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Augmentation of transpedicular screws by intraoperative vertebroplasty

Wzmacnianie śrub przeznasadowych metodą śródoperacyjnej wertebroplastyki

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Abstract

Background and purpose: The aim of the study was to determine the efficacy of posterior spinal stabilization, combined with intraoperative vertebroplasty defined as intraoperative filling of instrumented vertebral bodies (VB) with polymethylmethacrylate (PMMA).
Material and methods: Seventeen patients with osteoporosis or osteopenia underwent posterior spinal fusions. The surgical procedures included laminectomy, spondylodesis, insertion of pedicular screws, intraoperative vertebroplasty and correction of spinal deformity.
Results: Postoperative assessment showed improvement of pain in all cases. Motor deficit regressed in 2 of 3 afflicted patients. In 12 vertebrae (27.3%), the mass of PMMA extended from one endplate to another, filling 100% of VB height, in 7 (15.9%) it filled 90-99%, in 14 (31.8%) 80-89%, in 9 (20.4%) 70-79%, and in 2 (4.5%) it filled 50-60% of VB height. In the horizontal plane, PMMA filled central parts of 72.7% of vertebral bodies. PMMA completely surrounded 68.9% of screws, and partially surrounded 18.4% of screws, whereas 12.6% of screws had no contact with cement mass. Spinal stabilization reduced kyphotic deformity in 15 patients (range of reduction: 6°-25°; mean: 13.6°). During follow-up (3-32 months; mean: 16) implants of 11 patients were stable, 1 implant instability was diagnosed 7 months after surgery, 5 patients were lost to follow-up. Asymptomatic cement leaks occurred in 45% of vertebrae.
Conclusions: Intraoperative vertebroplasty performed after insertion of pedicular screws may be considered as a technical variation useful to stabilize osteoporotic spines. After

Streszczenie

Wstęp i cel pracy: Celem pracy była ocena przeznasadowej stabilizacji kręgosłupa, wzmocnionej śródoperacyjną wertebroplastyką, czyli śródoperacyjnym podaniem polimetakrylanu metylu (PMMA) do trzonów, w które wkręcono śruby przeznasadowe.
Materiał i metody: U 17 pacjentów z osteoporozą lub osteopenią wykonano stabilizacje kręgosłupa z dostępu tylnego. Operacje obejmowały: laminektomię, spondylodezę, wkręcenie śrub przeznasadowych, śródoperacyjną wertebroplastykę oraz korekcję deformacji kręgosłupa.
Wyniki: Ocena kliniczna wykazała zmniejszenie bólu u 17 pacjentów i zmniejszenie niedowładu u 2 z 3 pacjentów. W 12 trzonach (27,3%) masa cementu rozciągała się pomiędzy blaszkami granicznymi, wypełniając 100% wysokości trzonu, w 7 (15,9%) wypełniała 90–99% wysokości trzonu, w 14 (31,8%) – 80–89%, w 9 (20,4%) – 70–79%, a w 2 trzonach (4,5%) – 50–69% wysokości trzonu. Cement usytuowany był w centralnych częściach 72,7% trzonów. Cement całkowicie otaczał obwód 68,9% śrub, częściowo otaczał 18,4% śrub, a 12,6% śrub nie miało kontaktu z cementem. Stabilizacja kręgosłupa zmniejszyła kifotyczną deformację u 15 pacjentów (zakres korekcji: 6°–25°, średnia: 13,6°). Wycieki cementu, klinicznie bezobjawowe, dotyczyły 45% trzonów u 76% pacjentów. W okresie obserwacji wynoszącym od 3 do 32 miesięcy (średnia: 16 miesięcy) u 11 pacjentów nie stwierdzono destabilizacji implantu, u jednej osoby destabilizacja ujawniła się po 7 miesiącach od operacji.
Wnioski: Śródoperacyjna wertebroplastyka może być stosowana do wzmocnienia śrub przeznasadowych, wkręconych

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PMMA hardening, intraoperative manoeuvres to correct spinal deformity were possible without any damage of instrumented vertebrae.

