Effect of different preparation conditions on the properties of nano-hydroxyapatite/bamboo fiber composite membrane

Jiang Liuyun (jlytxg@163.com)
College of Chemistry and Chemical Engineering, Hunan Normal University https://orcid.org/0000-0002-8592-5736

Zhihong Jiang
Hunan Normal University

Bingli Ma
Hunan Normal University

Yingjun Ma
Hunan Normal University

Yue Wen
Hunan Normal University

Na Zhang
Hunan Normal University

Yan Zhang
Hunan Normal University

Shengpei Su
Hunan Normal University

Xionggui Tang
Hunan Normal University

Xiang Hu
Hunan Normal University

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Effect of different preparation conditions on the properties of nano-hydroxyapatite/bamboo fiber composite membrane

Liuyun Jiang [*a, b], Zhihong Jiang [a, b], Bingli Ma [a, b], Yingjun Ma [a, b], Yue Wen [a, b], Na Zhang [a, b], Yan Zhang [a, b], Shengpei Su [a, b], Xionggui Tang [*c], Xiang Hu [*d]

a National & Local Joint Engineering Laboratory for New Petro-chemical Materials and Fine Utilization of Resources, College of Chemistry and Chemical Engineering, Hunan Normal University, Changsha 410081, PR China

b Key Laboratory of Chemical Biology & Traditional Chinese Medicine Research (Ministry of Education, China), College of Chemistry and Chemical Engineering, Hunan Normal University, Changsha 410081, PR China

c College of Physical & Electronic Science, Hunan Normal University, Changsha 410081, PR China

d State Key Laboratory Developmental Biology of Freshwater Fish, School Life Science, Hunan Normal University, Changsha, 410081, PR China

Abstract

A novel nano-hydroxyapatite/bamboo fiber (n-HA/BF) composite membrane was obtained by a simple casting technique. The membrane forming mechanism and the effects of different forming membrane methods, drying methods and n-HA amounts on the properties of n-HA/BF composite membrane were investigated by Fourier Transform infrared spectroscopy (FT-IR), X-ray diffraction (XRD), scanning electron microscopy (SEM), contact angle, electromechanical universal tester, *in vitro* soaking in simulated body fluid (SBF) and *in vitro* cell culture experiment. The results demonstrated that the dispersity of n-HA nanoparticles in BF matix was not affected by the prepartion condition, however, the morphologies of membrane was determined by the different preparation conditions owing to different hydrogen bond shrinkage. Moreover, the hydrophilicity of the composite membrane was improved under the condition of the membrane formation in oven, freeze drying and high addition content of n-HA, and the mechanical properties of composite membrane depended on n-HA content. *In vitro* soaking behavior indicated that the degradability and bone-like apatite deposition could be controlled by different preparation conditions. And the cell proliferation experiment showed that the n-HA/BF composite membranes obtained under different preparation conditions were all non-toxic. The above results indicated that the casting technique could be used to prepare n-HA/BF composite membrane, and the properties of the composite membrane could be controlled by adopting different preparation conditions, which would have a great promising as guide bone tissue regeneration (GBR) membrane, and the study would provide a new application for BF in biomedical field.

Keywords: Bamboo fiber; nano-hydroxyapatite; composite membrane; degradation

Introduction

Guided bone regeneration (GBR) membrane is commonly used in bone defect, which was placed

Tel.: +86 0731 8887 3111; fax: +86 0731 8887 3111,
E-mail address: jlytxg@163.com, tangxg@hunnu.edu.cn, huxiangsky123123@163.com

on the bone defect area as barrier membrane to create a singular space, so as to prevent epithelial cells from growing into the defect, and permit osteoblasts to proliferate and new bone to form (Jiang et al., 2015; Niu et al., 2021; Li et al., 2020; 2015). Ideally, GBR membrane should possess appropriate mechanical properties, space-retention ability, biocompatibility and biodegradability (Lee et al., 2016; Yu et al., 2020; Hoornaert et al., 2016). To obtain a satisfactory GBR membrane, natural biodegradable polymers have become a research hotspot owing to better biocompatibility and biodegradability, compared with the synthetic polymers (Prajatelistia et al., 2021; Ma et al., 2019; Mora-Boza et al., 2020; Bierhalz and Moraes, 2017; Pappu et al., 2019; Gurunathan et al., 2015; Weng et al., 2020).

Bamboo fiber (BF) is a natural fiber extracted from bamboo, which has high strength, biodegradability and low cost. Therefore, BF is usually used as a reinforcing agent for polymers (Khalil et al., 2012; Liu et al., 2012; Phuong et al., 2019; Long et al., 2019; Zuo et al. 2019). In our group, we have systematically studied and concluded that BF had remarkable reinforce effect on the n-HA/poly (lactide-co-glycolide) (n-HA/PLGA) composite (Li et al., 2015; Jiang et al., 2017; 2018; 2019). Moreover, BF has been used to reinforce electrospunn membrane (Chingakham et al., 2020; Cai et al., 2018). However, as we know, casting membrane has denser structure, which would display better mechanical strength and slower degradation than electrospinning membrane (Oksana et al., 2020). Moreover, casting membrane could be prepared by a simple casting technology method. Therefore, we studied the reinforce effect of carboxylated BF on chitosan-based casting membrane via ionic crosslinking (Tang et al., 2020). However, the preparation procession of carboxylated BF was too tedious. In addition, in the above-mentioned study, BF was usually added in the primeval state fiber form as reinforcement,

65 which would be adverse for dispersion, so it would be expected to explore a novel BF-based
66 polymer membrane by a simple and green processing.

