Corrosion Resistance and In Vitro Cytocompatibility of Hydroxyapatite from ale-ale Clamshell Coating on CoCrMo Alloy

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Abstract. It has been conducted the synthesize of single phase of hydroxyapatite (HAp) from ale-ale (Meretrix meretrix) clamshell waste by using double-stirring precipitation method. The biocompatibility of HAp-coated CoCrMo alloy was examined as a coating material of implant. The coating of CoCrMo alloy which was treated by using electrophoretic deposition method showed that the surface morphology was well-densified and crack-free. Corrosion resistance test showed the corrosion rate at the level of 0.0055 mils per year (mpy) on HAp-coated CoCrMo alloy, this result was better than that of uncoated CoCrMo alloy (0.0224 mpy). In vitro cytocompatibility assay in endothelial cell of Calf Pulmonary Artery Endothelium (CPAE) (ATCC-CCL 209) showed that there was no toxicity in cell culture with the percent inhibition of 33.33% after 72 hours of coated CoCrMo alloy incubation. Based on this corrosion resistance and cytocompatibility properties, HAp-coated CoCrMo alloy has the potency for bone implant application.

1. Introduction

Ketapang Regency which is located in the southern part of West Kalimantan province is very famous for its typical clam called “ale-ale”. The catchment activity of ale-ale in the region take place throughout the year. Clam species of ale-ale (Meretrix meretrix) is not only found in West Kalimantan, Indonesia, but also in Malaysia which is usually found in back-water and estuaries along the coast [1]. Most of the muscles were used as culinary and the clamshell was thrown away or accumulated to pile up on the road. The solution to optimize the benefits of ale-ale clamshell under long term aspect is held by processing the waste of ale-ale clamshell into a precursor of calcium in synthesis hydroxyapatite (HAp).

Hydroxyapatite Ca₁₀(PO₄)₆(OH)₂ has similarities to the inorganic mineral component of natural bone and teeth, approximately 65% inorganic mineral of bone composed of HAp [2]. Calcium of clamshell is expected as a precursor to synthesize HAp. Mijan et al. [1] observed that M. meretrix clamshell composed mainly 95% (by weight) of CaCO₃. Hence, it is necessary to keep developing the study of HAp because the needs and demands of this biomaterial is very high especially used as a coating material on metallic orthopedic, such as the treatment of bone, either repair the fractured bones and fractures [2-4]. Demand for the metal as implant is intensive as various of bone damages such as
bone cancer, bone fractures, and osteoporosis that can be treated by implantation of bone tissue which lost or damaged [4-5].

Metal as implant is required of having the biocompatibility properties i.e corrosion resistance and compatible in living cells. Metallic implant will directly contact to living cells in human body. Therefore these properties are being the first and foremost requirements to select the biomaterial [4]. Metals which are not biocompatible, can cause inflammation and toxicity around the body tissue. CoCrMo alloy which was used as a metal implant was known of having better mechanical strength, elastic modulus, abrasion resistance, and corrosion resistance. However, CoCrMo alloy could release metal ions which cause adverse effects, swelling, and pain surrounding the body tissues [5]. Therefore bioimplant is required of having high corrosion resistance in highly corrosive body environment. Biocompatibility and bioactivity of HAp are able to increase the corrosion resistance of metallic implant to reduce the release of metal ions, increase the biocompatibility of metallic implants, and bioactivity of HAp acts as the growth of new bone tissue [4,6].

The failure of an implantation in term of its behaviour in living tissues has remained as the clinical problem. Moreover, Implants encountered different biological environment of very different physico-chemical nature and their interaction with the tissues and bones is a complex problem [5]. Ionita et al. [7] observed that the corrosion rate in simulated body fluid (SBF) for CoCrMo alloy treated with biomimetic coating (HAp) was lower than that of untreated CoCrMo alloy. Although, Sukaryo et al. [8] has reported that in vitro cytotoxicity assay in endothelial cells was not showed the morphological changes or cell death after 72 h of sample incubation from coated CoCrMo alloy, yet the cytocompatibility properties of HAp-coated CoCrMo alloy is important to know. It is because the corrosion resistance data showed that HAp-coated CoCrMo alloy better than that of uncoated CoCrMo alloy [7]. In addition, the potential of ale-ale waste clamshell as a precursor of HAp also has never been reported.