Key words: osteoporosis, pedicle screw, PMMA, spinal stabilization, vertebral fracture.

w trzony o obniżonej gęstości kości. Po stwardnieniu cementu możliwa jest korekcja kształtu kręgosłupa bez uszkodzenia osłabionych kręgów.

Słowa kluczowe: osteoporoza, PMMA, stabilizacja kręgosłupa, śruba przeznasadowa, złamanie kręgu.

Introduction

Osteoporosis is the most common cause of vertebral fractures in elderly patients. In 1995, Riggs and Melton estimated that osteoporosis causes about 700 000 vertebral fractures yearly [1]. These are predominantly compressive fractures of the vertebral body (VB), currently treated by minimally invasive methods, e.g. vertebroplasty or kyphoplasty [2-6]. Some fractures, however, cause severe consequences: spinal deformity, instability, spinal canal compromise and neurological deficit [3-5,7-11]. In such cases, open surgery is indicated, comprising decompression of the spinal canal and spinal stabilization [3,4,6,8-13]. Low bone mineral density caused by osteoporosis may lead to loosening of screws, hooks, wires or cables attaching the stabilizing device to the spine [3,4,6,8,11,13-18]. The same difficulties accompany spinal stabilization in cases of tumours or other metabolic diseases resulting in weakness of vertebrae [3,8,11,13,17,19]. Reinforcement of the spongious bone around screws with bone cement is used to prevent implant loosening [3,4,7,8,10-15,18,19]. Two methods of such reinforcement have been described, i.e. insertion of screws into vertebral bodies immediately after filling them with cement [4,7,8,10,12,13,15,18,19], and injection of cement through cannulated screws [3,12,17].

We developed a new and original method in order to reinforce screws in osteoporotic vertebral bodies. After typical insertion of pedicle screws, intraoperative vertebroplasty was performed. Polymethylmethacrylate (PMMA) was injected via bony biopsy needles inserted in the proximity of pedicles pierced with screws. This method allowed filling with PMMA not only the spongious bone in close proximity to the screws, but also the more distant and larger zone between endplates. These results have not been published yet. The objective of this study is to present the authors' own method and to evaluate clinical results.

Material and methods

This study included 17 patients (15 females, 2 males), treated between 2006 and 2011 – details are listed in Table 1. The age of participants ranged from 52 to 85 years (mean: 69). Eleven operations were performed for low-energy osteoporotic spinal fractures, diagnosed with preoperative computed tomography (CT) or magnetic resonance imaging (MRI). Fractures were classified according to Magerl *et al*. [20] as follows: 3 incomplete burst type A3.1.1; 9 vertebral collapse type A1.3; 2 superior wedge compressive type A1.2.1; and 1 inferior wedge compressive type A1.2.3. Four patients suffered from degenerative spondylolisthesis, one from lung carcinoma metastasis resulting in type A1.2.1 fracture and one from spondylodiscitis. All patients suffered from intractable back pain corresponding with affected spinal segments; three of them complained of radicular pain and three others had neurological deficits.

Indications for use of PMMA during surgery were based on preoperative bone mineral density (BMD) measurement, confirming osteoporosis in 10 patients (mean T-score: –3.40) and osteopenia in 4 others (mean T-score: –1.81). In the remaining 3 cases, the decision to augment was made intraoperatively when weak vertebral bone was detected with the pedicle probe (Table 1). The follow-up period of 13 patients ranged from 1 to 32 months (mean: 14.9 months); four patients could not be seen for the follow-up examination for different reasons. Clinical assessment included preoperative examination and follow-up examinations. In 13 cases, the visual analogue pain score (VAS) and Oswestry Questionnaire score were obtained preoperatively and at the last follow-up. Radiological evaluation was based on preoperative images (plain radiographs, CT or MRI) as well as images obtained from follows-up. The images were assessed for type of lesion, distribution of PMMA in vertebral bodies, relation between PMMA and screws, correction of spinal deformity, leak of PMMA and implant stability.