67 BF could be dictrectly dissolved into homogeneous solution and casting membrane would be
68 formed, whileas, pure BF membrane lacks osteoconductivity, which would be detrimental to
69 guide bone tissue regeneration, while nano-hydroxyapatite (n-HA) has good osteogenic activity
70 becausee of its similarity with inorganic component of natural bone, so it was normally added
71 into polymeric matrix as nanofiller to endow polymers with better biological performance (Zhao
72 et al., 2018; Muhammad et al., 2017). In addition, in our previous study, we found BF could
73 replace other polymers to develop n-HA/BF nanocomposite by co-precipitation method, and it
74 had a promising to be used as bone materials (Ma et al., 2020). However, whether BF could be
75 replayed other polymers to obtain n-HA/BF composite membrane by solution blending method,
76 and what effects would different prepartion conditions produce on the properties of the n-HA/BF
77 membrane, including different forming membrane methods, drying methods and n-HA amounts,
78 and whether the n-HA/BF membrane would be used as GBR membrane, which were all not be
79 reported and it was worth exploring.

80 Based on these, in this work, we attempt to study the fabrication of the n-HA/BF composite
81 membrane by casting method, and the effects of different preparation conditions including
82 forming film methods (in air and in oven), different drying methods (in air, in oven, in freeze
83 dryer) and different n-HA content (10%, 20%, 30% and 40%) on the properties of the n-HA/BF
84 composite membranes were studied by Fourier Transform infrared spectroscopy (FT-IR), X-ray
85 diffraction (XRD), scanning electron microscopy (SEM), contact angle, electromechanical
86 universal teste. Moreover, the degradation behavior of the n-HA/BF composite membrane was

investigated by soaking in simulated body fluid (SBF). Finally, the cell culture experiment was carried out. The main purpose of the work is to demonstrate the feasibility of the fabrication of the n-HA/BF composite membrane by a simple casting method, so as to provide a new GBR membrane by making full use of natural biomass resources.

Experiment Section

Materials

Bamboo fiber (BF) was provided by Zhejiang A&F University, whose size was Φ (0.03-0.2) mm × (6-10) cm. Dimethylacetamide (DMAc, AR) and LiCl (AR) were purchased from Aladdin. Ca $(NO_3)_2.4H_2O$(AR), $Na_3PO_4.12H_2O$(AR), P_2O_5, and NaOH (AR) were all from Tianjin Fengchuan Chemical Reagent Technologies Co. Ltd.. Other agents were analytical grade.

Preparation of the n-HA/BF composite membranes

Bamboo fiber was dissolved in DMAc/LiCl system with the concentration of 1.3 wt%. A certain amount of n-HA was dispersed in DMAc by ultrasonic treatment, which was slowly added into bamboo fiber solution with the magnetic stirring, and the evenly dispersed mixture solution was poured on the clean and dry glass plate, and the thickness of the membrane was adjusted by the glass rod with two copper rings. Then, the glass plate covered with n-HA/BF mixture solution was put in air or in oven (70 ℃) to form film, afterword, it was dried in air, in oven (70 ℃) or freeze drying, thus, n-HA/BF composite membrane with 20% n-HA were obtained by six methods, and the membranes were noted as air-air, air-oven, air-freeze drying, oven-air, oven-oven and oven-freeze drying, respectively. Moreover, n-HA/BF composite membrane with different n-HA contents of 10 %, 20 %, 30 % and 40 % n-HA were prepared by air-air method in the similar procedure.

Characterization of the composite membranes

The appearance of the membranes acquired by the two different preparation methods of air-oven and oven-oven were given as examples, which was taken by normal digital camera.

Thermo Niclet 670 spectrometer was used to analysis the Fourier transformation infrared (FTIR) of samples, and the collected spectrum range was 600~ 4000 cm^{-1}.

The phase analyses of samples were carried out by X-ray diffraction (XRD) (a Rigaku Corporation X-ray diffractometer) with Cu-Kα radiation, the scanning speed of 5°/min at 40 kV and 45 mA, the range of 2θ=10~70°.

The morphologies of samples treated with the gold sputtering were observed by scanning electron microscopic (SEM, S-520, Hitachi, Japan).

The contact angles of samples were measured with rotating drop interfacial tensiometer (TX500TM, Kono, USA). The sample was put on the slide, and the distilled water was dropped onto the membrane surface by stop drop method, then the water drop on the sample was observed.

