Dangers with cementation under low-viscosity state: Cement arterio-venogram and bone cement implantation syndrome

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ABSTRACT

Cement arterio-venogram is a rare event with cement extrusion into femoral nutrient vessels. In literature it is known to be benign with no significant clinical sequelae. It is postulated that it is due to high cement implantation pressure, that results in optimal cement filling quality. All previously reported cases were female patients, and it is thought to be a female only phenomenon due to the relatively narrow femoral canal leading to higher pressures during cementation. In this case series we report 3 cases different to existing literature. All 3 patients showed a cement arterio-venogram together with bone cement implantation syndrome and hypotension intra-operatively. It was also observed that during implantation the cement was of low viscosity. We postulate low cement viscosity during implantation with pressurization is also a contributing factor to these phenomena. This case series also demonstrates the first 2 male cases, showing this the even can occur in males too. The cement arteriovenogram is located at 41%–42% femur length which is within the 'third sixth' of the length of the femur. Good cementation techniques and prevention is also highlighted in this report.

Introduction

A significant factor determining the longevity of a cement femoral stem is adequate cement pressurization, which produces better cement interdigitation [1]. In-vitro studies have shown that the peak intramedullary canal pressure throughout the cementation process can reach up to 5003 mmHg, with a mean pressure of 3008 mmHg during insertion of a femoral implant [2]. High cement implantation pressure is postulated to be associated with cement implantation syndrome and the rare complication of cement arteriovenogram [3].

Cement arteriovenogram is the appearance of cement extrusion outside of bony cortex and into nutrient arteries or veins. A small, uniform, tubular cement streak outside of the medullary canal seen on X-ray represents leakage to an artery. While a larger calibre, tortuous course and valvular constriction represents leakage to a vein. Currently, in existing literature, it is reported the cement leaks in a posteromedial direction, corresponding to the second perforator of the deep femoral artery, which is comprised of one artery and two

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veins [4]. Studies have shown that it is located 170 ± 25 mm distal to the greater trochanter tip [5] or at the third sixth if a femur is divided to six parts [6]. It is also suspected this disease occurs in females only because of a smaller endosteal canal that leads to higher pressures [3]. In literature, there are 10 case series reported since 1984. Rarity of cases and studies limits our knowledge towards this phenomenon. Current evidence shows minimal associated cardiopulmonary effect, and the arterio-venogram generally undergoes a relatively benign course.

Our center is a regional tertiary trauma center in Hong Kong with approximately 400 hip fractures annually. We present 3 representative cement arterio-venogram cases with cardiopulmonary compromise during operation. Our findings deviate from what we understand regarding this disease. Based on our cases and current literature, we also have recommendations to prevent cement arterio-venogram and bone cement implantation syndrome (BCIS).
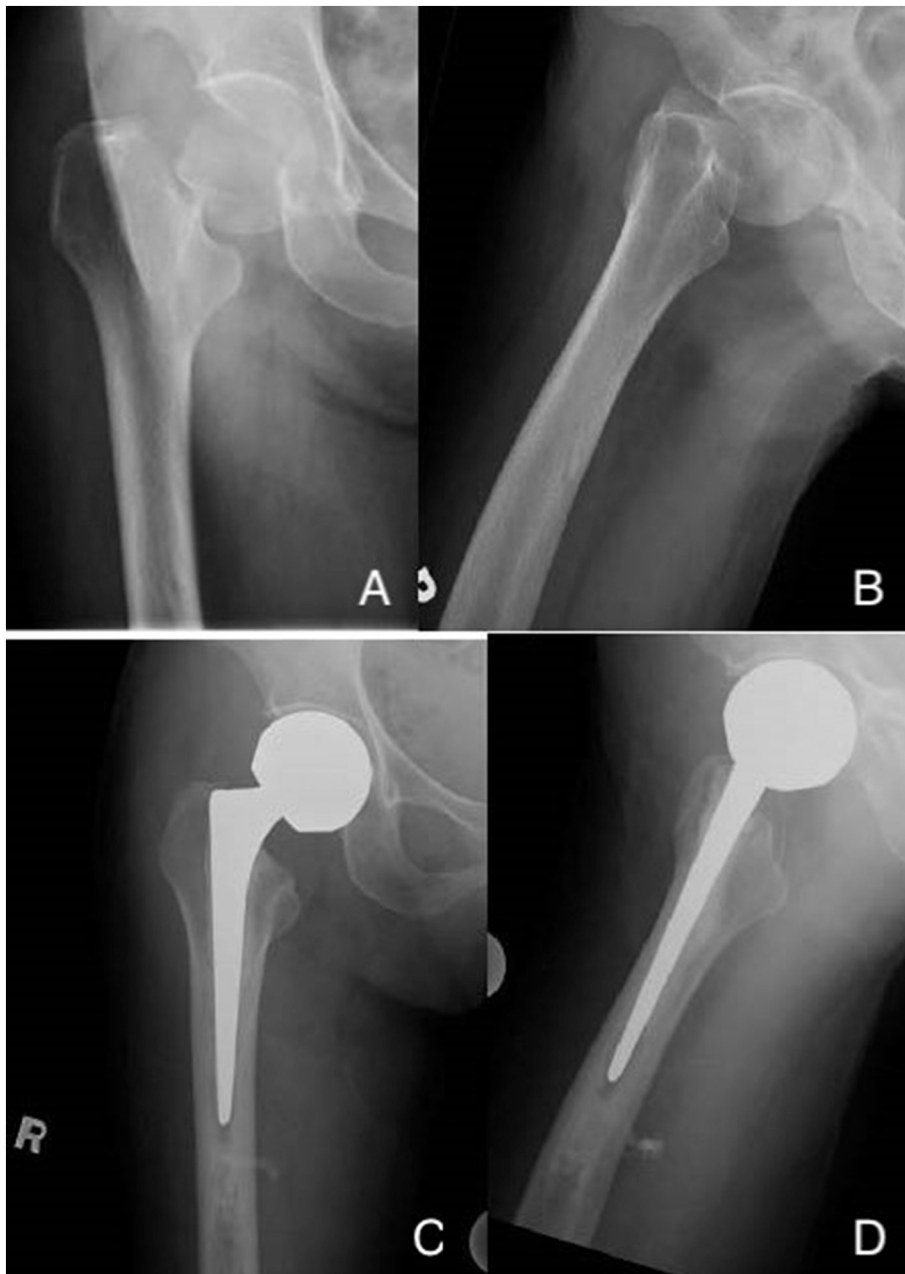