All patients were operated on under general anaesthesia, placed in a prone position, with a C-arm installed. The spine was exposed by posterior midline incision. The first step comprised neural decompression and widening of the compromised spinal canal. Discectomies were followed by interbody bony grafting with bony chips from laminectomy or by PLIF (posterior lumbar

Table 1. Clinical data for patients undergoing intraoperative vertebroplasty

Patient no.	Sex/Age [years]	Pathology*	Preoperative symptoms	Preoperative symptoms and correction of kyphosis	Follow-up
1	F/85	L1 fracture (A3.1.1) T-score: –5.40	Back pain Left quadriceps paresis: 3/5 VAS: 7, OSW: 88%	VAS: 1, OSW: 64% No paresis Correction Th12-L1: 0	32 months
2	F/68	L3 fracture (A3.1.1) T-score: –1.55	Back pain VAS: 7, OSW: 68%	VAS: 0, OSW: 22% Correction L2-L4: 18°	28 months
3	F/67	T12 fracture (A1.3) T-score: –0.94 Weak bone (intraoperative finding)	Back pain VAS: 10, OSW: 56%	VAS: 0, OSW: 12% Correction T11-L1: 10°	25 months
4	F/53	T11 fracture (A1.3) T12 fracture (A1.3) T-score: –4.34	Back pain VAS: 8, OSW: 48%	VAS: 2, OSW: 32% Postoperative pneumothorax Correction T8-L1: 8°	1 month
5	F/70	T12 fracture (A1.3) T-score: –3.96	Back pain Paraparesis 4/5 VAS: 10, OSW: 30%	VAS: 0, OSW: 18% No paresis Correction T11-L1: 22°	12 months
6	F/52	L1 fracture (A1.3) T11 fracture (A1.2.1) T12 fracture (A1.2.1) Weak bone (intraoperative finding)	Back pain Paraparesis 4/5 VAS: 9, OSW: 76%	VAS: 7, OSW: 66% Paraparesis 4/5 persisted Correction T10-L3: 16°	19 months
7	F/72	T12 fracture (A1.3) T-score: –3.2	Back pain	Back pain improved Correction T11-L1: 12°	1 week
8	M/79	T9/T10 spondylodiscitis T-score: –2.67	Back pain VAS: 8, OSW: 86%	VAS: 0, OSW: 14% Correction T8-T11: 13° Infection, 2 screws removed	7 months
9	F/83	L3-L4, L4-L5 degenerative spondylolisthesis L3-L5 kyphosis T-score: –2.78	Back pain VAS: 8, OSW: 66%	VAS: 0, OSW: 4% Correction L3-L5: 15° Complete correction of degenerative spondylolisthesis	15 months
10	F/71	L2 fracture (A1.3) T-score: –2.30	Back pain VAS: 10, OSW: 64%	VAS: 0, OSW: 14% Correction L1-L3: 10°	14 months
11	F/82	L2-L3, L3-L4 degenerative spondylolisthesis L2-L4 kyphosis T-score: –2.85	Back pain Left sciatic pain	Back pain improved Sciatic pain improved Correction L2-L4: 6° Complete correction of degenerative spondylolisthesis	3 weeks
12	F/68	L1 fracture (A1.3) T12 fracture (A1.2.3) T-score: –2.03	Back pain	No pain Correction T10-L2: 16°	1 week

Table 1. Cont.

Patient no.	Sex/Age [years]	Pathology*	Preoperative symptoms	Preoperative symptoms and correction of kyphosis	Follow-up
13	F/55	L1-L2 degenerative spondylolisthesis L1-L2 kyphosis T-score: –1.39	Back pain Left sciatic pain VAS: 4, OSW: 24%	VAS: 0, OSW: 4% Correction L1-L3: 11° Complete correction of degenerative spondylolisthesis	3 months
14	F/60	T12 fracture (A3.1.1) T-score: –3.11	Back pain VAS: 6, OSW: 82%	VAS: 0, OSW: 8% Correction Th10-L2: 14°	5 months
15	F/70	L2 fracture (A1.3) Weak bone (intraoperative finding)	Back pain	No pain Correction L1-L3: 25°	1 week
16	F/54	L3 fracture (A1.2.1) Lung carcinoma metastasis T-score: –2.60	Back pain Left thigh pain VAS: 9, OSW: 90%	VAS: 1, OSW: 13% No thigh pain Correction L2-L4: 8°	20 months
17	M/77	L4/L5 degenerative spondylolisthesis T-score: –3.13	Back pain VAS: 5, OSW: 33%	VAS: 0, OSW: 0% Complete correction of degenerative spondylolisthesis	13 months

