and highly malleable, it has been widely used in biological materials such as surgical sutures[10]. Studies have shown that n-HA is attached to PA66 through hydrogen bonds by the formation of a carboxyl-calcium-carboxyl linkage ([-COO]-Ca2+-[-COO]), which strong interaction between these chemical bonds provides the composite of both the mechanical strength of hydroxyapatite and the elastic properties of polyamide 66[26]. At the same time, nanoparticles and high interpenetrating porosity

make n-HA/PA66 composite with good bioactivity and high specific surface area. The three-dimensional pore structure not only facilitates the transport of oxygen and nutrients, but also the colonization of fibrovascular and nerves, which can provide good conditions for the adhesion, differentiation, and proliferation of osteoblasts for early osteoinduction[27][28]. Furthermore, the n-HA/PA66 strut has been found to have the features of good biosafety and osteoconductivity in vitro and in vivo studies[29][30][31], which is widely used in clinical work for bone repair.

The n-HA/PA66 strut has excellent mechanical strength. Liang et al.[28]showed that the compressive strength of the n-HA/PA66 composite was 95 MPa and its elastic modulus was close to the human cortical bone to the mechanical results. The "point-to-surface contact" between the titanium mesh cage and the endplate results in a very high-pressure intensity on the contact surface, making it easy for a stress-shielding effect to occur[32][33]. In contrast, the n-HA/PA66 strut ends have a wider surface to form "face-to-face contact" with the endplate, which can effectively distribute the load on the contact surface, avoiding cutting effects[21]. In addition, The grooves at both ends of the n-HA/PA66 strut are designed to increase the friction between the cage and the endplates can effectively avoid the sinking and displacement of the strut. Zhang et al. [34]found that in 117 patients with multisegmental cervical spondylosis who underwent anterior cervical laminectomy and fusion, the use of an n-HA/PA66 strut had similar excellent bony fusion rates to TMC, with a lower incidence of subsidence and better maintenance of the height of the fused segment. Hu et al.[35]reported the n-HA/PA66 strut has the advantage of high fusion rate and low subsidence rates compared to the PEEK cage during long-term follow-up. A long-term retrospective study of the utilization of n-HA/PA66 strut for cervical reconstruction after corpectomy similarly reported satisfactory clinical outcomes, high bony fusion rates, and acceptable subsidence rates are achieved[36]. In our study, all 32 patients achieved satisfactory bone fusion with no displacement or loosening at the final follow-up, although the fusion time was longer in the group using nano-hydroxyapatite 66 strut than in the iliac crest autograft group.

From our experience, We summarized the Indications for the application of n-HA/PA66 bioactive strut in spinal reconstruction as follows: (1) poor bone quality by severe osteoporosis or other causes; (2)Patient resistance or various reasons that cause difficulties in autologous iliac bone grafting; (3)severe vertebral destruction with extensive bone defects that cannot be satisfied by autologous bone grafting; (4) Poor tolerance of pain on preoperative assessment.

Limitations Of The Study

There are several limitations, Firstly, this study was based on a single-center retrospective study; Secondly, our study has a short follow-up period and the sample size was relatively small Therefore, we believe that multicenter, large-sample, prospective studies would be performed in the future to improve the level of evidence-based medicine.

Conclusion

Our study revealed that compared to iliac bone graft,nano-hydroxyapatite 66 strut can not only achieve a satisfactory fusion effect, safely and effectively rebuild spinal stability but also effectively reduce the occurrence of trauma and related complications. It indicates that the nano-hydroxyapatite 66 strut is a safe and reliable alternative to iliac bone grafts in the anterior reconstruction of lumbar tuberculosis.

Declarations

Acknowledgments

This work was supported by the Hangzhou Agricultural and Social Development Research Active Design Project (No. 20180417A04). Fundings include the cost of research and publication fees.

Author contributions

Y.J.K .and Z.P.conceived the original ideas and drafted this manuscript. H.S.P. and F.J .participated in surgical and drug treatment. Y.J.K. and Z.C.W. collected clinical data and follow-up details related to this study. F.J .and Z.P.performs the analysis of the results and helps to complete the processing of the data All authors have read and approved the manuscript.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare no competing interests.