Fig. 1. A, B Pre operative X-ray of case 1, anteroposterior and lateral respectively C, D, post operative X-ray of case 1, anteroposterior and lateral respectively. Both C and D showed features of venous filling including valvular constrictions, tortuous course, larger calibre. The leakage is in posteromedial direction.

Case 1

Ms. Y was a 76-year-old lady known to enjoy good past health and walks unaided. She slipped and fall in February 2017 suffering from right hip pain. Physical examination showed right hip tenderness, and the lower limb was in a shortened and externally rotated position. X-ray showed a displaced right neck of femur fracture (Fig. 1A, B). She had stable vitals with SpO2 97% in room air and blood pressure 155/95 Pulse 95 beats/min. Cemented hemiarthroplasty was performed two days after admission with a posterior approach. The intramedullary canal was prepared, cleaned with pulsatile lavage and dried with suction sponge. Stryker Universal Cement Restrictor (Stryker, US) 18.5 mm cement restrictor was inserted 2 cm distal to the stem tip. No vent tube was used. Cement was applied with cement gun in a retrograde fashion (Stryker, US). Pressurization with wedge adapter was performed. A medium viscosity cement, Antibiotic Simplex P (Tobramycin Full Dose) Bone Cement (Stryker, US) was used. The implant used was Exeter V40 Primary Standard Stem 33 mm, Unitrax 50 mm head with +4 mm adapter sleeve. Operative time was 2 h and 1 min.

Cement implantation syndrome had occurred intraoperatively. Before cement implantation, the vitals signs were normal, at 125/60 and heart rate 80 beat/mins. Immediately after applying cement, blood pressure had dropped from baseline 125/60 mmHg to 80/40 mmHg. Heart rate dropped from 80 beats/min to 60 beats/mins. Ephedrine 3 mg IV was used. The blood pressure recovered transiently to 95/45 mmHg but dropped to 80/45 shortly after. Heart rate remained at 75 beats/min. Atropine 0.9 mg was further given. There was no increase in oxygen requirement and SaO2 remains 98% - 99% in room air. Her blood pressure was stabilized to 120/60 mmHg in recovery room. There was no fever, rash, petechiae or confusion at recovery room or after returning to ward. The distal neurovascular status was intact.

Post operation X-ray (Fig. 1C, D) showed cement leakage with venogram change, characterized by a tortuous course with valvular appearance. CT showed 26 mm length cement leakage to posteromedial direction (Fig. 2). The femur length was 341 mm and cement leakage appeared at 143 mm from the greater trochanter tip, which was at 42.9% of the femur length. X-ray showed Barrack Grade B filling. CT measurement of intramedullary canal diameter was 9 mm × 12 mm (oval shape) at stem tip and AP X-ray showed 12 mm canal width. Bone cement was applied and pressurized early at a very low viscosity state.

After operation she was discharged from acute hospital 14 days, and she stayed in rehabilitation hospital for a further 14 days. She could walk with a frame after discharge. She was last followed up by our unit 5 months post-operation. She could walk with a stick and had no hip pain. X-ray showed good alignment with no implant loosening. She was diagnosed with metastatic pancreatic cancer 6 months after operation and succumbed one month later due to malignancy.

