Eur Spine J (2012) 21:1860–1866
DOI 10.1007/s00586-012-2400-2

ORIGINAL ARTICLE

Respiratory effects, hemodynamic changes and cement leakage during multilevel cement balloon kyphoplasty

Pavlos Katonis · Alexander Hadjipavlou · Xenia Souvatzis · Michael Tzermiadianos · Kalliopi Alpantaki · James Walt Simmons

Received: 20 September 2011 / Revised: 8 May 2012 / Accepted: 3 June 2012 / Published online: 18 July 2012

Abstract
Purpose The purpose of this study is to evaluate the effects of multilevel balloon kyphoplasty (BK) on blood pressure, blood gases and cement leakage.
Methods This is a prospective study of 63 patients: 31 were treated for osteoporotic vertebral compressive fractures (OVCF) and 32 for osteolytic tumors (OT). Twenty-six patients were treated at 1 level, 15 at 2, 2 at 3, 6 at 4, 3 at 5, 4 at 6, 5 at 7 and 2 at 8. PPMA was used in 43 patients and calcium phosphate in 20. All patients were treated under general anesthesia with continuous invasive monitoring of hemodynamic changes, arterial blood gases and peripheral and regional cerebral oxygen saturation.
Results Two patients had a transient drop in blood pressure between 21 and 42 % during simultaneous inflation of all four balloons at two levels and three more patients during cement injection (two PMMA, one calcium phosphate). Five patients had a cement leak (7.9 %), which was unrelated to the cement type or number of levels. Blood pressure, end-tidal carbon dioxide partial pressure and arterial oxygen partial pressure decreased statistically, but without any clinical significance after cement insertion. Peripheral and regional cerebral oxygen saturation remained unchanged. One-way ANOVA revealed no difference between these changes when clustered by the groups single level, two levels and three or more levels.
Conclusion BK performed under general anesthesia appears to be safe when applied in multiple levels in the same seating provided the balloons are inflated sequentially and not simultaneously and the cement is inserted slowly in a very doughy state. Close monitoring of cardiorespiratory factors is valuable. Its rare circulatory effects are unrelated to the number of levels or the cement type.

Keywords Multilevel balloon kyphoplasty · Blood gases · Hemodynamic changes · Cement leakage

P. Katonis · A. Hadjipavlou (✉) · M. Tzermiadianos · K. Alpantaki
Department of Orthopaedics and Traumatology, University Hospital of Heraklion, Voutes, 71003 Heraklion, Crete, Greece
e-mail: ahadjipa@yahoo.com; ahadjipa@otenet.gr

P. Katonis
e-mail: katonis@hol.gr

M. Tzermiadianos
e-mail: miketzermi@yahoo.gr

K. Alpantaki
e-mail: apopaki@yahoo.gr

A. Hadjipavlou · J. W. Simmons
International Spine and Orthopaedic Institute, 12770 Cimarron Path Suite 132, San Antonio, TX 78249, USA

X. Souvatzis
Department of Anaesthesiology, University Hospital of Heraklion, Voutes, 71003 Heraklion, Crete, Greece
e-mail: X.souvatzis@gmx.de

Introduction

Percutaneous balloon kyphoplasty has currently been established as an effective minimally invasive procedure for the treatment of osteoporotic vertebral compression fractures (OVCF), primary and metastatic osteolytic vertebral tumors (OT) [1]. However, cardiopulmonary complications such as transient hypotension and drop of oxygen saturation have been reported, but have not been widely scrutinized [1]. Augmentation of more than one vertebral body is reported as a risk factor for increasing the incidence of embolic phenomena [2]. Although PMMA toxicity has been ascribed for cardiopulmonary events, there is evidence that the potential cardiovascular complications during balloon kyphoplasty are highly related to increased interosseous pressure within the vertebral bodies rather than the PMMA toxicity itself [3, 4].

The purpose of the present study was to evaluate the safety of multilevel cement balloon kyphoplasty as related to hemodynamic, respiratory and local complications.

Materials and methods

This is a prospective study of 63 consecutive patients scheduled for cement kyphoplasty under general anesthesia from July 2006 until July 2007. Thirty-one of them had sustained an OVCF and 32 had OT. Twenty-six patients were treated at one level, 15 at two, 2 at three, 6 at four, 3 at five, 4 at six, 5 at seven and 2 at eigh levels. PMMA was used in 43 patients and calcium phosphate cement in 20 (Fig. 1).