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Figures

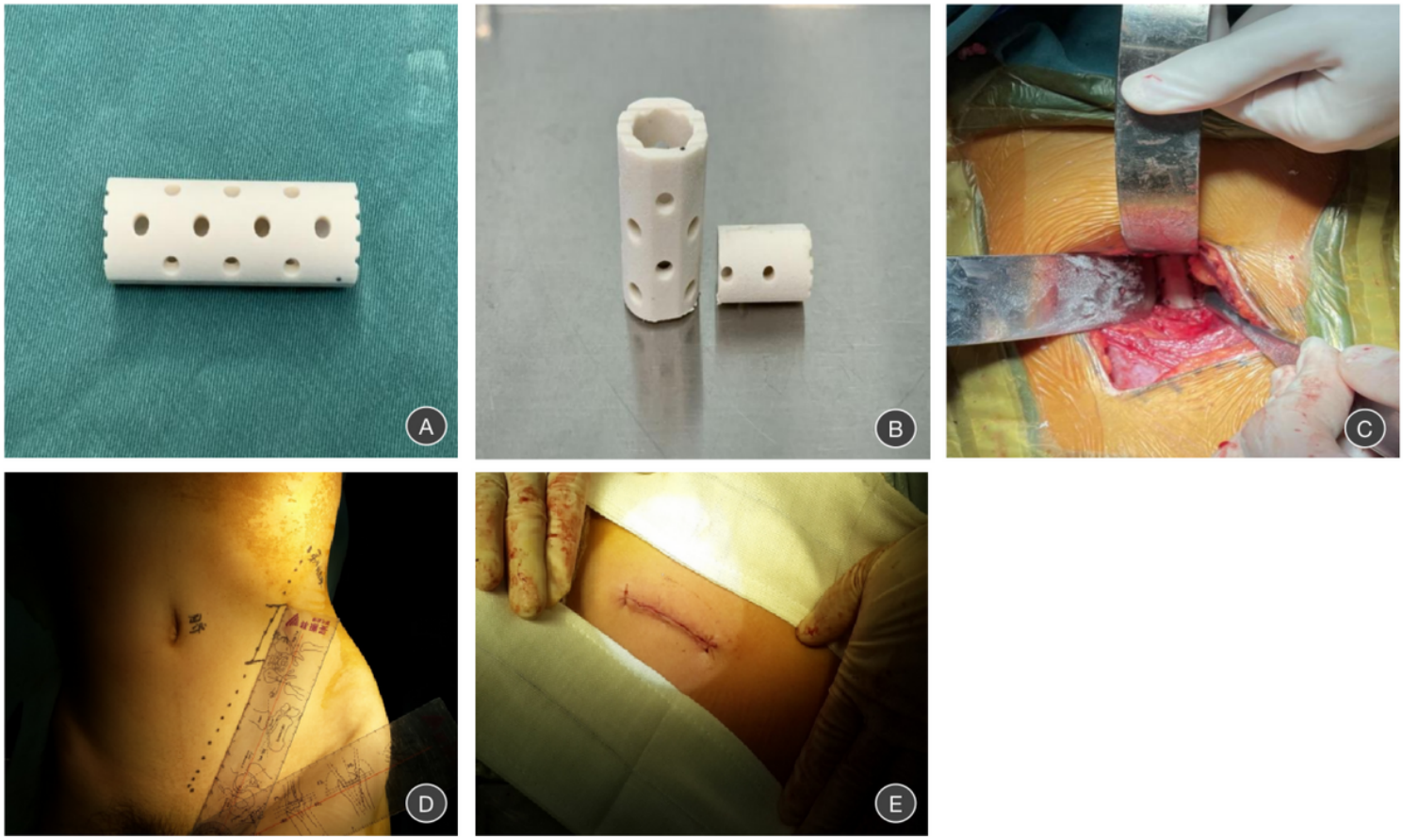

Figure 1

(A、B：Views of the nano-hydroxyapatite/polyamide66 strut. ：C：Intraoperative implantation of nano hydroxyapatite/polyamide 66 strut. ：D、E：Mini-open anterior approach of focal cleaning.

