Iranian Journal of Medical Hypotheses and Ideas

Original article

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Could percutaneous femoral head arthroplasty using calcium phosphate cement be a novel therapeutic method for late-stage Legg-Calvé-Perthes disease?

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Received: 11 Oct 2009
Accepted: 03 Nov 2009
Published: 21 Nov 2009
Iran J Med Hypotheses Ideas, 2009, 3:29

Abstract

Legg–Calvé–Perthes disease (LCPD) belongs to the category of aseptic osteochondroses of childhood which is characterized by idiopathic avascular osteonecrosis of the femoral head which can cause severe deformity of hip joint such as coxa plana and 'flattening femoral head'. As the harmonious structural relation of hip joint was broken, osteoarthritis of hip joint could be always observed in patients about 50 years old which finally needs to be treated with total hip replacement. In present most methods yield markedly to achieve good clinical results when dealing with late-stage of LCPD mainly because of inability of reconstruction of spherical shape of femoral head. So the direct urgent thing should be to find one way out to completely reconstruct the spherical shape of femoral head. By the enlightenment of percutaneous vertebroplasty (PKP) and biological properties of calcium phosphate cement (CPC), we hypothesize that percutaneous femoral head arthroplasty using CPC can solve the problem of reconstruction of spherical framework of femoral head in late-stage LCPD and pave a brand-new way to achieve excellent clinical results in patients of late-stage LCPD.

Introduction

Legg-Calvé-Perthes disease (LCPD) was described nearly simultaneously in the year 1910 by G. C. Perthes in Germany, A. T. Legg in the United States, and J. Calvé in France. It belongs to the category of aseptic osteochondroses of childhood which is characterized by a vascular necrosis of the femoral head, that can probably cause severe deformity of hip joint such as coxa plana and 'flattening femoral head' in late-stage of this disease[1]. During approximately 100-year research

and detailed characterization of its pathophysiology, clinical, radiological features, and natural history, LCPD remains a matter of debate in its etiology and methods for treatment [2-8]. The possible mechanisms triggering the disease may include repetitive microtrauma [2], vascular insufficiency [3], and skeletal retardation [4]. Currently all kinds of treatment are based on the principles such as maintenance or restoration of the central position of the femoral head, reduction of intra-pressure of femoral head and improvement of blood circulation of femoral head [5-8]. The purpose is to create a 'harmony' circumstance for 'self-repair' of femoral head. These measures show their advancement at the early-stage of the disease because the intact spherical framework of femoral head is remained [5,6,7,8]. However, the femoral head has already collapsed at late-stage of LCPD, that is to say, the spherical framework has been broken. So–called 'self-repair' of femoral head has to proceed in a deformed framework of femoral head. Therefore, most methods yield markedly to achieve good clinical results when dealing with late-stage of LCPD [6,7,8]. Patients always suffer the pain and difficulty in walking due to severe deformity of femoral head. As the harmonious structural relation of hip joint is broken ,osteoarthritis of hip joint can always be observed in patients about 50 years old which finally needs to be treated with total hip replacement. One direct urgent thing is to find a way out to completely reconstruct the spherical shape of femoral head.

Percutaenous kyphoplasty (PKP) and calcium phosphate cement (CPC)

As a variant of percutaneous vertebroplasty (PVP), percutaneous kyphoplasty (PKP) has been developed to restore vertebral body height and thus correct the kyphotic deformity of collapsed vertebraein cases of severe vertebral compressive fracture (VCF) [9,10]. In this procedure, an inflatable balloon is inserted into the centre of the fractured vertebra using the trans- or extra-pedicular approach. The balloon is then inflated to impact cancellous bone circumferentially around the balloon and thus creating a space while on the same time reducing the deformity. The central space is then filled with bone cement.

Due to its exothermic reaction during hardening, the inability of being remodeled, and the risk of inhibiting bone healing, polymethyl-metacrylate (PMMA) seems not to be the optimal choice when self-remodeling of bone is mandatory, even though which is regarded as the gold standard in arthroplasty. As an alternative for PMMA, calcium phosphate cement (CPC) has been applied in clinic in recent years [11-14]. CPC is composed of two components: a powder and a fluid. Firstly the powder and fluid are mixed into an injected paste. After injection, the paste hardens in a few minutes to form a carbonated calcium phosphate mass similar to the mineral phase of bone [15]. The cement interdigitates with adjacent bone, forming a solid structure that is more mechanically stable than cancellous bone graft. Complete hardening CPC has a compressive strength between that of cancellous and cortical bone [16]. Animal studies suggest that calcium phosphate has the property of osteoconduction and undergoes gradual remodeling over time [15]. The pattern of remodeling seems to be similar to that of normal bone including osteoclastic resorption of the cement, vascular penetration, and bone formation.

Hypothesis and perspective

As mentioned above, the primary problem of treatment for late-stage of LCPD is to rebuild the spherical shape of femoral head. Only after the spherical framework was rebuilt self-repair of femoral head proceed in satisfactory. By the enlightenment of PKP and biological properties of CPC, we hypothesize that percutaneous femoral head arthroplasty using CPC can solve the problem of reconstruction of spherical framework of femoral head in LCPD. The following are the steps in details:

Step1. Reconstruction of framework of femoral head

As applied in PKP, a work-tube was inserted under the surface of collapsed femoral head under guide of fluoroscopy during the operation with a minimal invasive wound in the skin(Fig.1). After confirming the correct position of work-tube, an inflatable balloon was inserted though the work-tube. The balloon was then inflated to rebuild the spherical shape of femoral head which could also be confirmed by fluoroscopy. While reshaping the femoral head, the balloon impacted the cancellous bone around it the same as in the procedure of PKP and produced a space for injection of CPC(Fig.2).