This study aimed to utilize the waste of clamshell as a precursor of calcium to synthesize HAp, obtain single phase of HAp by double stirring precipitation method, characterize the CoCrMo alloy after coating with HAp, and examine the biocompatibility of HAp-coated CoCrMo alloy by corrosion resistance test and in vitro cytocompatibility assay in endothelial cell of Calf Pulmonary Artery Endothelium (CPAE) (ATCC-CCL 209). The results are expected to provide the information of the potency of ale-ale clamshell for bone implant application.

2. Materials and Methods

2.1. Materials and Instrumentation

2.1.1. Materials. Materials used in this experiment are as follow: clamshell of ale-ale was collected from Ketapang West Kalimantan, CaCO₃ (Merck), CoCrMo alloy (Nilaco Corporation, Japan), carbon rods, (NH₄)₂HPO₄ (Merck), triethanolamine (TEA) (Merck), ethanol (Merck), 0.9% NaCl intravenous infusion (otsuka), endothelial cell CPAE (ATCC CCL-209) (American Type Culture Collection, U.S.A).  

2.1.2. Instrumentation. Instruments used in this study were ultrasonic processor CPX 130, ultrasonic cleaner US-3, analog micrometer, grinding paper grit 1000, cell culture equipments, X-ray Diffraction (XRD) Shimadzu XD-7000, Fourier Transform Infrared (FTIR) Spectrometer Bruker Tensor 3, Scanning Electron Microscopy (SEM) Carl-Zeiss Bruker EVO MA10, Energy Dispersive X-Ray Spectroscopy (EDX) Bruker, Particle Size Analyzer (PSA) Vasco DLS, Atomic Absorption Spectrophotometer (AAS) Shimadzu AA-7000, Electrophoretic Deposition (EPD) PS-520, and potentiostat/galvanostat M273.
2.2. Methods

2.2.1. Sample Preparation and Synthesis of HAp Powders. Washed clamshells were dried under the sunlight to remove adhering water. The dried waste shells were crushed into small portion using a grinder machine to fine powder and sieved to 100 mesh [1]. Phase of 100 mesh powder was carried out by XRD, quantitative determination of Ca was measured by AAS with $\lambda = 422.7$ nm [9], and the elemental analysis of the powder was determined by using the EDX. Waste shell powder was then calcined at 1000 °C for 3 h. The ash obtained from the calcination process converted under atmosphere conditions to generate active Ca(OH)$_2$. Phase of Ca(OH)$_2$ was carried out by XRD [10].

HAp powder was synthesized by utilizing double-stirring (ultrasonic-magnetic) precipitation method using Ca(OH)$_2$ and (NH$_4$)$_2$HPO$_4$ at mole ratio of Ca/P=1.67. Suspension of Ca(OH)$_2$ was prepared from Ca(OH)$_2$ powder extracted from ale-ale shells by dissolving 14.7410 grams of Ca(OH)$_2$ in 100 mL double distilled water, meanwhile, (NH$_4$)$_2$HPO$_4$ solution prepared by dissolving 15.7840 grams of (NH$_4$)$_2$HPO$_4$ in 100 mL double distilled water. Then, (NH$_4$)$_2$HPO$_4$ solution was slowly added dropwise to the suspension of Ca(OH)$_2$ and rigorously stirred for 2 h by using double-step stirring techniques (the magnetic stirrer and ultrasonic processor at 20 KHz frequency and 130 W power). In all experiments, the final pH was kept around 10. The wet cake was kept for 24 h of ageing at room temperature. Then, HAp precipitate was washed with distilled water. Gel obtained was dried at 100 °C in a dry oven and calcined at 1000 °C for 5 h. The characterizations of the phase and crystallite size of the resulted powder were carried out by using XRD. The functional groups were evaluated by using FTIR. The surface morphology and size of the product were assessed by using SEM. The particle size distribution was evaluated by using PSA [11].