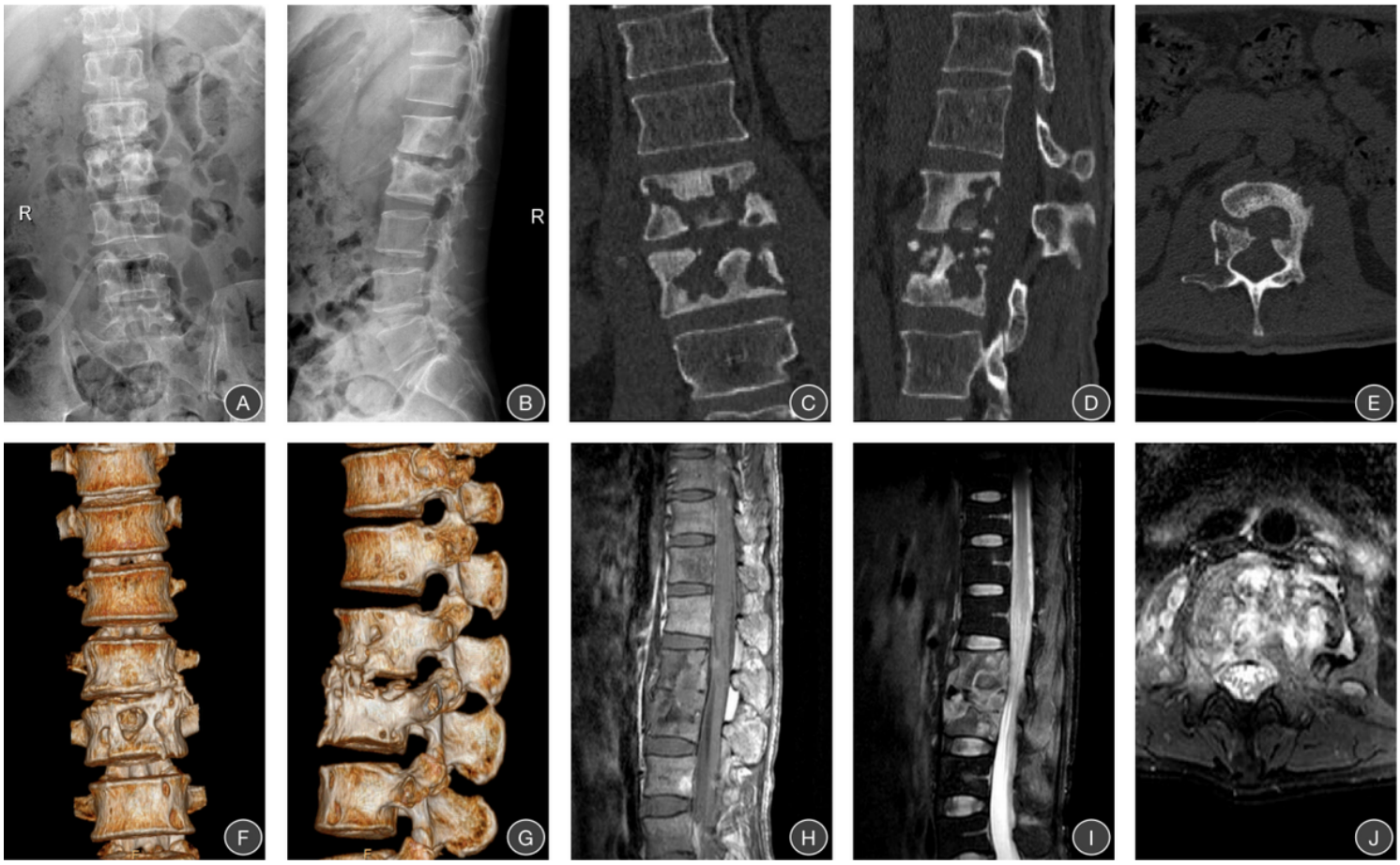

Figure 2

Typical cases of the n-HA/PA66 group. A 41-year-old man was diagnosed with L1-2 tuberculosis after a 1-year history of chronic low back pain secondary to paraplegia. (A-G) Preoperative X-ray and CT reconstruction showed marked destruction of L1 and L2 vertebrae and narrowing of the L1 -L2 intervertebral space. (H-J) Preoperative MRI showed abscess formation around the L1-L2 vertebrae and involved in the spinal canal with cord compromise resulted in neurologic deficits.

