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Bandung, 11 - 12 Nov 2016
Holiday Inn Pasteur

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Apatite cement versus carbonate apatite cement

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ABSTRACT

Apatite cement (AC) is one of innovations utilized for bone reconstruction. It has been used in clinical application including craniofacial surgery for several decades due to it self-setting property. AC will set and form hydroxyapatite upon setting reaction. Consequently, AC shows excellent tissue response and good osteoconductivity. However, the archetype has been shifting to carbonate apatite (CO_3Ap) cement. Researchesproved that AC will transforms to CO_3Ap in physiological body condition. The formation of CO_3Ap has been proposed as one of the keys for the replacement of AC to new bone since CO_3Ap will be resorbed by osteoclasts and replaced to new bone. This review will focus on recent research of advance improvements in AC and CO_3Ap cement reported by *in vitro, in vivo*, and clinical study.

Keywords:*Apatite cement, carbonate apatite cement*

INTRODUCTION

Brown and Chow in 1986 reported an equimolar mixture of tetracalcium phosphate (TTCP: $Ca_4(PO_4)_2O$) and dicalcium phosphate anhydrous (DCPA: $CaHPO_4$) or dicalcium phosphate dehydrate (DCPD: $CaHPO_4{\cdot}2H_2O$) set to form hydroxyapatite (HAp) in 30-60 minutes at an ambient temperature.[1,2] Apatite Cement (AC) invented by Brown and Chow is composed of two kind ofcalcium phosphate sources, TTCP and DCPA, and the setting reaction becomes more complex compared with gypsum or α-TCP. However, the setting mechanism of TTCP-DCPA based AC is the same with these gypsum or α-TCP based AC. In other words, they are based on dissolution-precipitation reaction.

When TTCP and DCPA, powder phase of TTCP-DCPA AC is mixed with an aqueous solution, both Ca^{2+} and PO_4^{3-} will be supplied, since both TTCP and DCPA have appropriate solubility. The resultant aqueous solution willbe supersaturated with respect to HAp since the solubility of HAp at neutral and alkaline region is very small. As a result, HAp crystals willbe precipitated and then interlocked to each other to form the set mass.

From different point of view, the replacement of AC by new bone formation is still is still debated.[3-17] These differences could be caused different animal experimental, different bone defect area and size, different composition of the AC or different powder and liquid mixing ratio. For example, one report concluded that the size of a cranial defect is one of the factor affecting resorption and replacement to new bone.[10]

Although detailed mechanism of AC's replacement to bone has not been clarified up to date, it is clear that AC would be replaced to bone at certain condition. The replacement of AC to bone relates to the formation of CO_3Ap. Thus, formation of CO_3Ap may be one of the keys for the replacement of AC to new bone since CO_3Ap is known to be resorbed by osteoclasts and replaced to new bone. The aim of the present study is to give a brief review of AC and CO_3Ap cement as substitution material of bone.

DISCUSSION

First advantage of AC or CO_3Ap cement is its self-setting ability in physiological condition. Since the paste of AC or CO_3Ap cement can be set and harden in bone defects, the bone defect can be filled with AC or CO_3Ap cement without leaving a gap to adjacent bone. The cells in bone such as osteoblasts cannot migrate if there is a gap between bone substitutes and adjacent bone. Second, AC or CO_3Ap cement paste showed good injectability that allows AC or CO_3Ap cement to be implantedby minimal invasive surgery techniques, that are less traumatic, reduced blood loss, shorter hospital stay and faster recovery. Third, AC or CO_3Ap cement showed excellent osteoconductivity, as a consequence of the transformation of AC to HAp or CO_3Ap upon setting reaction. Fourth, AC or CO_3Ap cement isreplaced by new bone with time even in some period of time. This property is very attractive, since sintered HAp cannot be replaced to bone. Bone are crucial not only for their mechanical role but also it biological role, such as blood formation. Therefore, bone graft that can be replaced to bone is a great deal. Fifth, the AC or CO_3Ap cement can be used to deliver drugs such as growth factor, antibiotic, anti-inflammatory, since set AC or CO_3Ap cement have micro porosity and are able to set at physiological condition.

Besides the benefits possessed by AC or CO_3Ap cement, they also have disadvantages. The lower mechanical properties of AC or CO_3Ap cement becomes an issue, limiting the use of AC or CO_3Ap cement only for non-load bearing area in clinical application. Therefore, AC or CO_3Ap cement may be better to be used in non-load bearing area such as cranial bone substitute or alveolar bone augmentation.

One of interesting manners reported for AC is the formation of CO_3Ap on the surface of AC. When TTCP-DCPA based AC was implanted at tibia of rat, CO_3Ap was found at

the surface of set AC after eight weeks implantation, despite no carbonate source was incorporated in the TTCP-DCPA based AC.[17] Since no carbonate was incorporated in the cement composition, carbonate contained in the CO_3Ap was thought to be supplied from the surrounding environment such as body fluid, blood, air, etc.

It should be noted that bone apatite is the CO_3Ap with other trace element such as Na^+, K^+, F^- as shown in Table 1.[18-19] Also, preparation of CO_3Ap powder is easy since CO_3Ap the most stable phase thermodynamically.[20-22] However, apatite powder including CO_3Ap powder causes inflammatory response called crystalline inflammatory response. Therefore, CO_3Ap should be used as cement, block or granular to arrest the response. Although CO_3Ap is the most stable calcium phosphate phase at physiological condition, it is unstable at high temperature required for sintering process and thermally decomposed to other calcium phosphate.

Table 1.Bone compositions of the human adult[18-19]

Compositions	Bone
Ca^{2+}	34.8
PO_4 as P	15.2
Na^+	0.9
Mg^{2+}	0.72
K^+	0.03
CO_3^{2-}	7.4
F^-	0.03
Cl^-	0.13

Bone remodeling is a lifelong process where mature or old bone tissue is replaced by newly formed bone. In this process, two cells known as osteoclasts and osteoblasts play an imperative role. Osteoblasts forms new bone and this has close relationship with osteoconductivity of apatite. On the other hand, osteoclasts remove matured bone. Osteoclast create Howship's lacuna where inside of the lacuna is made with acidic condition (~pH 4.5).[23] It has been reported that carbonate content in apatitic structure has close relationship with the solubility of apatite in acidic condition.[24] Therefore, it is reasonable to say that CO_3Ap is replaced to bone even though HAp is stable at the bone defect. In fact, CO_3Ap granules fabricated based on dissolution-precipitation reaction, and implanted into the cranial bone of rats, after implantation were found to be replaced to the newly formed bone 24 weeks.[25]Therefore; CO_3Ap may be a key factor for bone replacement.

CONCLUSION

Although AC has theability to transforms to HAp, the CO_3Ap cement are more beneficial than AC, because they are already in CO_3Ap form, which are more easily to replace by bone.

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