The tensile strengths of samples with the size of 0.2 mm × 4 mm × 60 mm were measured by electromechanical universal testing machine (WDW-20, China) with the speed of 5 mm/min under 60 % relative humidity at room temperature, and the mean value was calculated based on the five parallel samples of each specimen.

In vitro degradation of the composite membranes

The degradation of n-HA/BF composite membrane *in vitro* was studied by soaking in SBF, whose ion concentration was very similar to that of human plasma, and it was obtained according to the following procedure, that is, $NaHCO_3$ (0.350 g), NaCl (7.996 g), KCl (0.224 g), K_2HPO_4 ·

$3H_2O$ (0.228 g), $CaCl_2$ (0.278 g), Na_2SO4 (0.071 g), $MgCl_2 \cdot 6H_2O$ (0.305 g) were dissolved in deionized water in order, and buffer with trimethylolmethylaminomethane (6.057 g) and hydrochloric acid to adjust the solution to physiological pH=7.40 at 37 ℃ (± 0.5℃). The samples were taken out from SBF at 2, 4, 6 and 8 weeks, and filter paper was used to absorb surface residual washing water. The weight loss rate and water absorption were calculated as follows.

$$\text{Weight loss rate } /\% = (w_1 - w_3)/w_1 \times 100\%$$

$$\text{Water absorption } /\% = (w_2 - w_3)/w_3 \times 100\%$$

The original weight of the sample was noted as W_1, and the wet weight and the dry weight was noted as W_2 and W_3, respectively, after being entirely dried after soaking.

In vitro cell biocompatibility of the composite membranes

Bone mesenchymsal stem cells (BMSCs) were used to primarily assess *in vitro* cells viability, which was isolated according to the related literature (Hoseini et al., 2015; Ye et al., 2019). The samples with the thickness of 0.2 mm and diameter of 6.0 mm were cleaned with 75 % ethanol solution, sterilized under ultraviolet lamp. The treated samples were placed in a 96-well plate with the density of 4000 cells/well without disturbed in an incubator for 3 hours, then an additional 1 mL culture medium was added into each well.

The cell proliferation was evaluated by MTT (3-(4,5-dimethylthiazol-2yl)-2,5-diphenyl-2H-tetrazolium bromide) assay (Priyadarshini et al., 2018; Shakeri et al., 2014; Hivechi et al., 2021). At designated time of 1, 2 and 3 days, the medium for the cell-seeded materials were discarded, and 100 μL MTT solution with 3 mg/mL was added, incubated at 37 °C in an air atmosphere containing 5 % CO_2 for at least 4 hours, and 100 μL DMSO was added to dissolve the formazan crystals. Then the 200 μL purple solution was absorbed and transferred into a new 96-well plate,

and the optical density (OD) values of the solution were measured in microplate reader (Synergy HTX, BIOTEK, USA) at 495 nm.

Results and discussion

Characterization of surface-modified n-HA

Appearance of the membranes

Fig. 1 displays the n-HA/BF composite membrane appearance, it can be seen that the membrane formed in air had smaller area and thicker than that formed in oven, which was mainly caused from the different changes of the hydrogen bonds between the bamboo fiber molecules. In air, the bamboo fiber was easy to absorb the water, which would make the hydrogen bond shrinkage in the bamboo fiber, thus the bamboo fiber was gelled and DMAC/LiCl solution precipitated from the edge, resulting in thicker film and smaller area. While in oven, DMAC solvent was easy to volatilize and the hydrogen bond between the bamboo fiber molecules was destroyed, and the bamboo fiber has been formed before shrinkage, resulting in thinner film and larger area.

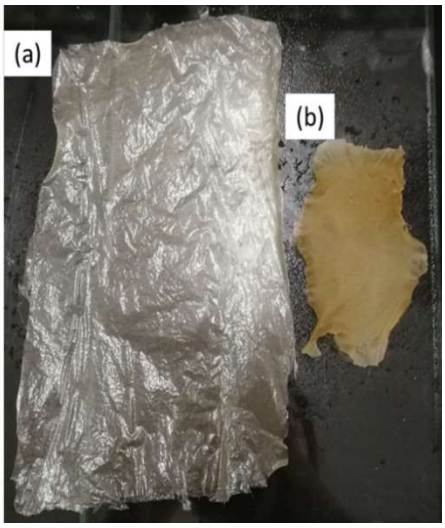

Fig.1. Membrane appearances formed by different conditions. (a) in oven, (b) in air.