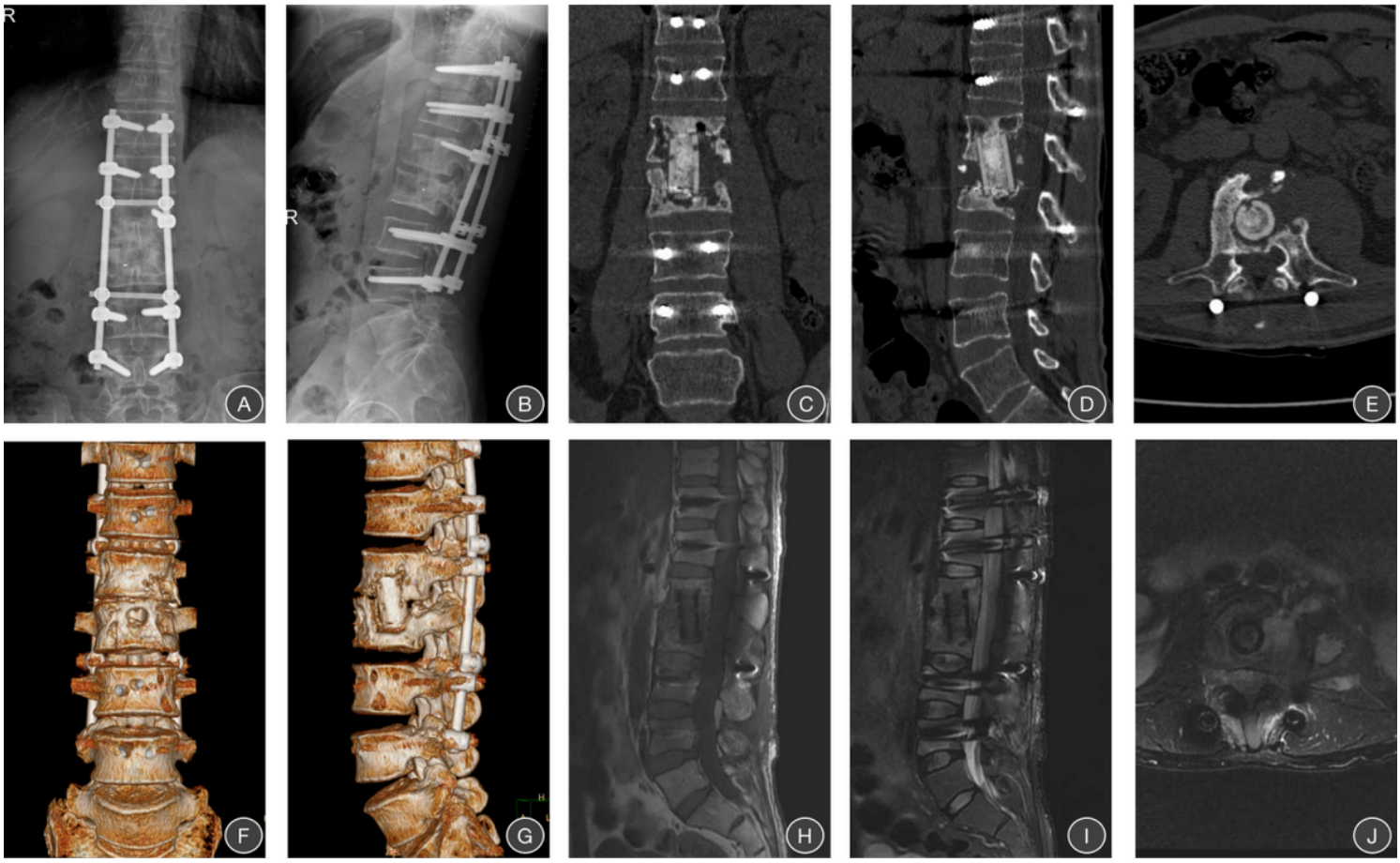

Figure 3

n-HA/PA66 group, three months after surgery (A-G) The X-ray and CT reconstruction showed that the interbody grafts using nano-hydroxyapatite/polyamide66 strut and the internal fixation instrument were in a good position. (H-J) Three months postoperative MRI showed that the L1 and L2 vertebrae lesions has debrided completely.