Step 2. CPC remodeling and self-repair of femoral head

CPC was served as a supporter to guarantee the spherical framework of femoral head not to transform(Fig.3). As the procedure of self-repair of femoral head went though, CPC underwent gradual remodeling including resorption of the cement, vascular penetration, and bone formation, which was replaced totally by the normal bone tissue in the end [15,16](Fig.4).What an amazing phenomenon just like a sustained released capsule in the 'sick' femoral head!

In order to make the hypothesis come reality, several key issues should be considered. Firstly, a specific balloon needs to be designed to facilitate the reconstruction of a spherical shape of femoral head. Then the other is the speed of CPC remodeling should be correlated to that of self-repair of femoral head. Finally, some methods should be taken to minimize the side-effect of CPC such as toxicity, leakage and embolism in vivo.

It is clear that there is a long way to put it in clinical application because the specific balloon is difficult to design and all instruments need further improvements. Although obstacles of this research exist, we believe that our idea of percutaneous femoral head arthroplasty using CPC should probably pave a brand-new way to achieve excellent clinical results in patients of late-stage LCPD.

Overview Box

What do we already know about the subject?
In present the topic is still at the state of hypotheses, however we have already taken some steps to build animal model of late-stage Legg-Calvé-Perthes disease for further study.

What does your proposed theory add to the current knowledge available, and what benefits does it have?
The percutaneous femoral head arthroplasty using calcium phosphate cement provides a guarantee to reconstruction of a spherical femoral head at cases of late-stage Legg-Calvé-Perthes disease and pave a novel way to cure the disease.

Among numerous available studies, what special further study is proposed for testing the idea?
Some key aspects of further study includes:1. A specific balloon needs to be designed to facilitate the reconstruction of a spherical shape of femoral head. 2. The speed of CPC remodeling should be correlated to that of self-repair of femoral head. 3. Minimizing the side-effect of CPC such as toxicity, leakage and embolism in vivo.

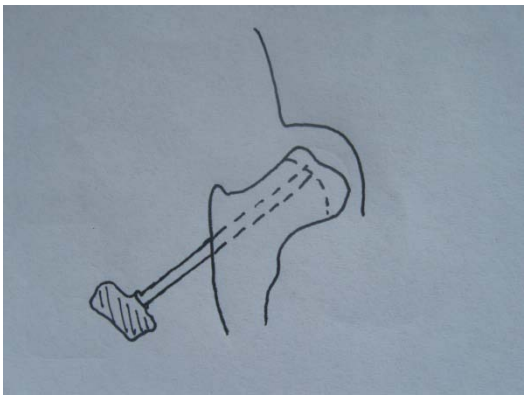

Figure 1. A work-tube was inserted near the sub-surface of collapsed femoral head under guide of fluoroscopy during the operation with a minimal invasive wound in the skin.

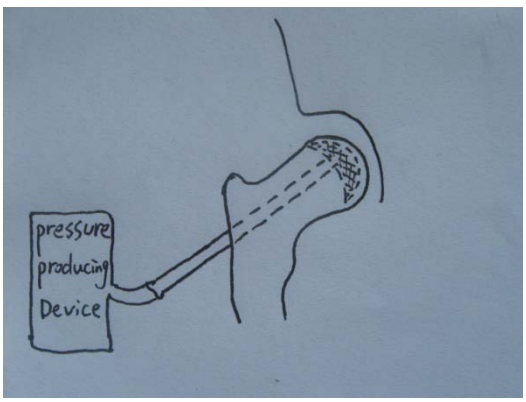

Figure 2. An inflatable balloon was inserted through the work-tube and inflated to rebuild the spherical shape of femoral head.

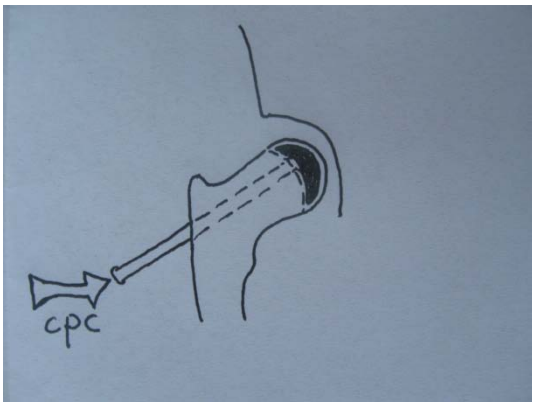

Figure 3. CPC was injected as a supporter to guarantee the spherical shape of femoral head not to transform.

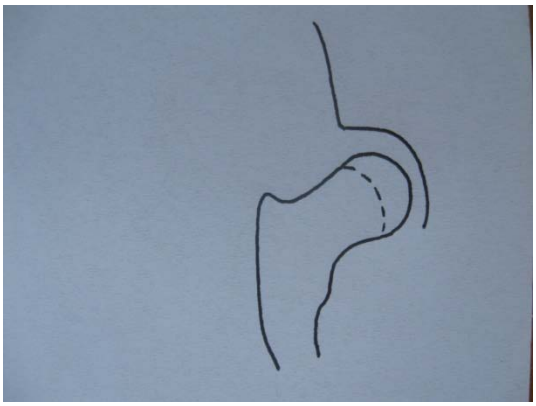

Figure 4. After self-repair of femoral head accompanying with remodeling of CPC, an intact spherical femoral head was regained.

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