Case 2

Mr. H was an 81-year-old gentleman with history of Type II diabetes mellitus (DM), hyperlipidemia, and Vitamin B12 deficiency. He could walk unaided before operation. He slipped and fell in July 2017, complaining of right hip pain. There was right hip tenderness with right lower limb pain on movement. Pre-operative vitals was stable, with SpO2 99% in room air, blood pressure 120/70 mmHg, and pulse 85 beats/min. X-ray showed a displaced right neck of femur fracture (Fig. 3A, B). A cemented hemiarthroplasty was performed on the second day of admission. Posterior approach was used. The medullary canal was prepared with pulsatile lavage and dried with suction sponge. Stryker Universal Cement Restrictor 24 mm (Stryker, US) was inserted 2 cm distal to the stem tip. No vent
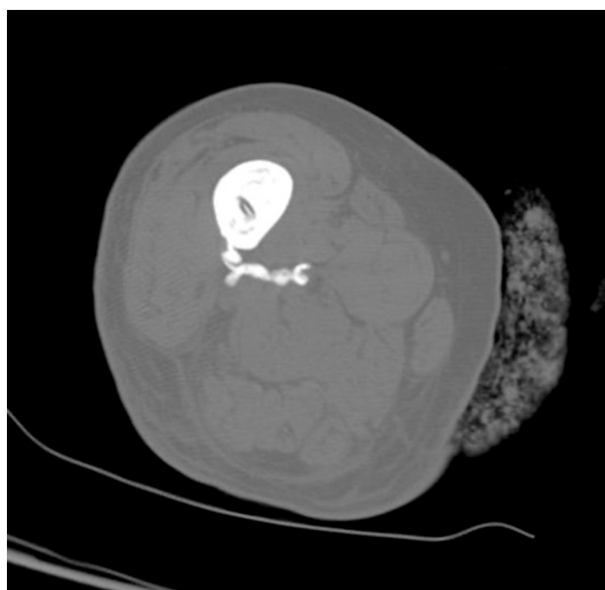

Fig. 2. Post operative axial CT of Case 1. It illustrates the venous filling features and posteromedial direction of leakage.
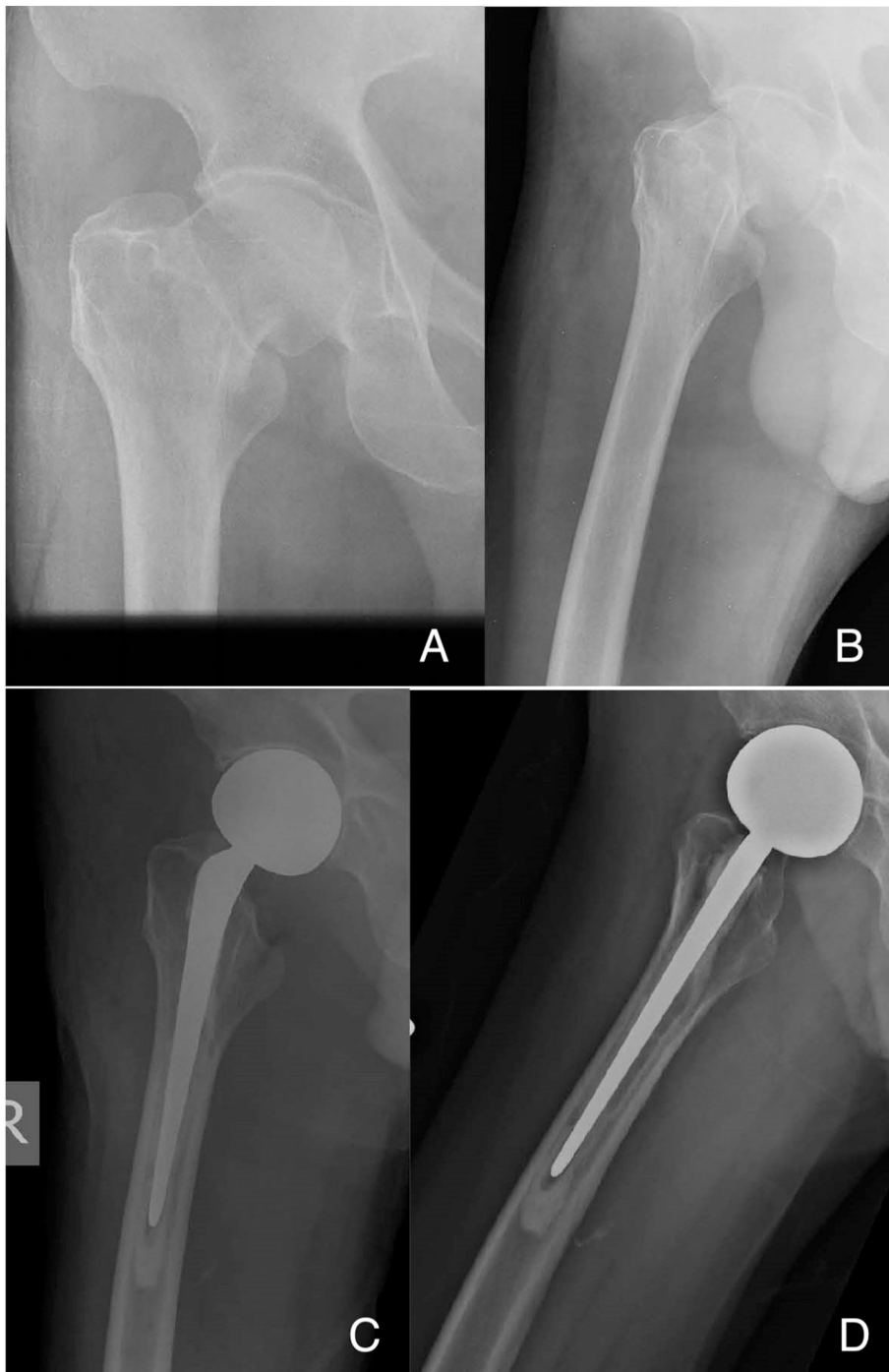
Fig. 3. A, B. Pre operative X-ray of case 2, anteroposterior and lateral respectively C, D post operative X-ray of case 2, anteroposterior and lateral respectively. Both C and D showed features of arterial filling including small calibre, straight course, valveless. The leakage is in poster-omedial direction.