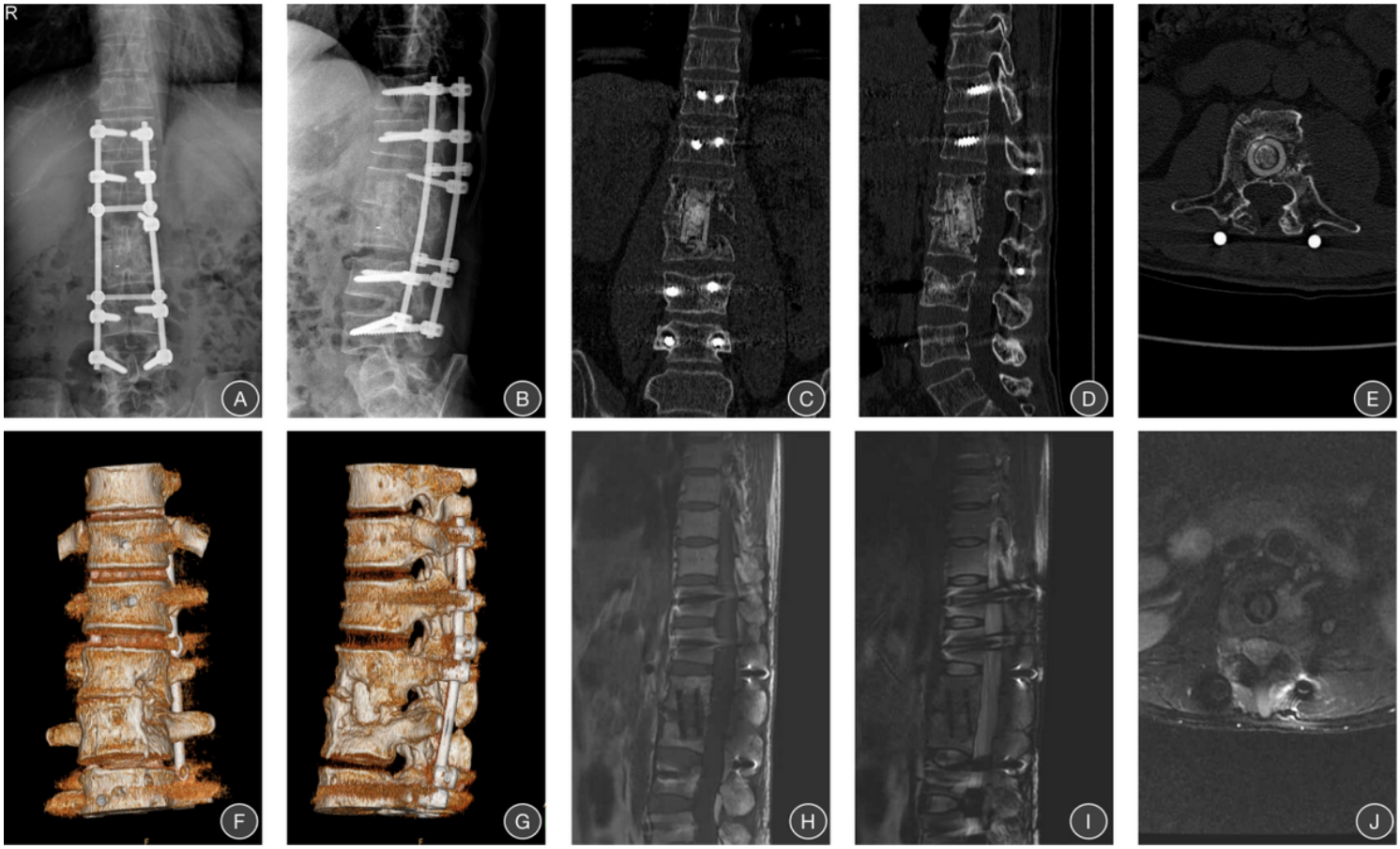

Figure 4

n-HA/PA66 group,A-JFinal follow-up (24 months) X-ray and CT reconstruction showed satisfactory bone fusion and no obvious displacement or subsidence of the nano-hydroxyapatite/polyamide66 strut; MRI showed the L1-L2 tuberculosis lesions have healed.