IR analysis

Fig. 2 is the FT-IR spectra of different n-HA/BF composite membrane obtained by different

methods and different n-HA contents. The characteristic peaks of 2920 cm^{-1} and 2846 cm^{-1} corresponded to the tensile vibration of C-H bond on methylene of BF existed in n-HA/BF composite membrane. In addition, the characteristics peaks at 3567.2 cm^{-1} attributed to the tensile vibration of OH^- and the peaks at 1095 cm^{-1}, 604 cm^{-1} and 565 cm^{-1} of PO_4^{3-} were related to n-HA (Chesley et al., 2020). The peak position did not transfer obviously when n-HA was added into BF, which indicated that n-HA was simply blended with BF without chemical change. Compared with the membrane formed in oven and in air, the peak intensity of the film formed in oven was markedly weakened, for example, the sharp peak at 1043 cm^{-1}, which was caused by less substance in the unit area for the thinner film formed in oven. Additionally, for the different n-HA/BF composite membrane with different n-HA contents, there was no obvious difference for the characteristics peak.

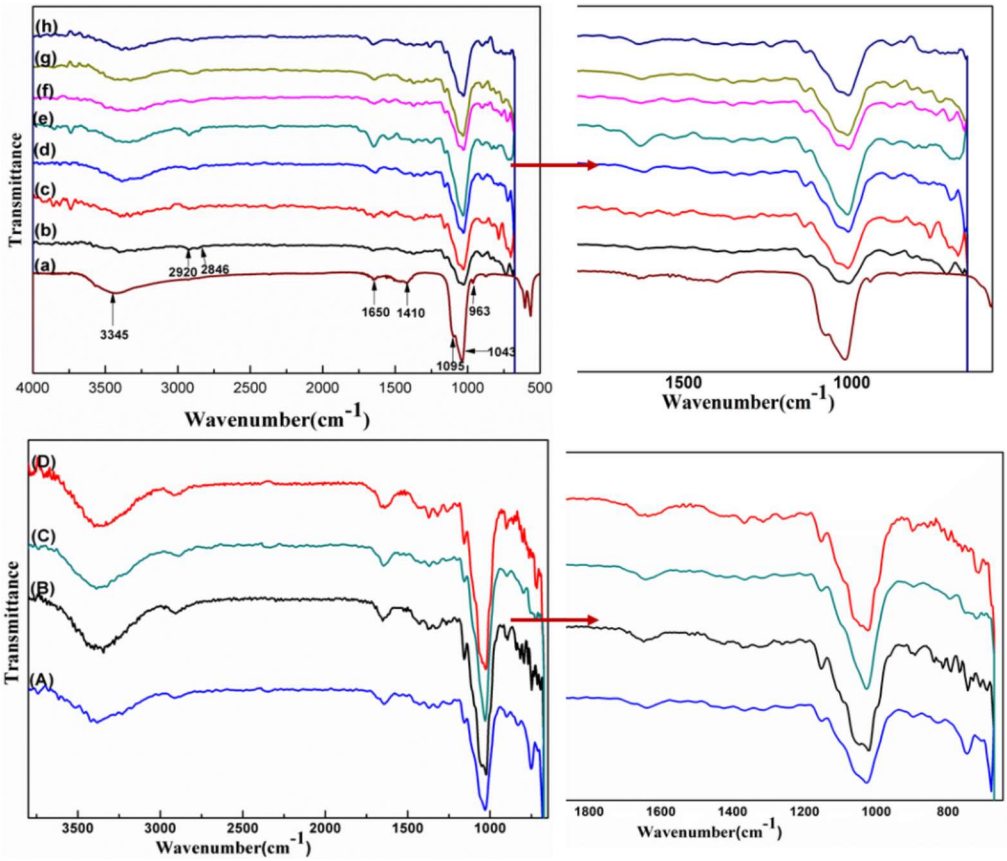

Fig.2. FTIR spectra of samples. (a)n-HA, (b)BF, (c)Air-Air, (d)Air-oven, (e)Air-freeze drying, (f) Oven-air, (g)Oven-oven, (h)Oven-freeze drying, (A)10% n-HA/BF, (B)20% n-HA/BF, (C) 30% n-HA/BF, (D)40% n-HA/BF.

XRD investigation

To further understand the phase structure of n-HA/BF membrane, XRD pattern is given in Fig.3. Obviously, the amorphous peak at 20.5 ° was the peak of bamboo fiber (Guimaraes et al., 2015), marked with "♦", and the peaks at 25 ° and 31 ° of n-HA were found, noted as "♣" (Ma et al., 2020). The crystallization peak position of n-HA in the composite membrane did not change, indicating that the two components of n-HA and BF were only blended. Similarly, the crystallization peaks of n-HA in Fig.3 (f), (g), (h) were also obviously weaker than those in Fig.3 (c), (d) and (e). This was because the content of n-HA in the membrane formed in oven was less than that in the membrane formed in air, which led to weaker crystal peak in the spectrum. With the increase of n-HA content, the characteristic peak and its crystallinity of n-HA in different membrane increased, which also confirmed that n-HA and BF were only blended without chemical reaction.