tube was used. A medium viscosity cement, Antibiotic Simplex P (Tobramycin Full Dose) Bone Cement (Stryker, US) was applied with cement gun in a retrograde fashion (Stryker, US). Pressurization with wedge adapter was performed. The implant used was Exeter V40 Primary Standard Stem 37.5 mm N0, Unitrax 50 mm head with +4 mm adapter sleeve. Operative time was 1 h 55 min.

Intraoperatively after cement application there was also a drop of blood pressure from 120/75 mmHg to 90/65 mmHg. Pulse raised from 65 beats/min to 90 beats/min. He was stabilized after given blood transfusion and fluid resuscitation intraoperatively. Post-

operatively the patient suffered from desaturation from 98% room air to 90% room air at recovery room. He was given 4 L oxygen via nasal cannula and SpO2 improved to 97%. His blood pressure was stabilized to 105/70 mmHg, pulse 75 beats/min. There was no fever, petechiae, or confusion at recovery room or after returning to ward. The lower limbs pulses were well palpable and there were no signs of deep vein thrombosis afterwards. On Day 4 after operation, he suffered from fever of 38.9 °C, cough and sputum and the diagnosis was hospital-acquired pneumonia. He had no desaturation. Ultrasonography and pulmonary angiogram showed no sign of deep vein thrombosis and pulmonary embolism. Chest X-ray showed mild right lower zone haziness, and he was treated with intravenous antibiotics.

Post-operation X-ray of the femur showed cement extrusion with the appearance of cement arterio-venogram (Fig. 3C, D). CT was performed showing it was 190 mm distal to the greater trochanter tip, and in a posteromedial direction (Fig. 4C). The cement demonstrated features of retrograde filling of the artery, with small calibre, relatively straight course and uniform diameter. A computed tomography (CT) was performed. The cement streak measured 21 mm in length. It was located at 40.9% of femur length from the greater trochanter. It is immediately proximal to cement restrictor.

Cement was placed early during a relatively low-viscosity state and brief pressurization was applied at this state. Post-operative X-ray showed Barrack D cement mantle quality (Fig. 3C, D). CT showed major cement defects around the stem (Fig. 4D). CT showed the intramedullary canal width was 19 mm diameter at the stem tip.