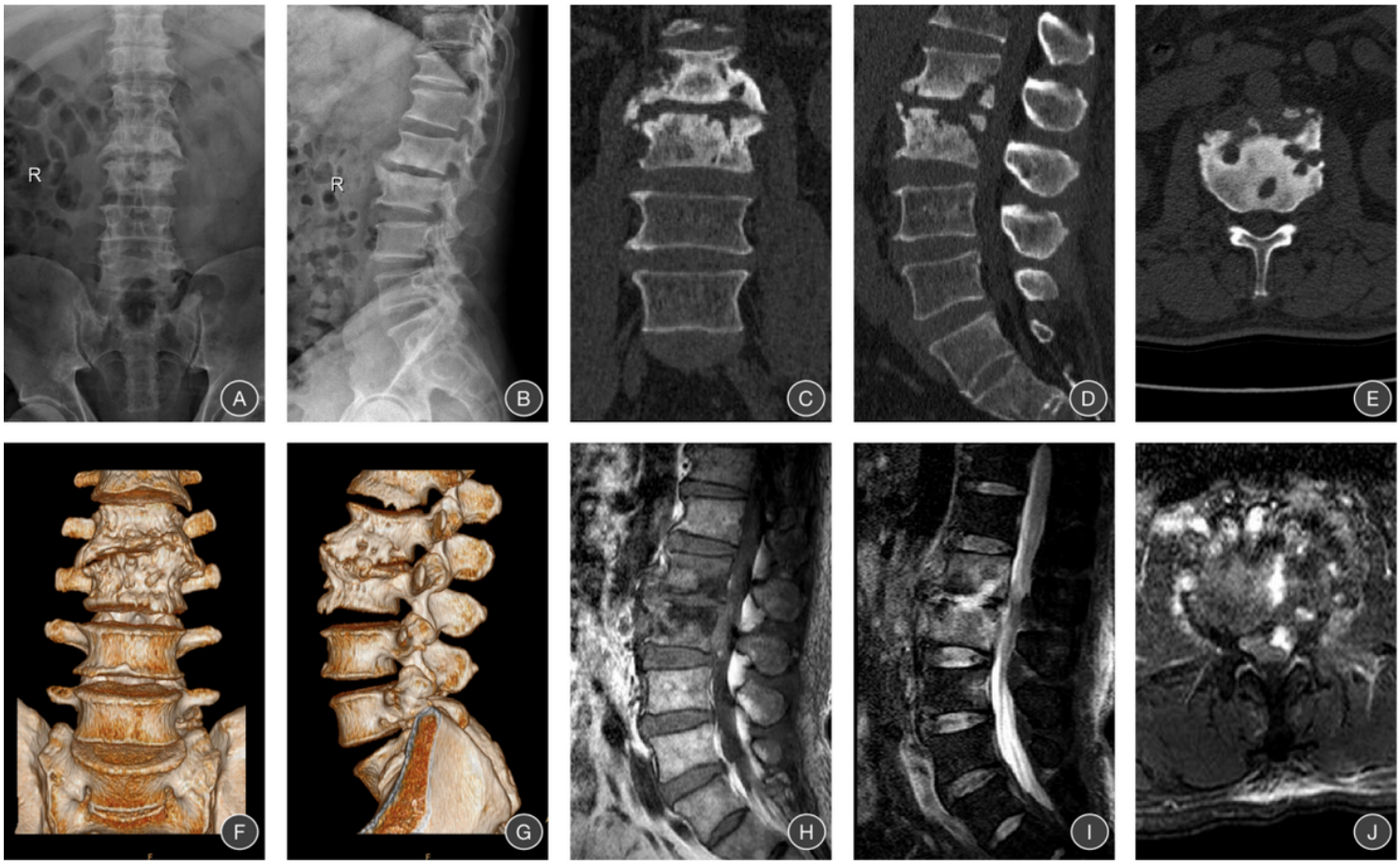

Figure 5

Typical cases of the AIBG group. A 58-year-old man was diagnosed with L2-L3 tuberculosis after a 6-month history of low back pain with bilateral lower extremity radiating pain. (A-G) Preoperative X-ray and CT reconstruction showed significant destruction of L2 and L3 vertebral bodies and corresponding narrowing of vertebral spaces. (H-J) MRI showed abscess formation around L2-L3 vertebrae with posterior spinal stenosis.