The following standardized anesthesiologic protocol was used: General anesthesia was induced with Fentanyl and Propofol and maintained with Sevoflurane. A non-depolarizing neuromuscular blocking agent, left to the anesthesiologist's choice, was given to facilitate tracheal intubation. A bolus of Fentanyl was administered when an inadequate level of analgesia occurred. A 20-G catheter was placed in the radial artery for obtaining blood gas analysis and monitoring invasive arterial blood pressure (ABP). Adhesive electrodes oximetry (INVOS^{TM} Cerebral/Somatic Oximeter, Somanetics^{TM}, Troy, MI, USA) [5] for monitoring the regional cerebral oxygenation were stuck symmetrically on the forehead, high above the eyebrows to avoid positioning over sinus cavities. Patients were then

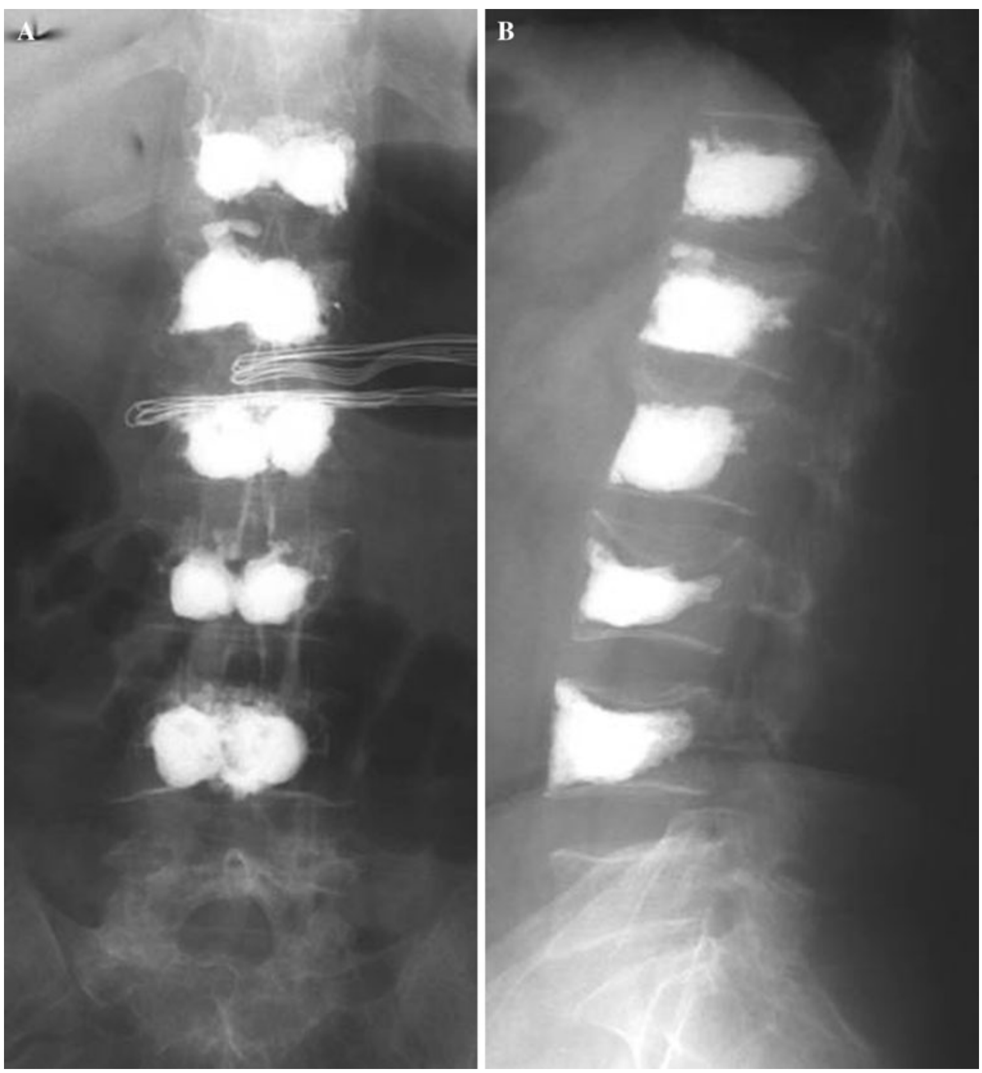

Fig. 1 Patient with OT (multiple myeloma) treated with five levels balloon kyphoplasty

placed in a prone position on a Jackson surgical table and the procedure was performed under general anesthesia in the usual fashion [6].