He was discharged from acute hospital on day 13 post-operation and stayed an additional 19 days in rehabilitation hospital. He
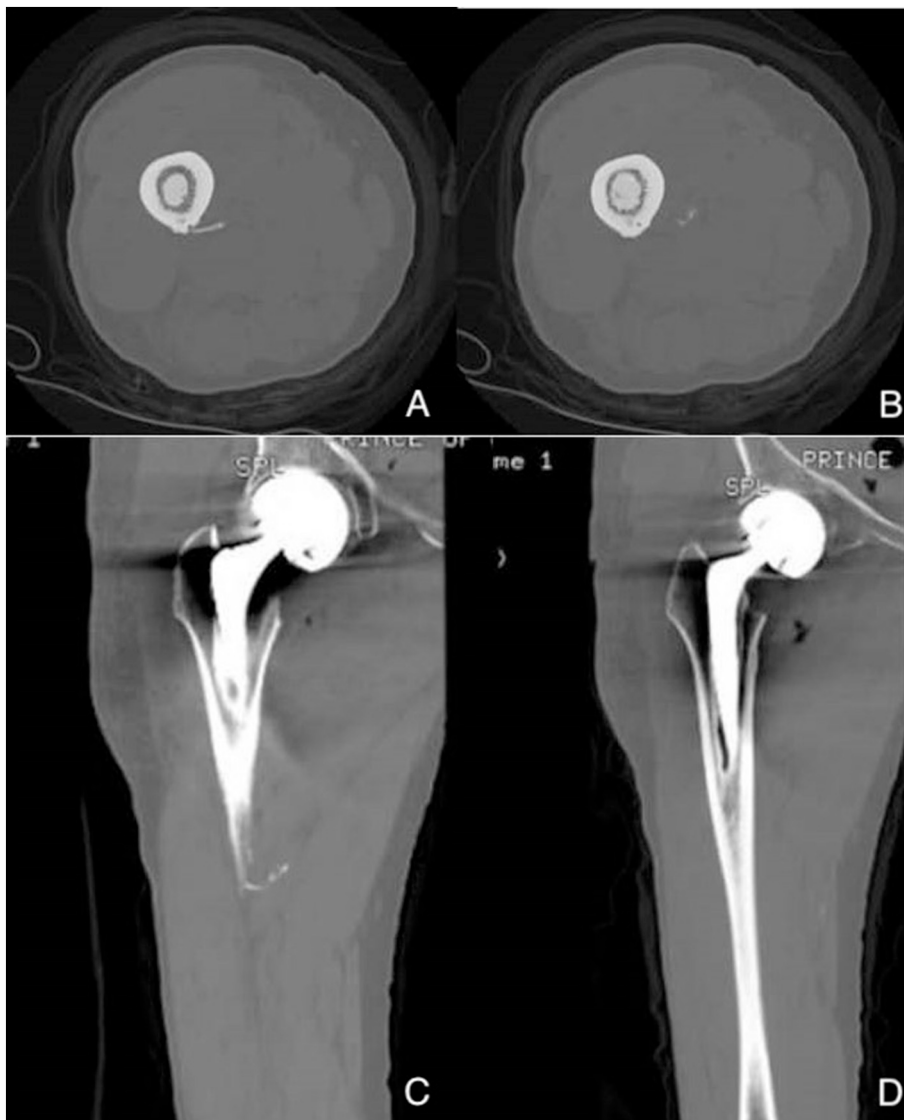

Fig. 4. A, B. post operative axial CT of Case 2 C. Post operation coronal CT of Case 2. It illustrates the arterial filling features and posteromedial direction of leakage. D shows the extensive cement defect around the stem.

could walk unaided upon discharge to home. He remains asymptomatic until now, 2 years 6 months post-operation. X-ray remained static, with Barrack D cement filling, same alignment, no loosening or subsidence, and same cement arterio-venogram appearance.

Case 3

Mr. W was a 90-year-old gentleman who had a history of pulmonary tuberculosis. He could walk unaided. He had slipped and fall December 2019 and suffered from left hip pain and could not weight bear. Physical examination showed left hip tenderness. His blood pressure was 145/90 mmHg and heart rate was 80 beats/min. X-ray showed a left hip displaced neck of femur fracture (Fig. 5A, B).