2.2.2. Electrophoretic Deposition of HAp Particles on CoCrMo Substrates. The suspension was prepared by adding 1 gram of HAp powder into 50 mL of absolute ethanol. The addition of 5 mL TEA (dispersant) into ethanol resulted in the positively charged particles. The prepared suspension was dispersed in a 38 kHz (360 W) ultrasonic waterbath vibrator for 30 min. Prior to deposition, CoCrMo substrates with the chemical composition of Co 66.76, Cr 28.11, and Mo 5.13 wt.% were polished up to 1000 grit paper followed by ultrasonic cleaning and subjected to ethanol for 5 min and rinsed in distilled water. Then CoCrMo substrates were dried for further coating process. CoCrMo substrate as the cathode and carbon rod as the anode were immersed in the suspension. The EPD process was conducted for 30 min, under a constant voltage of 120 V. The phase composition of coated surface was analyzed by using XRD. The thickness of the coating result was measured by using micrometer analogue. The surface morphology analysis of coated and uncoated CoCrMo alloy were carried out by using SEM [12].

2.2.3. Corrosion Resistance Test. CoCrMo alloy was cut rounded into equal size by polishing in the size of 14 mm diameters. The sample was immersed into three electrodes corrosion test instrument, which had been filled with 500 mL of NaCl intravenous fluids. Standard saturated calomel was used as the reference electrode, two carbon bars were used as supporting electrodes, and CoCrMo alloy was functioned as the working electrode. The corrosion cell was connected to the potentiostat M273 by applying a potential from -20 to 20 mV. From this measurement, anodic-cathodic tafel constants would automatically obtained and corrosion rate could be determined [13].

2.2.4. In Vitro Cytotoxicity Assay in Endothelial Cell CPAE. The cells were seeded (2 x 10$^4$ cells/well) in 6-well plate and the cells were incubated for 24 h at 37 °C with 5% CO$_2$. Meanwhile, the samples (CoCrMo and coated CoCrMo alloy) were cut into small pieces of 2 mm. The samples were sterilized with $\gamma$-radiation (15 kGy). Then the samples were placed in sterilized culture medium of CPAE (cells have reached confluence). Untreated cultures were used as negative control. The samples in culture medium were incubated for 72 h at 37 °C with 5% CO$_2$. The cells number was determined.
by using a hemocytometer. Cell viability was checked by trypan blue exclusion and the percent inhibition could be determined [14].

3. Results and Discussion

3.1. Results of Sample Preparation and Characterization of HAp Particles

The XRD pattern of ale-ale clamshell before calcination process showed that ale-ale clamshell is a single phase of CaCO$_3$ (aragonite) according to the JCPDS file No. 41-1475 (Figure 1).

![Figure 1. XRD pattern of ale-ale clamshell before calcination process.](image)

The calcination process of clamshell powder aimed to transform CaCO$_3$ into CaO by the chemical reaction CaCO$_3$(S) $\rightarrow$ CaO(S) + CO$_2$(g). CaO obtained then left at the room temperature so that the hydration of CaO into Ca(OH)$_2$ by the chemical reaction occurred: 2CaO(S) + 2H$_2$O(g) $\rightarrow$ 2Ca(OH)$_2$(S). The XRD pattern of ale-ale clamshell after being calcinated showed the phase of Ca(OH)$_2$ (portlandite) at 2θ = 18.04°, 28.71°, 34.13°, 47.29°, 50.84°, 54.39°, 59.44°, 62.68°, 64.43°, and 71.86° (according to the JCPDS file no. 44-1481) (Figure 2).

![Figure 2. XRD pattern of ale-ale clamshell after calcination process.](image)

The appearance of other peaks at 2θ = 23.11°, 29.42°, 35.95°, 39.41°, 43.15°, 48.52°, 57.30°, and 60.60° showed that the impurities of CaCO$_3$ which did not completely transformed into the Ca(OH)$_2$ were still exist, however it did not interfere to the presence of a single phase of HAp. The obtained Ca(OH)$_2$ was used as the starting material to synthesize HAp.
Analysis of calcium content by using AAS showed that ale-ale clamshell was 68.0454 % (by weight). The elemental compositions of ale-ale clamshell by using EDX showed that the dominant elements were calcium (Ca), oxygen (O), and carbon (C) with percentages of about 79.24, 17.79, and 2.97 wt.%, respectively. The EDX was performed to ensure that the main elemental compositions of the sample were calcium, oxygen, and carbon which was in agreement with the resulting phase from the XRD analysis (CaCO₃). The result of AAS and EDX proved that ale-ale clamshell was potential to be used as a precursor of calcium to synthesize HAp.