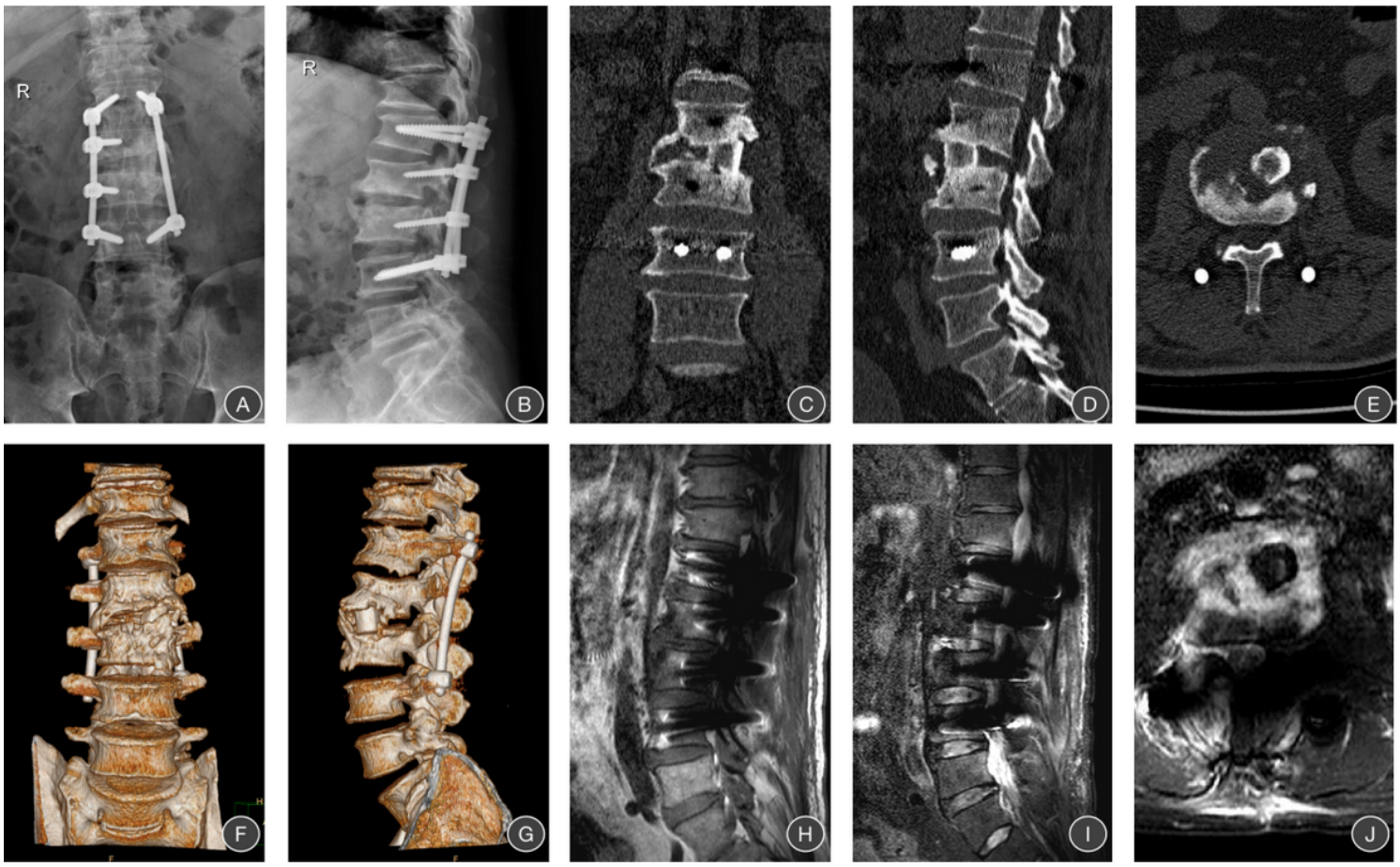

Figure 6

AIBG group ,three months after surgery (A-G) The X-ray and CT reconstruction showed a good position of internal fixation and the iliac bone graft is firm. (H-J) Three months of postoperative MRI showed the significant absorption of abscesses in L2-L3 vertebrae lesions and no obvious spinal canal stenosis.