**Fractures classified according to Magerl et al. [20]*
F – female, M – male, OSW – Oswestry Questionnaire score, VAS – visual analogue scale

interbody fusion) with titanium cages. In case of spondylodiscitis, debridement was followed by implantation of titanium mesh filled with autologous bony chips. In case of metastasis, the tumour was removed from the spinal canal and curetted from the afflicted VB. In all chosen pedicles, pilot holes for screws were made and screws were inserted consecutively. Only one vertebra was instrumented with one screw because the contralateral pedicle had broken. We used the following stabilizing systems: Diapason (Stryker) in 3 cases and S4 (Aesculap) in 14 cases. In the next step, bone biopsy needles were unilaterally inserted in vertebrae using an extrapedicular approach. Points of insertion were situated between the superior vertebral endplate and pedicle, in the line joining lateral margins of pedicles (Fig. 1). Needles were inclined caudally and medially and inserted to reach the anterior third of the VB between tips of screws (Figs. 2 and 3). Then, PMMA was injected consecutively through needles, which were removed afterwards. The goal of the injection was to fill the spongious bone in the proximity of screws and the maximum space between vertebral endplates with PMMA. The amount of PMMA injected per vertebra varied from 2 to 5 mL. After the PMMA had hardened, heads of screws were connected with longitudinal rods contoured to correct spinal deformity. Manoeuvres of screw compression or distraction were performed and finally the construct was locked by means of tightening the blockers. We used cement delivery systems of the following manufacturers: PCD (Stryker), Vertecem (Synthes) and Confidence (DePuy Spine, Johnson-Johnson). Augmentation required an additional 15 to 30 minutes per patient. In 17 patients we performed intraoperative vertebroplasty of 44 vertebrae with 87 pedicular screws.

Results

Clinical outcome

Clinical results are summarized in Table 1. To assess back pain in 13 patients, the VAS pain score and Oswestry Questionnaire were analysed preoperatively and at the last follow-up 1-32 months after surgery (mean: 14.9 months). This assessment revealed a decrease of mean VAS pain score from 7.76 (range: 4-10) to 0.84 (range: 0-7) and a decrease of mean Oswestry disability score from 62.38% (range: 24-90%) to 20.84% (range: 0-66%). The remaining 4 patients were