Analyses of blood gases were obtained at standardized time sets: (1) immediately before the balloon inflation, (2) 2 minutes after inserting the cement and (3) in the recovery room. If more than two vertebral levels were treated, supplemental blood gases were obtained after each additional level. Intraoperatively, invasive ABP, heart rate, end-tidal carbon dioxide partial pressure, peripheral oxygen saturation and regional cerebral oxygen saturation of the left and right hemispheres were continuously recorded. Alterations in ventilator settings and depth of anesthesia were avoided during the period of balloon inflation and cement insertion to prevent iatrogenic changes in ABP, oxygen saturation and blood gases. Additional data recorded were patient's age, height, weight, underlying disease, number of level treated, type of cement used, occurrence and type of cement leakage, ventilator settings and concentration of volatile anesthetic. In the recovery room patients received routinely oxygen via a face mask at a flow of 6–8 l/min.

In ten patients, the intrathoracic pressure was momentarily raised during the process of balloon inflation and cement insertion.

Post-operatively, all the patients underwent CT imaging as it was established in a standard post-op protocol in 2000. The cement extravasation was classified according to pattern of cement leakage as suggested by Yeom et al. [7].

Statistical analysis

Data are expressed as frequencies for qualitative parameters and mean ± standard deviation or median with range, where appropriate, for quantitative variables. Statistical analysis was performed with Chi-square test and Fisher's exact test for comparing categorical variables. Logistic regression analysis was employed for evaluating the influence of age and body mass index on cement leakage. Paired samples t test was used for assessing differences before and after cement insertion. Comparisons between the groups, one level, two levels and three or more levels of cement insertion were made with one-way ANOVA with Bonferroni adjustment. The statistical package used was IBM SPSS statistics v.19. A p value of 0.05 was considered statistically significant.

Results

Patient characteristics

Patients' median age was 68 (19–86) years (non-normal distribution). Patients' weight and height were 73.0 ± 13.0 kg and 163 ± 9 cm, respectively.

Problems related to balloon inflation

Two patients (KN and FK) showed a sudden decrease in ABP during the balloon inflation (Table 1), which was

Table 1 Decrease in systolic arterial blood pressure (SABP) during balloon inflation in two patients

Patients	KN	FK	
Gender	Male	Female	
Age (years)	71	66	
Underlying disease	Osteolytic tumor (OT)	Osteoporotic vertebral compression fracture (OVCF)	
Number of treated levels	7	6	
Sequence (levels in the same line were treated simultaneously, levels during which SABP drop occurred are underlined)	L3, L4	Th7, Th8	
	L5, S1	Th6, Th9	
	L2, Th12	Th10, Th11	
	L1		
SABP immediately before balloon inflation (mmHg)	118	110	140
SABP during balloon inflation (mmHg)	68	87	105
Percentage decrease in SABP (%)	42	21	25
Regional cerebral oxymetry recording before balloon inflation, percentage left/right hemisphere (%/%)	72/68	64/75	66/75
Regional cerebral oxymetry recording after balloon inflation, percentage left/right hemisphere (%/%)	61/62	66/75	64/69
Percentage decrease in cerebral oxymetry, percentage left/right hemisphere (%/%)	15/9	–	3/8

restored immediately by one bolus injection of the sympathomimetic agent Ephedrine.

One patient (KN a 71-year-old male) with OT, who was treated at seven levels in the same seating, developed instantaneously ABP drop during simultaneous inflation of four balloons at two levels (third and forth lumbar segment). Furthermore, this patient also exhibited significant fall in regional oxygen saturation during the process of balloon inflation.