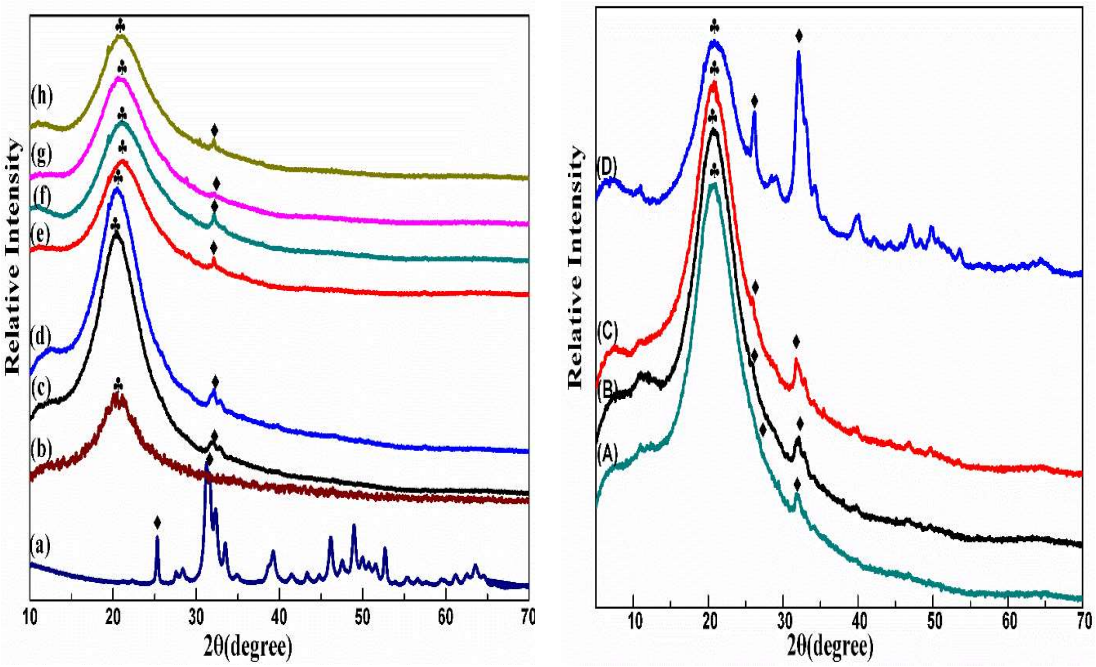

Fig. 3 XRD of samples. (a) n-HA, (b)BF, (c) Air-Air, (d) Air-oven, (e) Air-freeze drying, (f) Oven-air, (g) Oven-oven, (h) Oven-freeze drying, (A) 10% n-HA/BF, (B) 20% n-HA/BF, (C) 30% n-HA/BF, (D) 40%n-HA/BF.

SEM observation

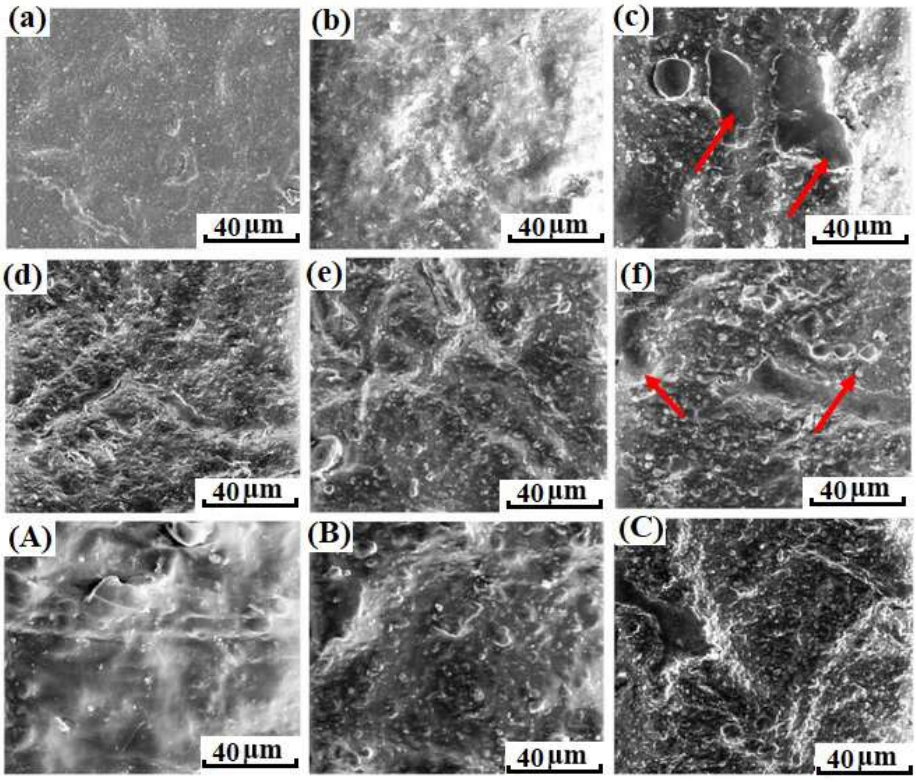

Fig. 4 SEM of samples. (a)Air-Air, (b)Air-oven, (c)Air-freeze drying, (d)Oven-air, (e)Oven-oven, (f)Oven-freeze drying, (A)10%HA/BF, (B) 30%HA/BF, (C)40%HA/BF.