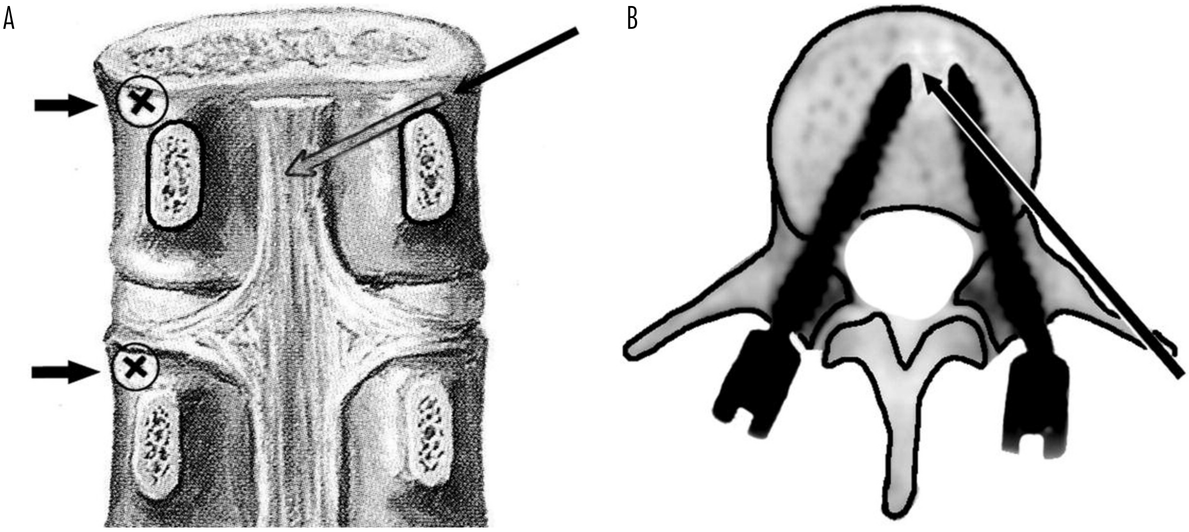

Fig. 1. A) Entry points of the needles (→ X) and needle trajectory (long arrows). B) Horizontal section of instrumented vertebra with needle trajectory (black arrow)

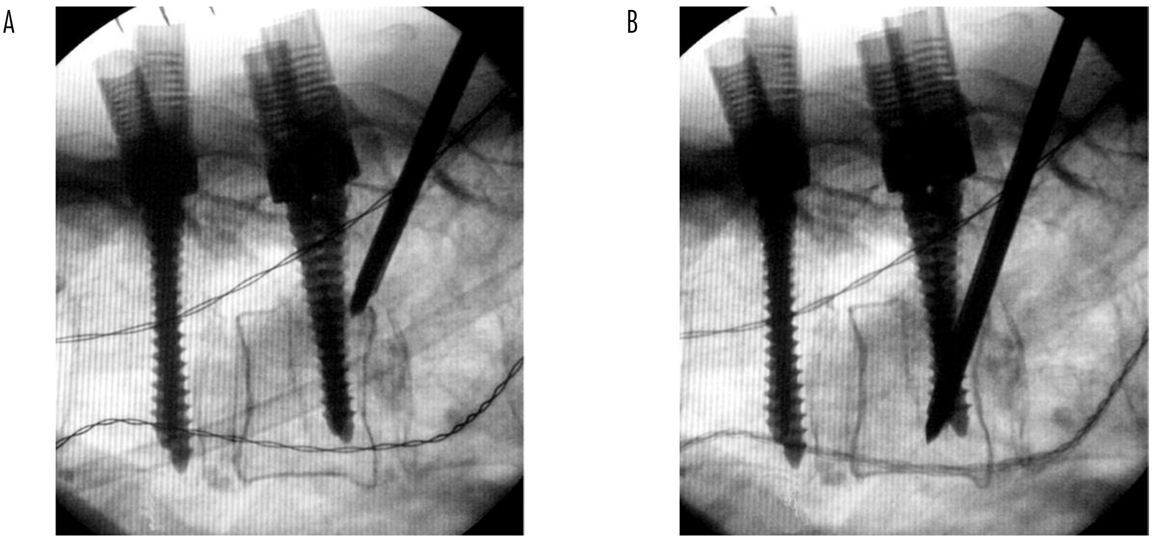

Fig. 2. Intraoperative lateral fluoroscopic view of needle insertion. A) The tip of the needle is touching the entry point. B) The needle is positioned in anterior third of vertebral body between screws

seen on discharge only; two of them had no pain and two reported significant improvement of back pain. Radicular pain disappeared completely in two patients and improved in one other. Motor deficits were graded preoperatively and at the last follow-up. Muscle strength was graded on a 0 to 5 scale, where 0 meant 'no contraction' and 5 meant 'full motor strength against resistance' [2]. Deficits observed in cases 1 and 5 regressed completely, whereas paraparesis in case 6 persisted.

There were 3 complications in the presented series. The most important one occurred 7 months after surgery (case 8 – spondylodiscitis). Exudation of pus in the proximity of the upper right screw was seen and infection with *Escherichia coli* was diagnosed. Revision surgery revealed mobility of 2 right screws of the construct. These screws were removed, whereas the left part of the construct as well as interbody mesh were considered stable and were left in place. In case 4, right pneumothorax was diagnosed on the seventh postoperative day and was successfully treated with drainage. In case 9, fracture of the L3 left pedicle occurred during instrumentation and this vertebra was instrumented by one screw.