HAp powder was prepared according to the following chemical equation:

\[
10\text{Ca(OH)}_2 + 6(\text{NH}_4)_2\text{HPO}_4 \rightarrow \text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2 + 6\text{H}_2\text{O} + 12\text{NH}_4\text{OH}
\]

The presence of HAp was presented in Figure 3.

![Figure 3. XRD pattern of HAp particles.](image)

The XRD pattern showed that the product was a single phase of HAp (according to the JCPDS file no. 09-0432) which had the strong characteristic peaks at 2θ = 31.83°, 32.24°, and 32.96° without any secondary phases. It was also proved by the crystallinity degree from XRD of HAp was 90.12% and the crystallite size of HAp was calculated by Scherrer formula found to be 41.08 nm.

Further, confirmation on the functional groups of HAp was performed by using FTIR and the result was shown in Figure 4. The wave numbers of functional groups that belong to HAp powders indicated PO₄³⁻ bands at 1092.02, 1038.29, 962.45, 602.30, and 571.71 cm⁻¹. Similar to that previous observed on PO₄³⁻ bands at 1090, 602, and 570 cm⁻¹ [12].
The OH\(^{-}\) stretching vibration was observed at 3572.28 and 632.18 cm\(^{-1}\). Similar to the OH\(^{-}\) stretching vibration reported by Farnoush et al. [12] was observed at 3572 and 632 cm\(^{-1}\). The water associated with HAp appeared at 3444.46 cm\(^{-1}\). The obtained result was similar to the water associated with HAp observed by Yoruc and Koca [11] appeared at 3461, 3437, 3436, and 3425 (3461-3436, 2926-2924) cm\(^{-1}\). The weak peak at 1496.07 cm\(^{-1}\) was attributed to CO\(_3^{2-}\). Similar to that previously observed the blunt and smooth peaks at 1470 and 1420 cm\(^{-1}\) were attributed to CO\(_3^{2-}\) ions which might be the result of the absorption of atmospheric CO\(_2\) on the surface of HAp particles [12]. It was also in agreement with CO\(_3^{2-}\) appeared at 1454.33 cm\(^{-1}\) reported by Herawaty et al. [15]. Dedourkova et al. [2] observed that the carbonate substitutions of hydroxyl or phosphate groups appeared during wet chemical precipitation because of ambient carbon dioxide solubilization related to vigorous stirring. The FTIR spectrum confirmed the presence of HAp.

The SEM images of HAp particles were presented in Figure 5. The particles possess spherical morphology, the average pore size distributed homogeneously, and had one of the nano sized spherical particle with the diameter size of approximately 167.9 nm.
The porous HAp had potency to provide a good biological environment to promote cell adhesion, cellular interactions, proliferation, and migration [4]. Thereby, HAp could be expected in having capability to support the bone tissue in growth upon implantation. The morphology of particles formed the agglomerates (Figure 5 a and b). The obtained result was similar to the SEM image of HAp which has been carried out by using the same precipitation method by Yoruc and Koca [11] which showed that HAp was spherical morphology and agglomeration of particles in HAp. Micro-sized particles occurred as a result of strong agglomerate of nano-sized particles. Dedourkova et al. [2] also observed the sphere-like primary crystals of nano HAp which were 30-50 nm in diameter and some aggregates.

The size distribution by intensity of HAp particles illustrated in Figure 6. Analysis of PSA showed the average of particle size distribution was 670.26 nm. The average of particle size distribution was still quite larger than that of the standard nano-size (size less than 100 nm) [16].

![Figure 6. Particle size distribution of HAp particles.](image)

One interesting property of nano HAp was when it bonds with bone, it formed an indistinguishable union with the surrounding bone tissue [4]. This result was related to the higher temperature in calcination caused the increase of crystalline size. This was caused by the growing number of contiguous atoms in order, which made the structure of HAp was getting perfectly. It was indicated by the growth of the amorphous phase into a crystalline phase [17]. The result was in good agreement with the XRD result which obtained a strong reflection peak in the as-synthesized HAp. It was concluded that the crystallization increased with the temperature, resulting in larger size, and cause sharper peaks of XRD. Similar to Manafi and Joughehdoust [18] reported that the influence of temperature in synthesis of HAp by hydrothermal method which indicated that amorphous HAp transformed into crystalline HAp under high-temperature conditions, the peak ascribed to HAp phases at a higher temperature of 200 °C showed better crystallization compared with HAp formed 150 °C even for a long reaction time.