Fig. 4 shows the morphologies of n-HA/BF composite membranes achieved by different methods. According to SEM micrographs, it can be seen that white particles existed in the composite membranes, which proved the existence of n-HA. However, there was subtle difference for the dispersion of n-HA particles in the membrane, and the n-HA was relatively more uniform in oven (Fig.4(d), (e), (f)) than in air (Fig.4(a), (b), (c)), which was caused by the different changes of hydrogen bond between molecules during the forming membrane of bamboo fiber. In oven, the solvent of DMAC was evaporated at high temperature, and the fiber morphology had been fixed before the hydrogen bond shrinking between bamboo fiber molecules, which would bring out better dispersion of n-HA. However, for the three different dry methods, the surfaces were compact without porous structures, and there was no obvious difference for the surface in air and in oven, which indicated that drying method in air or in oven

had little effect on the membrane morphology after bamboo fiber molding, and the compact structure could effectively prevent the invasion of connective tissue. While for the freeze-drying method, there was some closed pores on the surface of freeze-dried membrane (Fig.4(c), (f)), which was originated from the pores left by the sublimation of water molecules, and the porous structure was conducive for cell adhesion for guided bone regeneration. Additionally, for the composite membranes with different n-HA contents, the white particles gradually increased on the surface of the membrane, but there was no obvious agglomeration phenomenon, and there was no cavity between n-HA and BF, which indicated that the n-HA/BF composite membrane had good compositional compatibility of hydrophilic n-HA and BF.

Contact angle measurement

To further make clear the hydrophilicity of the n-HA/BF composite membrane, the contact angle of the n-HA/BF composite membranes were tested with rotating drop interfacial tensiometer by dropping distilled water onto the liquid surface, and the results are shown in Fig.5. As expected, the contact angle of all n-HA/BF casting membranes were less than 90 °, which proved that n-HA/BF casting membranes were hydrophilic membrane. Comparing with the membranes obtained by different methods, it could be found that the same forming membrane method had little effect on the contact angle (Fig.5(a) ≈ 5(b), 5(d) ≈ 5(e)), while the freeze-dried membrane possessed lower contact angle because of the rough membrane surface with the porous structure (Fig.5(c) and 5(f)), and the stronger hydrophilicity would be more useful for cell adhesion and proliferation (Dhinasekaran et al., 2021). However, for the same dried method, the membrane formed in oven had lower contact angle than that of the membrane formed in air (Fig.5(d) < Fig.5(a), Fig.5(e) < Fig.5(b)), and the reason was that the hydrogen

bonds between the bamboo fibers molecules was destroyed and the surface tension was reduced when the membrane was formed in oven. In addition, for the n-HA/BF composite membranes with different n-HA contents, the contact angle gradually decreased with the increasing of n-HA, which suggested that the higher n-HA content brought about better hydrophilicity of the membrane.

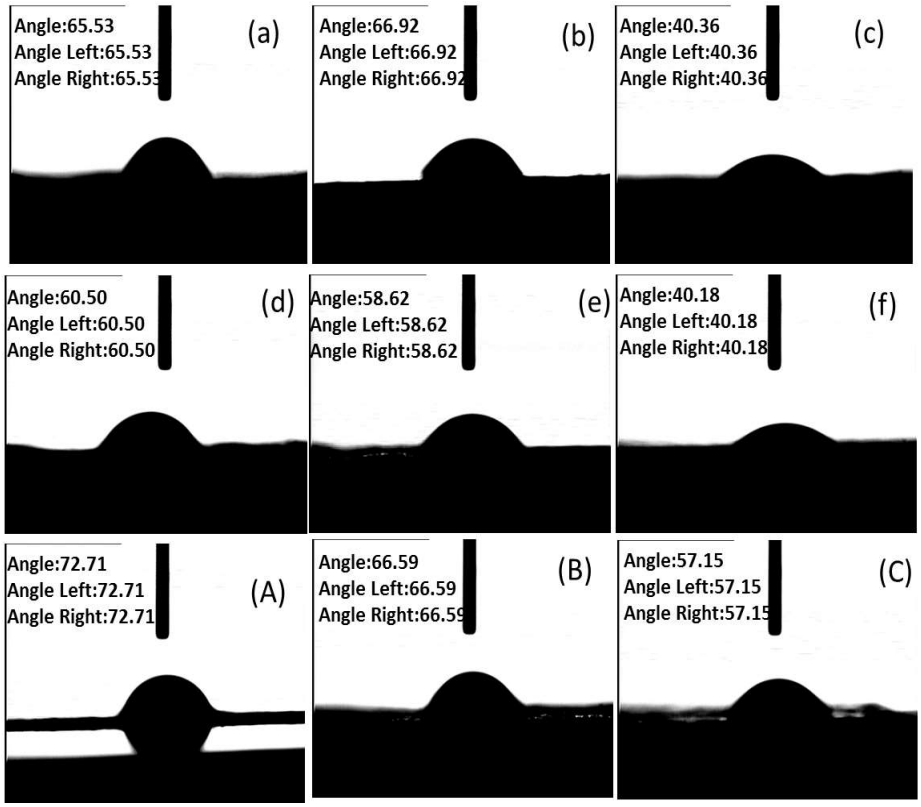

Fig.5. Contact angle of the n-HA/BF composite membranes obtained by different methods. (a) Air-Air, (b) Air-oven, (c) Air-freeze drying, (d) Oven-air, (e) Oven-oven, (f) Oven-freeze drying, (A) 10%-n-HA/BF, (B) 30% n-HA/BF, (C) 40% n-HA/BF.