A second patient (FK a 66-year-old female), suffering from intractable pain caused by OVCF, who underwent a six-level balloon kyphoplasty, developed twice a substantial drop in ABP. The first drop occurred instantaneously while the four balloons were inflated simultaneously at T7, T8 levels, and the second drop at T10, T11. No untoward hemodynamic changes were observed while simultaneously inflating the balloon at two levels in the L2 and L3 vertebrae. However, similarly, instantaneous drop in the ABP was monitored when again all four balloons at the last two levels (T10, T11) were tackled simultaneously in the usual fashion.

In the group of ten patients who underwent a rise of intrathoracic pressure, no adverse cardiopulmonary changes were observed.

Problems related to cement insertion

Cement leakage

Cement leakage occurred in five patients (two with OVCF, three with OT), an incidence of 7.9 %, but was not related to the disease ($p = 1.000$). Neither was cement leakage related to the type of cement (four PMMA, one calcium phosphate, $p = 1.000$), nor the number of levels treated ($p = 0.412$) or the patient characteristics age ($p = 0.583$) or body mass index ($p = 0.738$). In one patient, who suffered from hemangioma, we had observed a leakage of the routinely given radiopaque material through the posterior wall towards the epidural space and the inferior vena cava. The ensuing PMMA cement was inserted slowly and gingerly in a very dough state. No cement leakage was observed. Hemodynamic and respiratory changes remained unchanged. Since our technique consisted of inserting the cement slowly in a very doughy state and under constant fluoroscopic control, we have not seen any type B leakage. Two type S and three type C (two intradiscal and one lateral wall) cement leaks were observed.

Adverse effects related to ventilation parameters and vital signs

There were no differences in the settings of mechanical ventilation and depth of anaesthesia before and after the cement insertion (Table 2). Changes in vital signs and blood gas parameters before and after cement insertion are shown in Table 3. There was a statistically significant decrease after cement insertion for the systolic ABP (−3.9 mmHg, 95 % CI −7.1 to −0.6), the end-tidal carbon dioxide partial pressure (−0.6 mmHg, 95 % CI −0.9 to −0.4) and the arterial oxygen partial pressure (−6.3 mmHg, 95 % CI −10.6 to −2.0) (Table 3). However, these differences were not considered clinically significant.

A decrease in systolic ABP during cement insertion was observed in three patients (MD, GD, MA) (Table 4). The two patients with OT (six level osteolytic lesions) were treated with PMMA cement augmentation, showed a moderate ABP decrease, easily controlled with Ephedrine administration. In one of these two patients, the drop in ABP by 35 mmHg was accompanied by a very transient fall of peripheral oxygen saturation from 100 to 92 %. The changes recovered promptly. However, this patient who suffered from chronic obstructive pulmonary disease developed an acute respiratory insufficiency after waking from anesthesia and was treated with non-invasive ventilation in the intensive care unit for 24 h. The patient with underlying OVCF (MA) showed a mild ABP fall; however, it occurred immediately after radiographically detecting extravertebral extravasation of calcium phosphate cement through the anterior vertebral wall. In this patient ABP promptly recovered without any pharmacological intervention. No significant changes of the peripheral or cerebral oxygenation were observed.

Oxygen partial pressure showed a clinically relevant drop by 30 mmHg in one patient in whom a major ABP fall during balloon inflation was seen (patient KN Table 1). In no other patients in the study, a clinically significant fall of oxygen partial pressure was observed after inserting the cement.

Table 2 Monitoring of mechanical ventilation and depth of anaesthesia before and after cement insertion

	Before cement insertion	After cement insertion	*p* value (paired samples *t* test)
Inspiratory oxygen fraction (%)	42.2 ± 5.2	42.2 ± 5.2	0.784
Inspiratory sevoflurane concentration (%)	2.1 ± 0.6	2.2 ± 0.5	0.587
Respiratory rate (min^{-1})	12.2 ± 1.8	12.2 ± 1.9	0.182
Tidal volume (ml)	494 ± 72	496 ± 73	0.085

Values are mean ± SD

Table 3 Changes of vital signs and blood gas parameters before and after cement insertion

