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Review Article

Bone-Cement: The New Medical Quick Fix

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Abstract Bone Cement is being widely used in vertebroplasty, a minimally invasive surgical procedure to treat spinal fractures and collapsed vertebrae. It is being labeled as a concrete success in medical field. It is being used to treat fractures due to osteoporosis, menopause, steroids, hyperthyroidism and chronic obstructive pulmonary diseases. In this technique a needle with bone cement (PMMA, polymethylmethacrylate) is injected into the collapsed vertebra after administering local anesthesia to patient. It solidifies within few minutes and provides support to damaged bone resulting in relief to the patient. It also prevents the movement between different parts of the broken bone. Hence it requires a short hospital stay for the patient and the procedure can be performed with much ease and at significant lower costs. Patient can resume normal activity within a day or so. Bone cement is now being referred to as the quick medical fix material for early repair of fractures.

Keywords: Bone cement, Biomaterial, Kyphoplasty, Polymethylmethacrylate, (PMMA)

Introduction

About 160,000 Total Hip Replacements (THRs) around the world are performed every year. Ninety per cent of all hip replacements need some sort of revision. The main reason for this revision is the loosening of the implant [1]. Self-curing acrylic bone cement is a grouting agent used in total hip replacement surgery to support the prosthesis within the intermeduallary cavity of the femoral bone. Optimum penetration of bone cement into the porous cancellous bone is paramount in order to achieve adequate load transfer across the different interfaces [1, 2]. The degree of interdigitation of the cement is influenced by its rheological properties and the porosity of the cancellous bone structure [2].

The objective of bone and joint replacement is to provide improved motion of the joint and to replace damaged bone structures. The materials used are required to transmit and withstand the stress applied to the structure, within the body environment, while interacting with the existing bone such that the function of the bone and prosthetic is maintained over a long period [2]. The materials used for these applications include metals, ceramics and polymers. Metals dominate the bulk of the implant structure while ceramics and polymers are typically used at interfaces and near articulating surfaces. The metals include stainless steel, co-based alloys, titanium alloys. The ceramics that are commonly used in bone and joint replacement include alumina and zirconia [3, 4].

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The polymers employed frequently are polymethylmethacrylate (PMMA) or bone cement, which is injected between the prosthesis and bone to transfer loading between the bone and the prosthesis [3]. Ultra high molecular weight polyethylene (UHMWPE) is also sometimes employed for load bearing surface due to its good wear resistance and low friction properties [4].

Bone cement has been used in great number of clinical applications to secure a firm fixation of joint prosthesis such as hip and knee joints [4, 5]. The ready bone cement is a compound consisting of 90 % of polymethylmethacrylate, (PMMA), the rest are mainly crystals of barium sulfate or zirconium oxide that make the resulting product radio-opaque. Bone cement is used for fixation of the artificial joints to the skeleton. It acts, however, not as glue; it acts as filler. The familiar materials like Plexiglas or Lucite consist of pure PMMA while Plexiglas is considered to be a strong plastic material [5].

Structure of Bone cement (PMMA)

The microscopic structure of bone cement is made by two substances glued together. One substance is the small particles of pre-polymerized Polymethylmethacrylate (PMMA), so called “pearls”. These pearls are supplied as a white powder. The other substance is a liquid monomer of MMA (MethylMethacrylate). Both substances are mixed together at the operation table with added catalyst (dibenzoyl peroxide) that starts the polymerization of the monomer fluid [6]. Basically, the bone cement consists of individual acrylic PMMA spheres "pearls" that are glued together and embedded by a net of the polymerized monomer. The polymerized monomer net that keeps the pearls together has a honeycomb-like structure [7].

Development of Bone Cement

Bone cement consists of PMMA powder and monomer methacrylate liquid. When these two components are mixed together, the monomer liquid is polymerized by the free radical (addition) polymerization process. An activator, dibenzoyl peroxide will react with a monomer to form a monomer radical which will then attack another monomer to produce a dimer. The process will continue until long-chain molecules are produced. The monomer liquid will wet the polymer powder particle surfaces and link them together after polymerization. In this mixture the individual pearls are dispersed within the liquid and swell up [7]. When the liquid monomer polymerizes and the bone cement hardens, the individual pearls are entrapped and glued within a net of the polymerized monomer, but there is no chemical binding between the pearls and the polymerized monomer. The resulting net (honeycomb)-like structure gives the function of bone cement - filling the space between the skeleton and the total joint device [8, 9].
The polymerization is accompanied by development of heat so that the surface temperature of a massive ball of polymerizing bone cement reaches temporarily 60 to 100 degrees Celsius [9]. The resulting product is a doughy white mass which polymerizes to a hard and brittle substance within ten minutes. A thin layer of polymerizing bone cement is cooled by the mass of the total joint on one side and by the skeleton itself permeated with blood 37 degree C warm on the other side [8]. This allows the surface temperature of bone cement layer to never reach temperatures over 47 degree C for longer time periods because the skeleton's cells cannot survive [9].