Tensile strength test

Fig. 6 is the tensile strengths of all the n-HA/BF composite membranes. We found that membrane formed in air had higher mechanical strength than that in oven. Comparing to the membrane formed in air (Fig.6 (a), (b), (c)), the tensile strength of membrane dried by freeze-drying was the worst, and the tensile strength of the membrane dried in air was improved

by 69.64%, and dried in oven was increased by 51.7% than dried by freeze-drying, respectively. Likely, for the three membranes formed in oven (Fig.6(d), (e) and (f)), the tensile strengths of the membranes dried in air and in oven were improved by 23.89% and 5%, respectively. The reason was that the freeze-drying membrane was porous structure, and the forming membrane or dry membrane in oven caused the destruction of intermolecular hydrogen bond during molding, resulting in thinner membrane and larger area, so as to possessed lower tensile strength. For the n-HA/BF composite membranes with different n-HA contents, the tensile strength increased at first but decreased with the increasing of n-HA content, and the 20% n-HA/BF composite membrane represented the highest tensile strength, which was accord with the principle of nanoparticles filler reinforce polymer (Yadav et al., 2020), and the mechanical strength could meet the application requirement of GBR membrane (Castro et al., 2018).

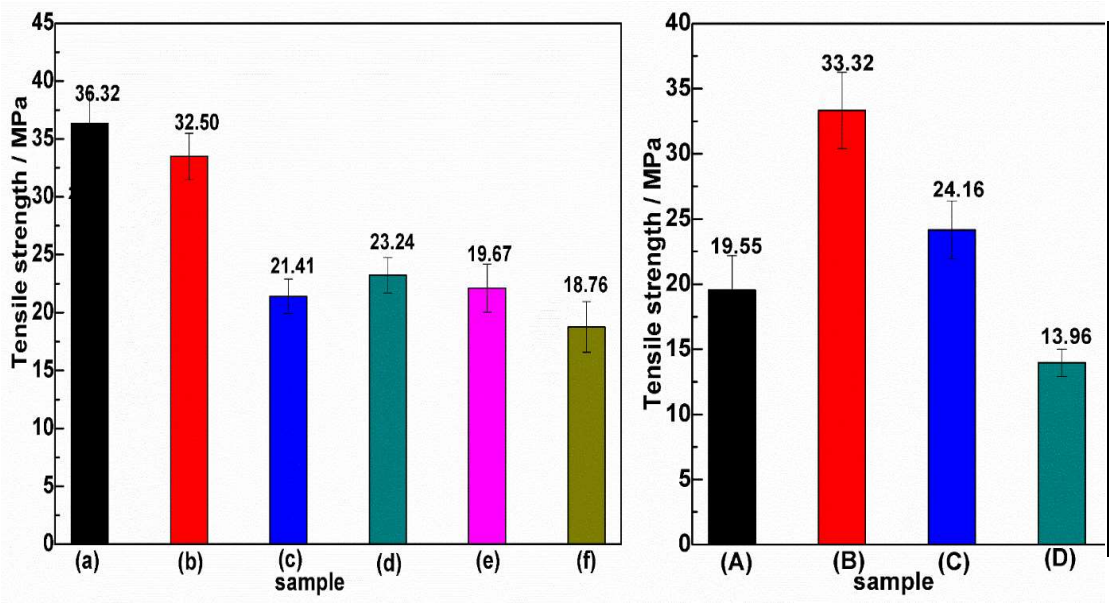

Fig.6. Tensile strength of the samples. (a) Air-Air, (b) Air-oven, (c) Air freeze drying, (d) Oven-air, (e) Oven-oven, (f) Oven-freeze drying, (A) 10% n-HA/BF, (B) 20% n-HA/BF, (C) 30% n-HA/BF, (D) 40% n-HA/BF.