Parameters	Before cement insertion	After cement insertion	Significance of the changes	
			Paired samples *t* test	Difference between groups: 1, 2 and 3 or more levels (one-way ANOVA)
Systolic arterial blood pressure (mmHg)	116.4 ± 18.9	112.5 ± 20.2	0.020	0.181
Heart rate (min^{-1})	67.1 ± 12.9	66.6 ± 13.1	0.421	0.097
Peripheral oxygen saturation (%)	99.2 ± 1.1	99.1 ± 1.5	0.159	0.238
End-tidal carbon dioxide partial pressure (mmHg)	30.7 ± 4.1	30.1 ± 4.1	0.0001	0.120
Arterial oxygen partial pressure (mmHg)	180.0 ± 48.2	173.6 ± 49.4	0.004	0.957
Arterial carbon dioxide partial pressure (mmHg)	39.6 ± 5.6	39.7 ± 4.7	0.776	0.990
pH	7.447 ± 0.046	7.444 ± 0.046	0.134	0.114
Regional left cerebral oxygen saturation (%)	64.6 ± 8.5	64.2 ± 9.1	0.201	0.274
Regional right cerebral oxygen saturation (%)	64.7 ± 8.3	64.3 ± 8.5	0.218	0.258

One-way ANOVA of the changes, clustered by the number of levels

Values are mean ± SD

Table 4 Decrease in systolic arterial blood pressure (SABP) during cement insertion

Patient	MA	GD	MD
Sex	Female	Male	Male
Age (years)	65	64	74
Underlying disease	OVCF	OT	OT
Number of treated levels	Two	Six	Four
Cement type	Calcium phosphate	PMMA	PMMA
Radiographic signs of cement leakage	Yes	No	No
SABP immediately before cement insertion (mmHg)	135	110	100
SABP during cement insertion (mmHg)	110	75	65
Percentage decrease in SABP (%)	19	32	35

Comparison of the groups according to the number of levels treated

One-way ANOVA revealed no difference between the changes before and after cement insertion when clustered by the group, single level, two levels and three or more levels (Table 2). There were also no statistically significant differences in blood gas parameters in the recovery room between the groups single level, two levels and three or more levels as well (arterial oxygen partial pressure $p = 0.189$, arterial carbon dioxide partial pressure $p = 0.329$, pH $p = 0.243$).

Discussion

Percutaneous balloon kyphoplasty was introduced at the late 90s and has currently become a widespread method in the treatment of OVCF and OT [1, 8]. Complications associated with balloon kyphoplasty include those attributed to the technique itself, such as cement extravasation, intracanal cement leak resulting in neurological damage, infection and those ascribed to cardiopulmonary events such as pulmonary embolism. The latter occur after migration of fat, bone marrow particles, or PMMA through the epidural or vertebral venous system; it is rarely of clinical significance with balloon kyphoplasty method of cementoplasty and has been reported to increase with the number of vertebral levels treated [2]. The specific advantages claimed for balloon kyphoplasty over percutaneous vertebroplasty consist of cement injection with lower pressure and its ability to reduce fracture deformity [1]. The risk of cement leak during cement augmentation has been reported as 19.7 % with vertebroplasty versus 7.0 % with kyphoplasty [9]. Apparently, the unique ability of BK is the creation of a cavity into the vertebral body, by the balloon inflation, that allows the insertion of very viscous cement at a much lower pressure. Furthermore, the packing of the cancellous bone at the periphery of the expanded balloon also augments the prevention of the cement leakage through the vertebral body [10]. Although cement leak is well tolerated and reports on lethal pulmonary cement embolism after kyphoplasty have not been reported in the available English language reports, it is, however, the main cause of pulmonary and neurological complications [11]. Comprehensive understanding of the pathophysiological characteristics of these complications due to extrusion of fat, bone marrow and cement is vital to anticipate the problems that may occur during the procedure. For example, a drop in ABP or changes in blood gases in an old osteoporotic patient can be easily misconstrued as result of cardiopulmonary disease [4].