Radiological assessment

The craniocaudal extent of cement (PMMA height) and the distance between endplates above and below the PMMA mass (VB height) were measured on sagittal CT reconstructions or lateral plain radiographs (Fig. 4A). Based on these measurements, the percentage of VB height filled with cement was calculated. The following formula was used to calculate this value: *percentage of VB height filled = PMMA height × 100%/VB height.* In 12 (27.3%) vertebrae, PMMA extended from one endplate to another, filling 100% of VB height, and in 7 (15.9%) it filled 90-99%. Details are listed in Table 2.

Location of cement mass in relation to the midline was estimated on anteroposterior plain radiographs or CT images (Fig. 4B). Central location of PMMA, defined as presence of predominant cement mass in the central third of the VB, was found in 32 (72.7%) vertebrae. Lateral location (predominant cement mass in the lateral part of the VB) was present in 12 (27.3%) vertebrae (Table 2).

We distinguished 3 types of cement location in relation to screws (Fig. 5): (a) PMMA completely surrounding the circumference of the screw's thread (60 screws – 68.9%), (b) PMMA partially surrounding the thread (13 screws – 18.4%), (c) no contact between PMMA and screw (11 screws – 12.6%). A very good result of screw augmentation was achieved in 22 (50%) vertebrae with both screws completely surrounded by PMMA. In 21 vertebrae, at least 1 screw was completely or partially surrounded by PMMA. In 1 vertebra, there was no contact between PMMA and any screw.

Fig. 3. Intraoperative view of needles and screws

Segmental kyphosis (angle between superior endplate of the highest instrumented vertebra and the inferior endplate of the lowest instrumented vertebra) was measured on plain radiographs or CT reformatted images obtained preoperatively and after surgery. Instrumentation allowed reduction of preoperative kyphotic deformity of the stabilized segment in 15 patients (Fig. 6). The reduction ranged between 6° and 25° (mean, 13.6°). In 1 patient (case 1, fracture of L1), the preoperative angle of the T12-L2 segment was equal to 0 and after surgery remained unchanged (Table 1). In 4 patients with degenerative spondylolisthesis, vertebral displacements were completely reduced.

Stability of the construct was assessed in 12 patients based on CT scans or plain radiographs obtained at the last follow-up (range: 3-32 months; mean: 16). In 11 patients, neither signs of screw loosening nor motion of stabilized segments were noted. In 1 patient (aforementioned case 8), mobility of right-sided screws was

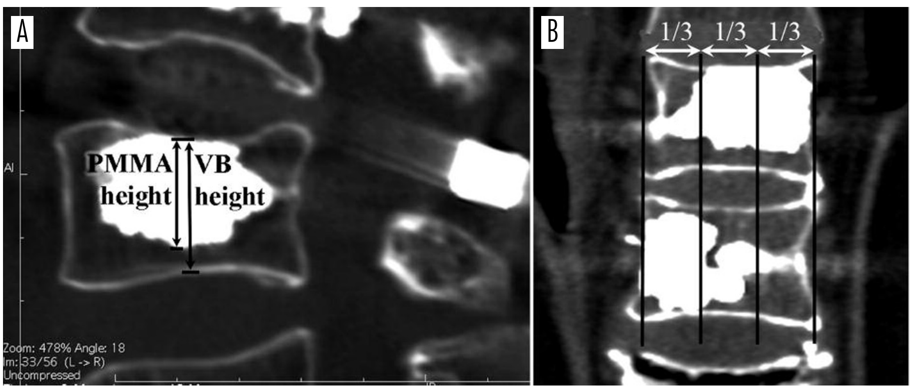

Fig. 4. A) Lateral CT image reconstruction showing measurements of PMMA height and VB height to calculate the percentage of distance between endplates filled with PMMA. B) Frontal CT image reconstruction showing cement mass occupying central and lateral third of upper vertebral body and predominantly lateral third of lower vertebral body

Table 2. Distribution of polymethylmethacrylate (PMMA) in 44 vertebral bodies

% of vertebral body height filled with PMMA	Vertebral body with PMMA situated centrally	Vertebral body with PMMA situated laterally	Total
50-69%	2	–	2 (4.5%)
70-79%	3	6	9 (20.4%)
80-89%	10	4	14 (31.8%)
90-99%	6	1	7 (15.9%)
100%	11	1	12 (27.3%)
Total	32 (72.7%)	12 (27.3%)	44 (100%)