Factors affecting Bone Cement Properties

The bone cement that is prepared by the surgeon at the operation table is a material with many drawbacks such as it is mechanically weak because it has entrapped impurities such as air and blood, it is brittle, it has low endurance limit and is prone to fatigue failure, it spawns small particles from its surface containing hard crystals of Barium sulfate which scratch and damage the fine joint surfaces of the artificial joint [8]. The small cement particles may cause osteolysis - "bone dissolving disease". It has very large surface which may support colonization of bacteria and development of postoperative infections. It may cause allergy and anaphylactic reaction during the operation [10].
Apart from these drawbacks it has some advantages which make it quite useful. The advantages of bone cement are it has a very long (>35 years) track record of being put to use which none of the other cement less competitors have. The surgeons are quite comfortable using the bone cement. The operation technique with bone cement is more forgiving. Self-curing acrylic cements, consisting mainly of polymethylmetacrylate (PMMA), are widely used in dentistry and orthopedic surgery. One of the major side effects of the standard PMMA application is tissue necrosis at the bone-cement interface due to the rise of temperature during the polymerization reaction. This may also lead to aseptic loosening over time. Therefore, intense research is being carried out in the development of bone cements with new compositions [11].
The success of the implant fixation is associated with the mechanical interlock between the cancellous bone and the cement, and this depends on the viscosity of the initial dough [11]. The ability to penetrate deeper into the skeleton depends on the viscosity of the bone cement. More liquid products penetrate the skeleton easily while the more viscous products stay at the surface. Studies have demonstrated that the use of low viscosity cements in surgery of total hips produced more failures than use of conventional doughy products [11, 12]. The factors affecting bone cement properties can be classified as intrinsic and extrinsic. The intrinsic factors are composition of monomer and powder, particle size, shape and distribution degree of polymerization. The extrinsic factors are mixing environment, temperature, mixing technique, curing environment, pressure, and contact surface [12].
When the surgeon presses the doughy bone cement into the prepared cavity in the bone, small quantities of monomer fluid are still present in the product. The toxic monomer fluid may leak into the circulation and cause sudden blood pressure fall during the cementing of the total hip device [12]. The fully polymerized bone cement also contains air bubbles which were entrapped in the product during the mixing procedure. These air bubbles diminish the strength of the polymerized bone cement [13].

Improvements in Bone cement preparation

Manufacturers have now developed new vacuum mixing systems that decrease the amount of air bubbles in the ready bone cement. The vacuum system also suctions out the vapors of the loose monomer which remained after imperfect mixing of the substances [12]. The monomer liquid evaporates even at room temperature, so the manufacturers further developed clever small mixing apparatuses that are closed. These apparatuses suction continually the noxious vapors and absorb them into an active carbon filter so that the monomer does not leak into the operation room atmosphere. Moreover, constant suction also keeps low air pressure and diminishes the number of air bubbles that are mixed into the product by stirring and mixing the powder with the liquid [13].

Vertebroplasty

Approximately 700,000 vertebral, or spinal bone, fractures occur each year usually in women over the age of 60. Researchers estimate that at least 25 percent of women and a somewhat smaller percentage of men over the age of 50 will suffer one or more spinal fractures [13]. Younger people also suffer these fractures, particularly those whose bones have become fragile due to the long-term use of steroids or other drugs to treat a variety of diseases such as lupus, asthma and rheumatoid arthritis. Of particular concern are spinal fractures caused by a progressive weakening of the bone, a condition called osteoporosis [12]. The pain and loss of movement that often accompany bone fractures of the spine are perhaps the most feared and debilitating side effects of osteoporosis. For many people with osteoporosis, a spinal fracture means severely limited activity, constant pain and a serious reduction in the quality of their lives [14].

Fractures of the vertebrae have traditionally been much more difficult to manage than broken bones in the hip, wrist or elsewhere. These broken bones can often be successfully treated with surgery [14]. But surgery on the spine is extremely difficult and risky and has not been used to treat vertebral fractures associated with osteoporosis except as a last resort. Until recently, reduced activity and pain medications, many of which cause problematic side effects or invasive (and often unsuccessful) back surgery were virtually the only treatments available. Today, however, there is a safe, non-surgical interventional radiology treatment called vertebroplasty that has been shown to be extremely effective in reducing or eliminating the pain caused by spinal fractures [14]

Vertebroplasty was first performed in 1984 to treat patient with painful hemangioma. Vertebroplasty is a minimally invasive, typically outpatient, non-surgical image guided therapy used to strengthen a broken vertebra (spinal bone) that has been weakened by osteoporosis or cancer [14, 15]. Individual vertebra weakened by disease can collapse suddenly under the force of normal, daily activity; the resulting intense pain causes limited mobility and other significant reductions in quality of life. Vertebroplasty not only relieves pain, but it can increase the patient's functional abilities, allowing a return to the previous level of activity preventing further vertebral collapse. It is quite successful at alleviating the pain caused by a compression fracture [15]. Percutaneous vertebroplasty is a newer technique in which medical grade cement is injected through a needle into a painful fractured vertebral body. During vertebroplasty, the collapsed vertebra is stabilized with specially formulated acrylic bone cement. In addition to providing pain relief, vertebroplasty can prevent further collapse of the vertebra, height loss and spine curvature [15]. This stabilizes the fracture and allows most patients to significantly decrease or actually discontinue medications and resume normal activity. Kryptonite Bone Cement is designed to be the non-toxic medical grade cement that is used for the procedure [16].