Several authors have blamed PMMA toxicity for cardiopulmonary complications during cement augmentation procedures and suggest the use of less toxic, non-PMMA bone cement [12, 13]. In our series, the occurrence of cement leakage and ABP drop were unrelated to the type of cement used. Also, in an experimental animal model, Aebi et al. [14] showed that a potentially severe cardiovascular event could be caused by fat embolism during vertebroplasty independently of the augmentation material. The viscosity of the cement and the amount of the cement injected represent the most important factors of extravasation. Some authors advise against attempting to inject more than 5 ml of PMMA into each vertebra, or 30 ml in total, or three levels per session [15–17]. Augmentation of more than one vertebral body has been associated with an increased risk of cardiovascular complications [3]. The reasons must be sought in the rise in the intraosseous pressure during augmentation, which lead to mobilization of bone marrow into the circulation, or to decrease of the sympathetic tone, rather than to the PMMA toxicity [3]. In our series the common denominator of significant drop in SABP was the simultaneous inflation of four balloons in two vertebrae—a technique that we no longer encourage—and we advocate sequential balloon inflation under cardiorespiratory scrutiny when multilevel augmentation is required. A drop in regional cerebral oximetry may be another early warning sign of fat or cement embolism. The cerebral oximetry device estimates brain tissue oxygenation by measuring the absorption of infrared light [18, 19]. Restoring cerebral oxygen desaturation has been found to reduce adverse surgical events [20, 21].

Other methods have also been promoted for the prevention of cement leakage and pulmonary embolism, such as the eggshell technique and patient positioning. The eggshell technique has been promoted particularly to prevent cement leakage when the vertebral confinement is violated [6, 22].

The positioning of the patient and the anesthetic safety measures during the procedure appear to be also of clinical significance. The effect of body position on intra-abdominal and intrathoracic pressures on venous return through the vertebral venous system has been emphasized since the 1970s [23]. It has been demonstrated that compressing the inferior vena cava results in raising the vertebral intraosseous pressure [24]. As a corollary to this it appears that a high venous pressure may render the cement insertion safer during kyphoplasty and diminishing the risk of fat, bone marrow, or cement embolus [24]. This situation can only be achieved when the patient is under general anesthesia. This allows the anesthesiologist to elevate intrathoracic and intra-abdominal pressures (i.e., venous pressure), when inflating the balloons or inserting the cement, to avoid undesirable cardiorespiratory changes. However, high intrathoracic pressure may dramatically impair venous return to the heart leading to hemodynamic collapse, especially in elderly and cardiopulmonary compromised patients [4]. The raise of intrathoracic and intra-abdominal pressure technique should be applied very briefly and only during balloon inflation and cement insertion. This technique was successfully applied in ten patients with multilevel kyphoplasty who tolerated the procedure very well and without a hitch. It remains to be seen whether this technical expedience is of real value when dealing with multilevel balloon kyphoplasty.

Using a proper surgical and anesthetic technique, the risk of embolic complications and cement leakage can be substantially reduced. The importance of manipulating intrathoracic and intra-abdominal pressure during balloon inflation may be of practical importance to minimize intraoperative cardiorespiratory problems.

In conclusion, multilevel cement balloon kyphoplasty can be safely and effectively achieved under proper surgical and anesthesiological technical guidelines. Optimal placement of the balloon and a very slow insertion of doughy cement in the vertebral body under constant imaging control minimizes the risk of local and intravascular cement extravasation. Staged balloon inflation seems to reduce the incidence of cardiopulmonary complications. Constant and careful monitoring of hemodynamic and respiratory parameters (oxygenation and ventilation) of the patient is mandatory.

Conflict of interest None.

References

1. Hadjipavlou AG, Tzermiadianos MN, Katonis PG, Szpalski M (2005) Percutaneous vertebroplasty and balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures and osteolytic tumours. J Bone Joint Surg Br 87(12):1595–1604
2. Wiles MD, Nowicki RWA, Hancock SM, Boszczyk B (2009) Anaesthesia for vertebroplasty and kyphoplasty. Curr Anaesth Crit Care 20:38–41
3. Aebli N, Krebs J, Schwenke D, Davis G, Theis JC (2003) Pressurization of vertebral bodies during vertebroplasty causes cardiovascular complications: an experimental study in sheep. Spine (Phila Pa 1976) 28(14):1513–1520