Left cemented hemiarthroplasty was performed 1 day after admission. A posterior approach was performed. Medullary canal was prepared, cleaned by pulsatile lavage and dried with suction sponge. Stryker Universal Cement Restrictor 24 mm was inserted 2 cm distal to stem tip. No venting tube was used. Cement was applied with cement gun in a retrograde fashion (Stryker, US). Pressurization with wedge adapter was performed. A medium viscosity cement, Antibiotic Simplex P (Tobramycin Full Dose) Bone Cement (Stryker, US) was used. An Exeter V40 Primary Standard Stem 35.5 mm offset and 50 mm Unitrax head was used.
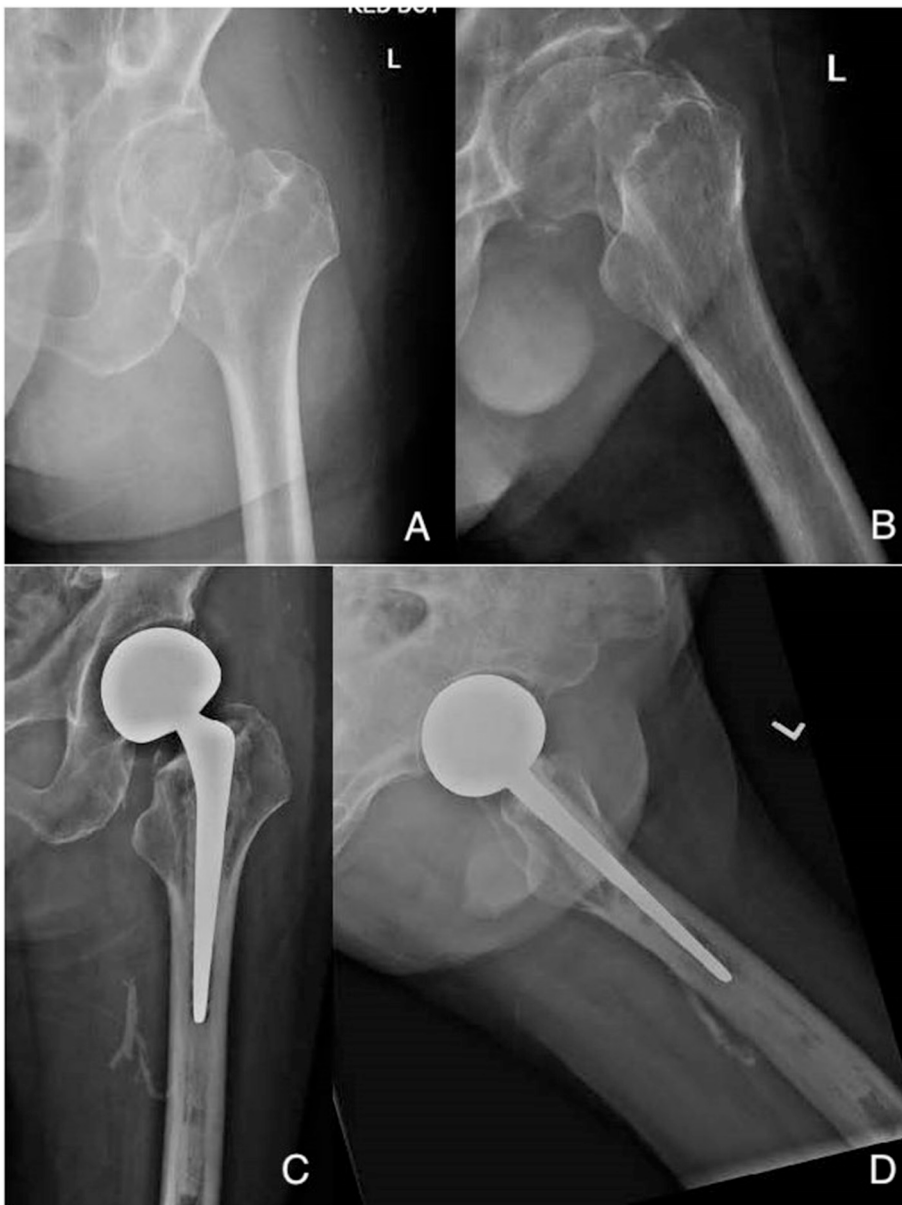

Fig. 5. A, B Pre operative X-ray of Case 3 anteroposterior and lateral respectively C, D post operative X-ray of Case 3, anteroposterior and lateral respectively.

Intraoperatively immediately upon cement implantation, he suffered from a period of blood pressure drop from 110/65 mmHg to 80/58/mmHg. Heart rate has increased from 65 beats/min to 90 beats/min. There was not increase in oxygen demand. Phenylephrine 300 µg and fluid resuscitation was given. His blood pressure stabilized after 20 min. His vital signs were stable in recovery room, with blood pressure 120/65 mmHg and heart rate 70 beats/min. His oxygen saturation was 97% room air. There was no confusion, petechiae or fever in recovery room or after returning to ward. The lower limbs pulses were well palpable and there were no signs of deep vein thrombosis afterwards.

Postoperative X-ray showed cement arteriovenogram with arteriogram features (Fig. 5C, D), characterized by straight course, uniform diameter and absence of valvular constrictions. From X-ray, using the Unitrax head diameter (50 mm) as scale, the cement arteriovenogram was estimated to be at 179.5 mm from tip of greater trochanter. The cement arteriogram length is estimated to be 73.9 mm in length. It propagates in a posteromedial and proximal direction and outlined part of the deep femoral artery. The cement filling quality was Barrack D. An early CT scan of femur was arranged, but the patient defaulted the scan. It is postulated the bone cement was placed very early under low viscosity and pressurized at that state.

On Day 4 after the operation, he suffered from fever, sputum and cough. He suffered from hospital acquired pneumonia with Methicillin-Resistant *Staphylococcus aureus* (MRSA) infection. It was treated with intravenous vancomycin. He stayed in acute hospital for ten more days and stayed in rehabilitation hospital for twelve more days. He could walk with quadripods upon discharge. He was last followed up one year two months after operation. He could walk with a stick. X-ray showed static x-ray appearance of cement arterio-venogram and there was no loosening or malalignment of the implant.