People with persistent back pain caused by vertebral compression fractures are potential candidates for vertebroplasty. They are tested with the help of MRI, bone scans, X-rays and other additional tests to check for potential bone damage symptoms [10]. The most common causes of these fractures are osteoporosis and bone tumors. Patients taking high doses of steroids for the control of diseases such as lupus, scleroderma, asthma or chronic obstructive pulmonary disease might also be candidates [16]. The procedure is typically performed in the radiology suite, where the patient lies face down on a table. A local anesthetic is used to numb the affected area of the patient's spine, where the physician inserts one or two needles through a small incision in the patient's skin. Under X-ray (fluoroscopic) guidance, the physician inserts the needles into the fractured vertebra and slowly injects a small amount (~1/4 ounce) of acrylic resin bone cement into the vertebra. The bone cement hardens quickly [17]. When appropriate amount of bone cement has been delivered into the vertebral body, the physician removes the needles and covers up the incision. The patient is kept for observation for a few hours following the procedure. In rare cases, the patient is kept overnight for observation.

Patients typically spend about an hour in the radiology suite for treatment of a single vertebra [16]. Each vertebra takes about half an hour, so treatment of multiple vertebral fractures takes longer. Patients typically spend two to three hours following the procedure in a comfortable observation area to be sure there are no complications or side effects. There is typically no hospitalization associated with vertebroplasty. Most patients report significant pain relief within a few hours of the procedure. The most recent studies report 90% and higher success rates for significantly relieving pain associated with vertebral compression fractures and improved mobility [16, 17]. The resulting benefits in quality of life and wellbeing are equally high; most patients are able to return to their normal activities within a few days. Complications from the procedure are rare, affecting only about 1-3% of patients with osteoporotic compression fractures [17].

Benefits and Risks involved

As the pain of a compression fracture is alleviated by vertebroplasty, patients feel significant relief almost immediately. About 75 percent of patients regain lost mobility and become more active, which helps combat osteoporosis [16]. After vertebroplasty, patients who had been immobile can get out of bed, reducing their risk of pneumonia. Increased activity builds more muscle strength, further encouraging mobility. Usually, vertebroplasty is a safe and effective procedure but certain risks are involved [17].

A small amount of orthopedic cement can leak out of the vertebral body. This does not usually cause a serious problem, unless the leakage moves into a potentially dangerous location such as the spinal canal [16]. Other possible complications include infection, bleeding, increased back pain and neurological symptoms such as numbness or tingling. Paralysis is extremely rare. Sometimes the procedure causes another fracture in the spine or ribs [16, 17].

Limitations

Vertebroplasty is not used for herniated disks or arthritic back pain. It is not generally recommended for healthy young patients, mostly because there is limited experience with cement in a vertebral body for longer time periods. The procedure cannot serve as a preventive treatment to help patients with osteoporosis avoid future fractures. It is used only to repair a known, non-healing compression fracture [16]. Vertebroplasty will not correct an osteoporosis-induced curvature of the spine, but it may keep the curvature from worsening. It may be difficult for someone with severe emphysema or other lung disease to lie facedown for the one to two hours vertebroplasty requires. Patients with a healed vertebral fracture are not candidates for vertebroplasty [17].

Kyphoplasty

This is a newer technique developed for treating spinal fractures due to osteoporosis. It offers an additional benefit for myeloma patients over vertebroplasty in that it helps restore the height of the compressed vertebra [16]. Like vertebroplasty, kyphoplasty is a minimally invasive procedure that is performed using local or general anesthesia. A small incision is made by the physician on each side of the fractured vertebrae using X-ray guidance. Using special instruments, a path into the bone is created. Two tiny tubes are inserted, each containing a small inflatable balloon, into the compressed vertebra. For visualization the balloons are inflated with a radiopaque dye, with the intent of restoring the vertebra to its original height [17]. The balloons are then removed, and the cavities created by the balloons are filled with bone cement. The bone cement usually hardens within 15 minutes stabilizing the bone and preserving the re-established height. Kyphoplasty relieves pain and restores spinal alignment that may help prevent future fractures. On average, it takes about 30 to 45 minutes to treat each fracture [17].

Conclusion

Kyphoplasty and vertebroplasty are effective, minimally invasive procedures for the stabilization of osteoporotic vertebral fractures leading to a statistically significant reduction in pain practiced by large number of physicians these days. Although both kyphoplasty and vertebroplasty are effective treatments for fractures, some clinicians prefer kyphoplasty due to incidence of cement leakage, injection of cement under low pressure and restoration of height achieved. Kyphoplasty significantly restores vertebral body height in fresh fractures. The restoration of vertebral height and reduction of kyphosis may have an influence on the long term clinical outcome [17].

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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