3.2. Characterization of the Coatings

The mechanism of EPD involves two steps. At the first step, an electric field was applied between two electrodes, then the charged particles suspended in a suitable liquid move toward the oppositely charged electrode (electrophoresis). At the second step, the particles accumulated and deposited on the electrode and create a relatively compact and homogeneous film (deposition) [19]. The XRD pattern of HAp-coated CoCrMo alloy could be seen in Figure 7.
The XRD pattern of the coating resulted in diffraction peak that correspond to the standard of HAp (JCPDS file No. 09-0432). The main crystalline phase of coating was still HAp and a small impurity phase of CaCO$_3$ at 2θ = 44.47° which indicated the result of the absorption of atmospheric CO$_2$ on the surface of HAp particles. The crystallinity degree of HAp-coated on CoCrMo was 83.28%.

The crystallinity degree of HAp-coated on CoCrMo was lower than that of the crystallinity degree of HAp before the coating process. It was probably caused by the influence of voltage and the time on the EPD process. The high voltage and the deposition time were the important factors in the preferential deposition of small particles [20]. It was in agreement with this result showed that the voltage was used in the EPD process could minimize the size of the particles, as a consequently the crystallinity degree be lower than HAp before the coating. The lower the crystallinity degree, the smaller crystalline size of HAp. Thus, peak broadening of HAp-coated on CoCrMo was the consequence of small crystal size of the coating material. EPD in this process successfully did not affect the structure of HAp.

The SEM image of the the surface morphology of CoCrMo alloy after being coated by HAp was shown in Figure 8. The surface morphology of HAp-coated CoCrMo alloy was homogenous, spherical shape, well densified, and fracture free. The thickness of coating was about 0.08 μm.

This indicated that ethanol with the addition of TEA as dispersant was effective in breaking up the agglomerated particles to produce the stable colloidal suspension. TEA was proven to be an efficient dispersant for the EPD process. The –OH group of HAp would probably be hydrogen-bonded to
aliphatic alcohol and the –OH group of TEA. The aliphatic chains of TEA might also act as a steric barrier between two particles and improve the dispersion stability. Therefore, the addition of TEA was in favor of EPD of HAp coatings [21]. Javidi et al. [6] also reported that the surface morphology of HAp coated on 316L stainless steel represented continuous, uniform, and crack-free.

3.3. Corrosion Resistance
Corrosion resistance test aimed to obtain the information of biocompatibility of HAp-coated CoCrMo alloy. In this study, HAp-coated CoCrMo alloy was conditioned as implant in biological environment which would be in direct contact with the intravenous fluids, which was conditioned as the medium of body fluids. The amount of material that would be dissolved from the unitary surface in a given length of time measured by corrosion rate. Corrosion rate was quoted in mills per year (1 mpy = 2.5410^-3 mm year^-1). The corrosion rate of HAp-coated CoCrMo alloy in chloride acid solution medium, in comparison with the uncoated substrate was shown in Figure 9. It was observed that the corrosion rate for the coated sample was four orders of magnitude lower than that of the uncoated substrate. It proved that coated metal was better than metal without HAp coating.

![Figure 9. Corrosion rate of uncoted CoCrMo and HAp-coated CoCrMo alloy.](image)

According to the rule established by Fontana [22], the smaller the value of corrosion rate, it would have an increasingly good corrosion resistance. The corrosion rate value of HAp-coated CoCrMo alloy was in the outstanding level of corrosion resistance which was of the best level performance in the corrosion resistance. This result indicated that HAp-coated on CoCrMo alloy could act as a protective layer against ion diffusion and corrosion, and also improved the corrosion resistance of the CoCrMo substrate in the body fluid environment. The metallic ion release from CoCrMo alloy could be minimized by HAp as osseointegration agent. Salman et al. [23] reported that application of HAp as coating of the metallic implants, combined the strength and toughness of the substrate with bioactive characteristic of the coating material which was able to induce the surrounding bone tissue in growths and future formation of chemical bonding. Further, the presence of HAp coating could improve corrosion resistance of the coated implant in human body which could reduce the metallic ion release and also promotes fixation via chemical bonding.