4. Groen RJ, du Toit DF, Phillips FM, Hoogland PV, Kuizenga K, Coppes MH, Muller CJ, Grobbelaar M, Mattyssen J (2004) Anatomical and pathological considerations in percutaneous vertebroplasty and kyphoplasty: a reappraisal of the vertebral venous system. Spine (Phila Pa 1976) 29(13):1465–1471
5. Murkin JM, Arango M (2009) Near-infrared spectroscopy as an index of brain and tissue oxygenation. Br J Anaesth 103(Suppl 1):i3–i13
6. Gaitanis IN, Hadjipavlou AG, Katonis PG, Tzermiadianos MN, Pasku DS, Patwardhan AG (2005) Balloon kyphoplasty for the treatment of pathological vertebral compressive fractures. Eur Spine J 14(3):250–260
7. Yeom WJ Kim, Choy WS, Lee CK, Chang BS, Kang JW (2003) Leakage of cement in percutaneous transpedicular vertebroplasty for painful osteoporotic compression fractures. J Bone Joint Surg Br 85(1):83–89
8. Pflugmacher R, Beth P, Schroeder PS, Schaser KD, Melcher I (2007) Balloon kyphoplasty for the treatment of pathological fractures in the thoracic and lumbar spine caused by metastasis: one-year follow-up. Acta Radiol 48(1):89–95
9. Eck JC, Nachtigall D, Humphreys SC, Hodges SD (2008) Comparison of vertebroplasty and balloon kyphoplasty for treatment of vertebral compression fractures: a meta-analysis of the literature. Spine J 8(3):488–497
10. Phillips FM, Todd Wetzel F, Lieberman I, Campbell-Hupp M (2002) An in vivo comparison of the potential for extravertebral cement leak after vertebroplasty and kyphoplasty. Spine (Phila Pa 1976) 27:2173–2179
11. Hulme PA, Krebs J, Ferguson SJ, Berlemann U (2006) Vertebroplasty and kyphoplasty: a systematic review of 69 clinical studies. Spine (Phila Pa 1976) 31:1983–2001
12. Bai B, Jazrawi LM, Kummer FJ, Spivak JM (1999) The use of an injectable, biodegradable calcium phosphate bone substitute for the prophylactic augmentation of osteoporotic vertebrae and the management of vertebral compression fractures. Spine (Phila Pa 1976) 24:1521–1526
13. Bostrom MP, Lane JM (1997) Future directions: augmentation of osteoporotic vertebral bodies. Spine (Phila Pa 1976) 22:38S–42S
14. Aebli N, Krebs J, Davis G, Walton M, Williams MJ, Theis JS (2002) Fat embolism and acute hypotension during vertebroplasty: an experimental study in sheep. Spine (Phila Pa 1976) 27:460–466
15. Lee B, Lee S, Yoo T (2002) Paraplegia as a complication of percutaneous vertebroplasty with polymethylmethacrylate: a case report. Spine (Phila Pa 1976) 27:419–422
16. Bohner M, Gasser B, Baroud G, Heini P (2003) Theoretical and experimental model to describe the injection of a polymethylmethacrylate cement into a porous structure. Biomaterials 24: 2721–2730
17. Coumans JV, Reinhardt MK, Lieberman IH (2003) Kyphoplasty for vertebral compression fractures: 1-year clinical outcomes from a prospective study. J Neursurg Spine 99:44–50
18. Tobias JD (2006) Cerebral oxygenation monitoring: near-infrared spectroscopy. Expert Rev Med Devices 3(2):235–243
19. Murphy GS, Szokol JW, Marymont JH, Greenberg SB, Avram MJ, Vender JS, Vaughn J, Nisman M (2010) Cerebral oxygen desaturation events assessed by near-infrared spectroscopy during shoulder arthroscopy in the beach chair and lateral decubitus positions. Anesth Analg 111(2):496–505
20. Gottlieb EA, Fraser CD Jr, Andropoulos DB, Diaz LK (2006) Bilateral monitoring of cerebral oxygen saturation results in recognition of aortic cannula malposition during pediatric congenital heart surgery. Paediatr Anaesth 16(7):787–789
21. Murkin JM, Adams SJ, Pardy E, Quantz M, McKenzie FN, Guo L (2011) Monitoring brain oxygen saturation during coronary bypass surgery improves outcomes in diabetic patients: a post hoc analysis. Heart Surg Forum 14(1):E1–E6
22. Greene DL, Isaac R, Neuwirth M, Bitan FD (2007) The eggshell technique for prevention of cement leakage during kyphoplasty. J Spinal Disord Tech 20:229–232
23. Theron J, Moret J (1978) Spinal phlebography. Lumbar and cervical techniques. Springer-Verlag, Berlin
24. Vogelsang H (1970) Intraosseous spinal venography. Excerpta Medica, Amsterdam