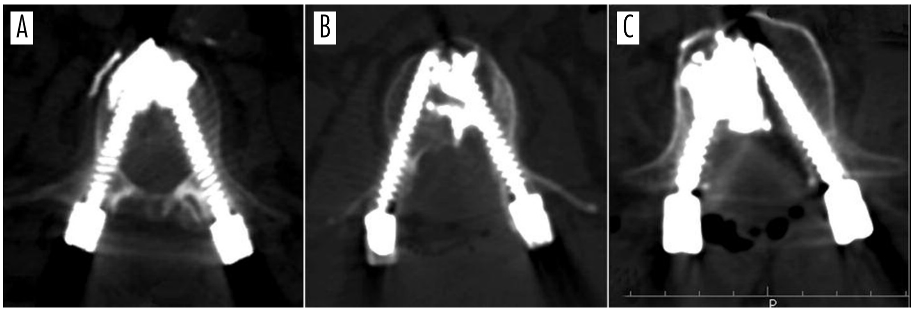

Fig. 5. Relation between cement and screws. A) Both screws inside the cement mass, threads are completely surrounded by PMMA. B) Cement adheres to both screws, threads are partially surrounded. C) Right screw outside the cement mass

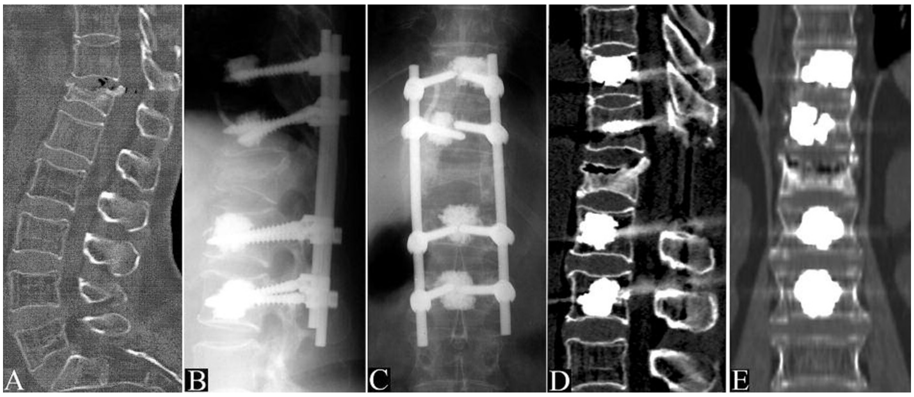

Fig. 6. Case 14: a 60-year-old female. A) Preoperative CT – fracture of T12 type A3.1.1 with canal compromise and kyphotic deformity (Cobb angle T10-L2: 17°). B-C) Postoperative plain radiographs, stabilization T10-L2. D-E) Postoperative reformatted CT images showing distribution of cement inside the vertebral bodies and correction of kyphosis (postoperative Cobb angle T10-L2: 3°, correction: 14°)

diagnosed during revision surgery; there was no definite radiological evidence of screws loosening due to artefacts provoked by cement.

Leak of PMMA was observed in 20 (45%) vertebrae and afflicted 13 (76%) patients. Anterior leaks towards paravertebral veins or the anterior longitudinal ligament were present in 11 vertebrae, whereas leaks towards the spinal canal or intervertebral foramina took place in 9 vertebrae; none of these leaks caused any neurological symptoms.