Outstanding level of corrosion resistance also supported by surface oxide film formed on metallic materials which played an important role as an inhibitor for the release of metallic ions. The passive oxide layer also developed in CoCrMo alloy in the biological solution. The presence of chromium was capable of forming the passive Cr2O3 layer CoCrMo alloy. The passive Cr2O3 layer CoCrMo alloy behaved as an effective barrier to corrosion, and increased the resistance to charge transfer at the corrosion interface [24]. Therefore, the passive oxide Cr2O3 developed the CoCrMo alloy was able to
increase the corrosion resistance in the substrates. It was also supported from analysis of EDX and XRD resulted possibly chrome oxide [13].

3.4. In Vitro Cytocompatibility

In this study, in vitro cytocompatibility test aimed to determine cell viability in direct contact with the samples. Cell viability expressed by cytotoxicity assay after 72 h incubation in endothelial cell CPAE (ATCC CCL-209). Endothelial cells were chosen because they were the key cells that involved in blood vessel formation [25]. Hydroxyapatite was able to increase the proliferation of endothelial required for the formation of new blood vessels (angiogenesis). The formation process of new blood vessels was very important in the repair process of damaged tissue, tissue growth, and the healing process [26]. Therefore, HAp-coated CoCrMo alloy as implant material which functioned to accelerate the healing process should not causes the cytotoxicity in endothelial cell culture.

The percent inhibition showed the inhibition of cell growth due to the exposure by the sample. The percent inhibition was expressed in median effective dose (ED50). If the percent inhibition in excess of 50%, the sample classified as toxic [27]. The percent inhibition of endothelial cells was shown in Table 1.

Table 1. Percent inhibition of endothelial cell viability after 72 h of samples incubation.

| No | Sample                    | Inhibition (%) |
|----|---------------------------|----------------|
| 1  | CoCrMo                    | 100            |
| 2  | CoCrMo+Hap                | 33.33          |
| 3  | Negative control (untreated control cells) | 0 |

Based on the percent inhibition, the uncoated CoCrMo alloy classified as toxic. This was also confirmed from the cells morphology of uncoated CoCrMo alloy after 72 h in incubation, indicated no cell was still alive in endothelial cell (Figure 10d). This is different with the endothelial cells of untreated control cells (Figure 10a and b) and uncoated CoCrMo alloy at 24 h (Figure 10c). It might be caused by the metallic ion releasing from CoCrMo alloy. In contrary, the percent inhibition obtained from HAp-coated CoCrMo alloy did not exceed 50% so that it was qualified as an biocompatible implant. This was also confirmed from the morphology of endothelial cells at 24 h (Figure 10e) and 72 h after incubation (Figure 10f) of HAp-coated CoCrMo alloy showed that endothelial cells has been adapted to the biomaterial implant.
The result of this cytocompatibility was in accordance with enhanced corrosion resistance of HAp-coated CoCrMo alloy. Previously, in vitro cytotoxicity studies on the L-929 cell in individual extraction mediums of uncoated and HAp-coated ZK60 alloy (Mg-5.5wt%Zn-0.5wt%Zr) showed that with enhanced corrosion resistance by the coating, the coated ZK60 will had higher cytocompatibility than the uncoated one [28]. Furthermore, the high degree of crystallinity of HAp coating also demonstrated its influence on good biological cellular responds at in vitro assay. Yang et al. [28] also reported that the coated ZK60 alloy had excellent biological cellular responds, as well as enhanced bioactivity, due to the high degree of crystallinity of HAp coating. Cell viability also reported by Huan et al. [29] which stated that a lower corrosion resistance leads to a higher pH value caused by corrosion, which finally reduces cell viability.

4. Conclusion
The calcium content of ale-ale clamshell could be utilized as a starting material in synthesis of hydroxyapatite. Hydroxyapatite which was synthesized by using double-stirring (ultrasonic-magnetic) precipitation showed the single phase of hydroxyapatite without any secondary phase. Hydroxyapatite particles which were electrophoretically deposited on CoCrMo alloy showed that the surface morphology was well-densified and crack-free. Hydroxyapatite-coated CoCrMo alloy had a better corrosion resistance than that of uncoated CoCrMo alloy. In vitro cytocompatibility assay in endothelial cells CPAE (ATCC-CCL 209) showed that there was no toxicity in cell culture of hydroxyapatite-coated CoCrMo alloy. Based on its corrosion resistance and cytocompatibility properties, hydroxyapatite-coated CoCrMo alloy had the potency as biocompatible implant for bone implant application.
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