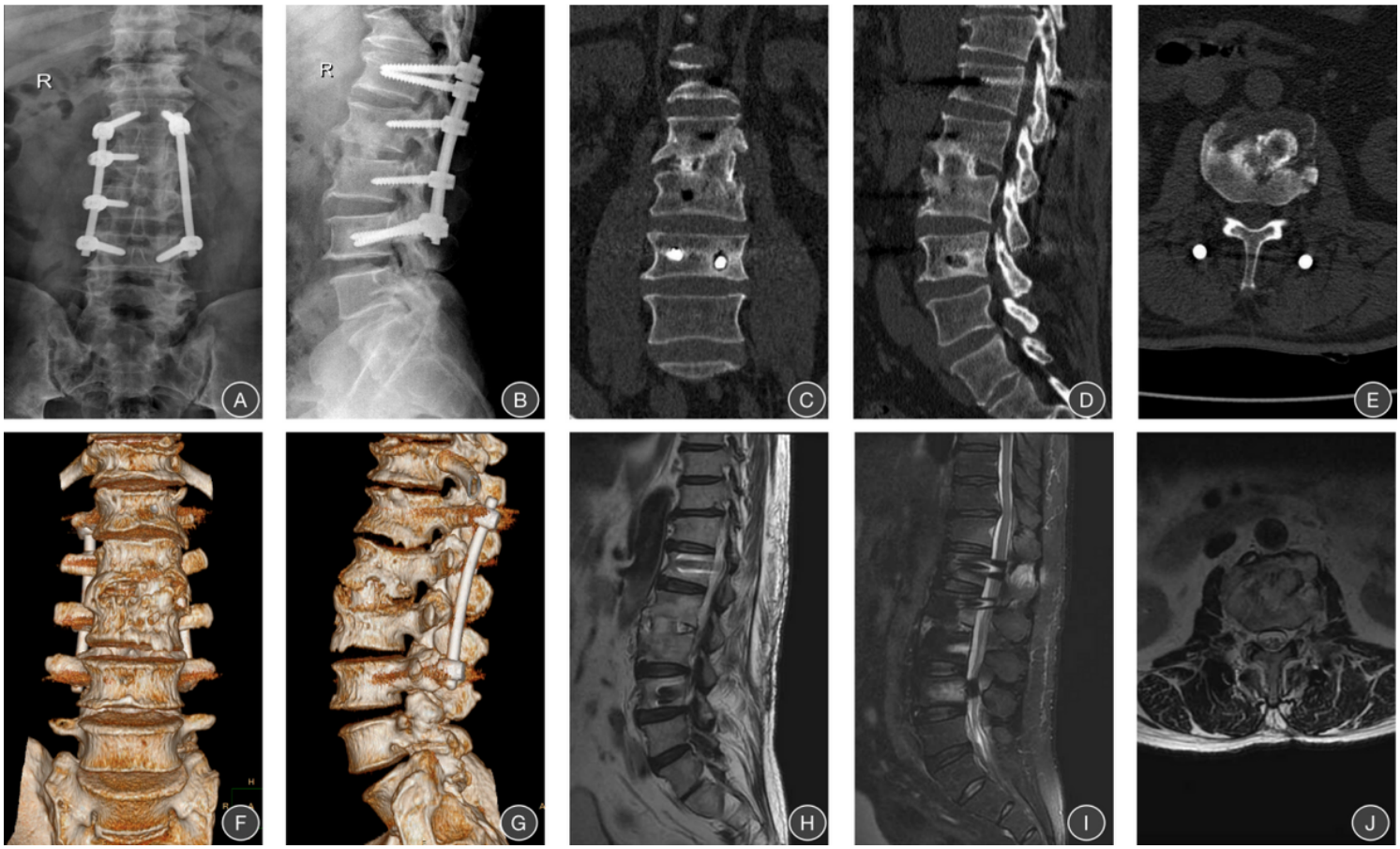

Figure 7

AIBG group,A-JFinal follow-up (24 months) X-ray and CT reconstruction showed good bone fusion and no obvious bone absorption or fractures; MRI showed the L2-L3 tuberculosis lesions are cured.