Discussion

Augmentation of transpedicular screws with bone cement is used to reduce the risk of implant loosening [4,6-8,11-19]. The majority of authors implementing this solution at first applied the cement into vertebrae and afterwards inserted pedicular screws. The most frequently described method of cement delivery entailed creation of tunnels through pedicles, which were later filled with cement, and lastly pedicular screws were inserted in them [4,7,10,12,13,17-19]. Cement was injected into tunnels with vertebroplasty needles or other cannulas [7,10,19]. Intraoperative balloons for kyphoplasty were also used to prepare voids for cement and screws [7,12]. Some researchers concluded that the aforementioned methods resulted in screw reinforcement 1.5-1.8 times higher than controls (Becker) [12], and increased pullout strength by 90-255% over osteoporotic controls (Burval) [7], or by 181-213% (Sarzier) [18]. These results vary, as they were dependent on different variables: method of cement delivery and degree of osteoporosis. Frankel *et al.* [8,15] constructed a fenestrated tap with which they prepared a pedicular tunnel and injected the PMMA into the VB; after removing this tool, screws were inserted instead. This method resulted in a significant increase of pullout strength ranging from 119% to 162% [15]. Yamana *et al.* constructed a nail without threads, which was inserted into the pedicular tunnel previously filled with cement. These authors estimated that the mean pullout strength of a cemented nail was 760 N, whereas the pullout strength of non-augmented pedicular screws was 346 N [11].

Augmentation of vertebral bodies can also take place after insertion of screws. This is possible due to the use of cannulated screws [3,12,14,17]. Researchers favouring cannulated screws point out the following advantages: possibility of reinsertion in case of improper positioning of the screw; the stage of cement delivery takes place after all screws are inserted; and injection though the screw is easier than consecutive filling of pedicular tunnels [12]. The drawback is the risk of cement leakage towards the dural sac if perforations of screws are close to the spinal canal [12]. We intended to combine the proven mechanical effect of vertebroplasty with the advantages of cement delivery after proper insertion of screws. In our method, the first step consisted of insertion of pedicular screws in chosen vertebrae. In the second step, setting this method apart from others, vertebroplasty needles were inserted extrapedicularly into vertebral bodies containing screws (one needle per vertebra), to serve as a way for PMMA injections. After hardening of PMMA, corrective manoeuvres of spinal curve were performed as well as final tightening of the construct. In 2004, Boszczyk described intraoperative vertebroplasty via needles inserted into vertebral bodies through the spinal canal opened by laminectomy [2]. However, in his method laminectomy of each augmented vertebra is necessary; moreover, neural structures can be compressed or the dural sac damaged by the needle. We suggest a needle entry point distant to the neural structures, situated outside the spinal canal, cranially and laterally in relation to the pedicle.

We wish to highlight the advantages of our method: PMMA filled the central part of 32 vertebral bodies and completely surrounded threads of both screws in 22 vertebrae; in 42 vertebrae, the layer of PMMA filled at least 70% of the distance between the endplates, and the best result – PMMA extending from one endplate to another – was achieved in 27.3% of vertebrae. None of the 44 needles damaged neural structures.

The biomechanical value of augmentation may be estimated based on laboratory tests performed by Higgins [21], who concluded that unipedicular injection of an amount of cement equal to 20% of VB volume resulted in 36% strength increase as compared with non-augmented controls. In our series, only one case of implant destabilization was observed. Leaks of PMMA – all asymptomatic – were observed in 20 (45%) vertebrae and mainly were provoked by the surgeon's tendency to fill as many vertebral volumes as possible. Boszczyk observed leaks from 73% of vertebrae treated with intraoperative vertebroplasty [2]. Frankel found asymptomatic leaks in 39% of patients whose vertebrae were augmented via a fenestrated tap [8]. Yamana estimated the presence of cement leak in 27-74% of patients treated with percutaneous vertebroplasty [11]. Hulme *et al.* [5] based on a meta-analysis of 69 clinical studies concluded that cement leakage occurred in 41% of vertebrae during percutaneous vertebroplasty. Higgins estimated in vitro leak as high as 61.1% in vertebrae filled with 10% cement per volume and 90% in vertebrae filled with 20% cement per volume [21]. In our opinion, intraoperative vertebroplasty performed after insertion of pedicular screws may be considered as a technical variation useful to stabilize osteoporotic spines. This study does have the following limitation: as only 17 patients were operated on, statistical analysis was not possible. The authors intend to continue these investigations.

Conclusions

1. Intraoperative vertebroplasty performed after insertion of pedicular screws may be considered as a technical variation useful to stabilize osteoporotic spines.
2. After PMMA hardening, intraoperative manoeuvres to correct spinal deformity were possible without any damage of instrumented vertebrae.

Disclosure

Authors report no conflict of interest.

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