Discussion

Our case series reported a phenomenon different from existing literature. Most published cases series did not have cardiopulmonary complications. To the authors knowledge, forty-two reported cement arterio-venogram cases, but only 3 medical complications occurred, including 1 right middle lobe pneumonia [7], 1 unrelated myocardial infarction [8] and 1 precipitation of known heart failure [8]. All our 3 cases (100%) demonstrated different degrees of cardiopulmonary impact intraoperatively upon cementation, which may represent cement implantation syndrome changes. Case 1 suffered from grade 2 BCIS while Case 2 and 3 suffered from grade 1 BCIS. BCIS is a systemic insult caused by bone cement usage with medical sequalae including hypotension, hypoxia, cardiac arrhythmia. The aetiology is postulated to be bone cement molecules, bone marrow, fat and other micro-emboli forced into the systemic circulation under high pressure, and high temperature condition during cement implantation [9]. As cement arterio-venogram is the extrusion of polymerized cement into an artery or a vein, cement arterio-venogram is likely a risk factor of BCIS [10]. In fact, Olsen et al. reviewed 1016 cases and the incidence of BCIS grade 1 (moderate hypoxia SpO2 < 94% or Hypotension fall in systolic blood pressure >20%) was 21% with a mortality of 9.3% [11]. Incidence of grade 2 BCIS (severe hypoxia SpO2 < 88% or Hypotension fall in systolic blood pressure > 40%) was 5.1% while mortality was 31%. With all our cement arterio-venogram cases presenting with BCIS with low cement viscosity upon implantation, we postulate there is a strong association.

The exact cause of cement arterio-venogram remains unknown. A biomechanical study by McCaskie et al. showed the highest intramedullary pressure occurred during implant insertion, with peak pressure 5003 mmHg and mean 3008 mmHg [2]. Cement gun injection of cement creates a peak pressure 2051 mmHg and a mean pressure 374 mmHg [2]. Literature has postulated cement arterio-venogram is associated with high intramedullary cement pressure and therefore assumably better cementation quality [12]. Our cases appear to demonstrate the contrary. Case 2 and Case 3 both presented with Barrack grade D cement filling, and Case 2 demonstrated large cement defect on CT. Moreover, McClelland postulated smaller prosthesis may produce less pressure during implant insertion and prevent cement embolic complications [7]. In contrast to this, Case 1 used a small femoral stem of offset 33 mm, but cement arterio-venogram still presented. Therefore, poor cement quality and small implant size can still produce cement arterio-venogram in both arterial and venous morphology.

We postulate cement implantation pressure is not the sole factor, but a low viscosity texture may also be a significant contributor. It is reasonable that low viscosity bone cement can extrude through small femoral vascular channels easier than high viscosity cement under lower pressure. Volatile Poly(methyl methacrylate) PMMA monomer molecules can also escape into circulation when

Table 1
Current reports on cement arteriovenogram.

Author	Number	Gender	Cardiopulmonary complications	Other complications
Weissman [8] 1984	8	8F, 0M	Myocardial infarction $N = 1$, 12.5%	Nil
			Recurrence of known congestive heart failure $N = 1$, 12.5%	
Brandser [14] 1995	4	4F, 0M	Nil	Nil
Knight [3] 1999	8	8F, 0M	Nil	Nil
Skyrme [15] 2001	1	1F, 0M	Nil	Nil
Nogler [16] 2002	1	1F, 0M	Nil	Nil
Panousis [17] 2006	1	1F, 0M	Nil	Nil
McClelland [7] 2006	1	1F, 0M	Nil	Chest infection N = 1, 100%
Wang [18] 2012	3	3F, 0M	Nil	Nil
Vankatesh [19] 2018	2	2F, 0M	Nil	Nil
Garriguez-Perez [10] 2020	14	14F, 0M	Nil	Fracture $N = 2$, 14.3%
Wan 2021	3	1F, 2M	Bone cement implantation syndrome $N = 3$, 100%	Chest infection N = 1, 33.3%

polymerization just starts when viscosity is low. In all our cases, the surgeons reported early application and pressurization of bone cement in low viscosity texture. Bone cement has mixing, waiting, working and hardening phases. Mixing phase occurs when the monomer and polymer are mixed and polymerization just starts. Waiting phase is when polymerization just begins and bone cement demonstrates a sticky appearance. Working phase is when viscosity is high enough, and feels 'doughy' and is non-sticky to gloves, and is suitable for implantation. All the cementation must be finished before the setting phase, which occurs when the polymerization is complete. This is when the cement hardens [13]. Bone cement is to be applied during working phase ('doughy phase') with high viscosity, but premature application at waiting phrase ('sticky phase') with low viscosity is not uncommon [13]. Perfect cement application time is difficult to predict as cement curing time depends on multiple factors that cannot be standardized [13]. Bone cement polymerization rate is also increased by higher temperatures (1 degree Celcius rise accelerate polymerization by 5%) [13], rapid or machine-driven mixing, and high humidity [9]. The authors believe that cement implantation pressure is only one of the factors for cement arterio-venogram and further reports are needed as the reported incidence is as low as 0.9% - 1.6% [3]. Further studies on the effect of viscosity is also needed, although it is difficult to conduct due to the lack of objective and quantitative measurement means.

Anatomical factors that contributed to cement pressure has also been suggested [3]. In the current literature (Table 1), all cement arteriovenogram occurred in female patients [3,7,8,10,14–19]. Knights et al. postulated cement arteriovenogram occurred in female patient with small statue and small endosteal canal, allowing cement gun to have a tight seal and a good fit of the cement restrictor [3]. Garríguez-Pérez provided a comprehensive summary and update regarding this phenomenon and also suggests that can only occur in female although the exact mechanism is unknown [10]. To our knowledge, our case series reports the first two male cases, and also evidence of cardiopulmonary compromise, which is different from current literature findings. This suggests that the anatomy of the canal is not necessarily the only contributing factor. Table 1 shows the current reports regarding cement arteriovenogram available including our own findings.

The extruded cement fills the second perforator branch up to deep femoral artery in a retrograde manner. Knight et al. [3] found cement extrusion was at vascular channel and vascular foramen. Faruk et al. performed cadaveric studies of 20 fresh human cadavers, and he reported the nutrient artery and its foramen arising from 166 ± 10 mm from the greater trochanter. This was a branch of second perforating artery from the deep femoral artery. If the femur is divided into six parts, the position of the nutrient artery and foramen is found to lie consistently in the third sixth. Both Case 1 and Case 2 show the cement arterio-venogram is located at 41%–42% of femur length, consistent with 'third sixth' (33.3%–50% femur length). However, all 3 cases nutrient foramen position fall outside of Faruk's 166 ± 10 mm range [6], probably due to stature and ethnicity difference. Nagel et al. [4] showed that the nutrient artery foramen contains 1 artery and 2 veins in their anatomical study. A clear identification of position of the relatively benign cement arterio-venogram helps to differentiate it from the more sinister cause of cement extrusion including cortical perforation with cement extrusion. No association of cement arterio-venogram has been found with deep vein thrombosis or limb ischemia so far [10].

Multiple measures can be utilized to avoid BCIS and cement arteriovenogram. The surgeon should apply cement at working phrase, rather than at waiting phrase at low viscosity. Classical teachings include applying when 'doughy', that the cement is not sticky to gloves. Usual mixing time is 1 min, cement application is at 3.5–4 min, and pressurization at 4 min or when doughy. Stem is to be inserted at 6 min and held still, until setting time at 12–15 min [13]. An experienced surgeon will wish to insert implant later to minimise risk of stem movement in cement mantle and minimise risk of high intramedullary pressure when viscosity is low. The unexperienced surgeon may wish to apply cement, pressurize and insert stem as soon as possible to avoid risk of 'premature setting'. One major factor contributing to variability of setting time is the 'temperature' factor. It involves not only the controllable or known shelf temperature and body temperature, but also mixing instrument temperature, room temperature and cement bowl temperature. Most of these factors are considered uncontrollable but countermeasures can be taken. The manufacturer of Simplex P (Simplex brocher) Speedset cement recommends using 22.8 degree Celsius water bath for temperature equilibrium with powder, cement bowl, and mixing instruments right before mixing. The mixing [20] is performed for 1 min and the setting time is reproducible at 10 min. Other than using manufacturer's recommendation, one can devise their own standardized environment involving mixing instruments, cement bowl, the liquid and powder of bone cement, room temperature, humidity, etc. The authors believe standardizing curing time is a most reliable way to prevent premature cement application.

Furthermore, Donaldson et al. [9] has performed a literature review and suggested multiple measures to reduce BCIS risk. Intramedullary lavage and good hemostasis before insertion was recommended. Use of vacuum mixing can significantly reduce cardiopulmonary complication rate compared to finger packing, likely because of removal of excessive volatile components [21]. Drill-hole venting of femoral cortex can also reduce BCIS risk but risk of femoral fracture exists. The use of retrograde cement gun is associated with more even intramedullary pressure and less BCIS occurrence. Use of a short stem implant if possible, or using cementless implant in patients with high cardiopulmonary risk, was also suggested. The cardiopulmonary risk factors include old age, poor physiological reserve, impaired cardiopulmonary function, osteoporosis, bony metastasis, and pathological fractures. Pathological fractures is associated with increased, abnormal vascular channels. Anaesthetic efforts were also recommended, including the avoidance of volatile anaesthetic agents use upon cementation, increasing oxygenation upon cementation, ensuring adequate hydration, and consider the use of invasive monitoring including pulmonary artery catheter or transoesophageal echocardiogram for high risk patients.

In conclusion, we have reported 3 representative cases that has difference from literature. All our cases suffered from cement arterio-venogram as well as bone cement implantation syndrome. Our findings suggest that low cement viscosity is a potential factor for the contribution of these phenomena. It prompts us to believe that cement arterio-venogram is not as harmless and benign as we thought. Furthermore, cement arterio-venogram is not a gender-specific disease. Further reports to understand this disease are warranted.

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