In vitro degradation and cell culture

Weight loss of composite membrane after degradation

Fig.7 gives the weight loss rate of the n-HA/BF composite membranes. It can be seen that the weight loss rate of the composite membrane first decreased and then increased within 8 weeks. During the first 4 weeks, the weight loss rate was negative continuously, which indicated that the mass of composite membrane did not decrease but increased after immersion, meaning that the amount of apatite deposited on the surface of the membrane was greater than the mass of degradation, so that the total mass of composite membrane was greater than that before immersion. Similarly, the weight loss rate of 4-8 weeks was negative, but exhibited an upward trend, suggesting that the membrane had more visible degradation trend. Comparing to the different composite membranes, the weight loss rate of the membrane obtained by oven-freeze drying method changed the most among the membrane different methods, which indicated that bone like apatite adhered the most owing to the porous structure, and the more apatite deposition would have better biological activity. Moreover, for the composite membranes with different n-HA contents, the higher the content of n-HA, the greater the negative value of weight loss rate, which revealed that the higher content of n-HA was more favorable for the bone-like apatite deposition (Kumar et al., 2014).

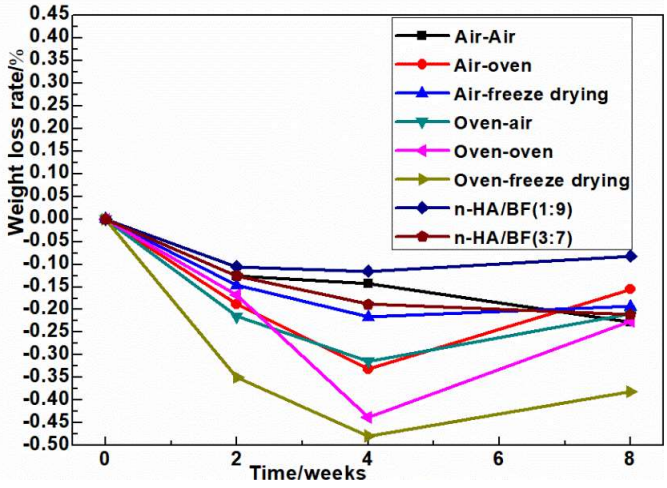

Fig.7 Weight loss rate of samples in SBF.

Water absorption of composite membrane after degradation

Fig.8 is the water absorption of n-HA/BF composite membrane. The results indicated that the water absorption of n-HA/BF composite membrane had a similar trend during the immersion process, that is, the water absorption increased slightly at the initial degradation, and then decreased a little from 4 weeks to 8 weeks, which was caused by the bone-like apatite deposition with the extension of soaking time. Moreover, the freeze-dried membrane had the lowest water absorption, and the main reason was that the porous structure had the fastest degradation, which would produce much micropore and bring more apatite deposition, and it could be proved by the weight loss result. Similarly, for the composite membrane with different n-HA contents, the higher BF content, the higher water absorption had, which was related to the water absorption of BF. In a word, the water absorption results indicated that the n-HA/BF composite membrane had good degradation and water absorption performance.

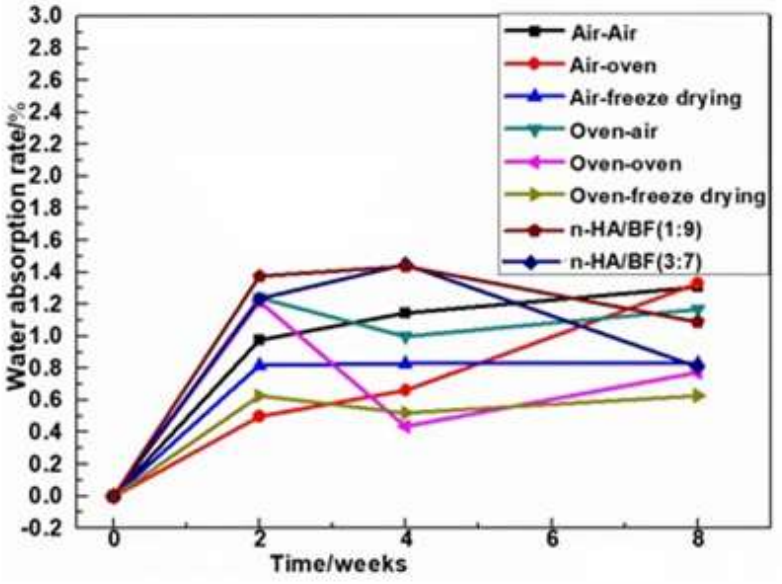

Fig.8. Water absorption rate of samples in SBF.

SEM observation of composite membrane after degradation

Fig. 9 shows the surface morphology of n-HA/BF composite membrane after soaking in SBF for

8 weeks. It can be found that new bone like apatite was disposited on the surface of the n-HA/BF composite membrane. However, comparing to the different composite membranes, the composite membrane formed in air had less bone like apatite (seen Fig.9 (a), (b), (c)) than the membrane formed in oven (seen Fig.9 (d), (e), (f)). The reason was that the hydrogen bond shrank between bamboo fiber molecules, and n-HA particles were wrapped in the inner part of the membrane when the membrane was formed in air. While the composite membrane was formed in the oven, the intermolecular hydrogen bond was broken, and n-HA particles were dispersed on the surface of the membrane, which was more conducive to the deposition of bone-like apatite on the surface of the membrane, and the bone-like apatite would help to improve interface between the tissue-implant and its surrounding tissues (Zhu et al., 2020).

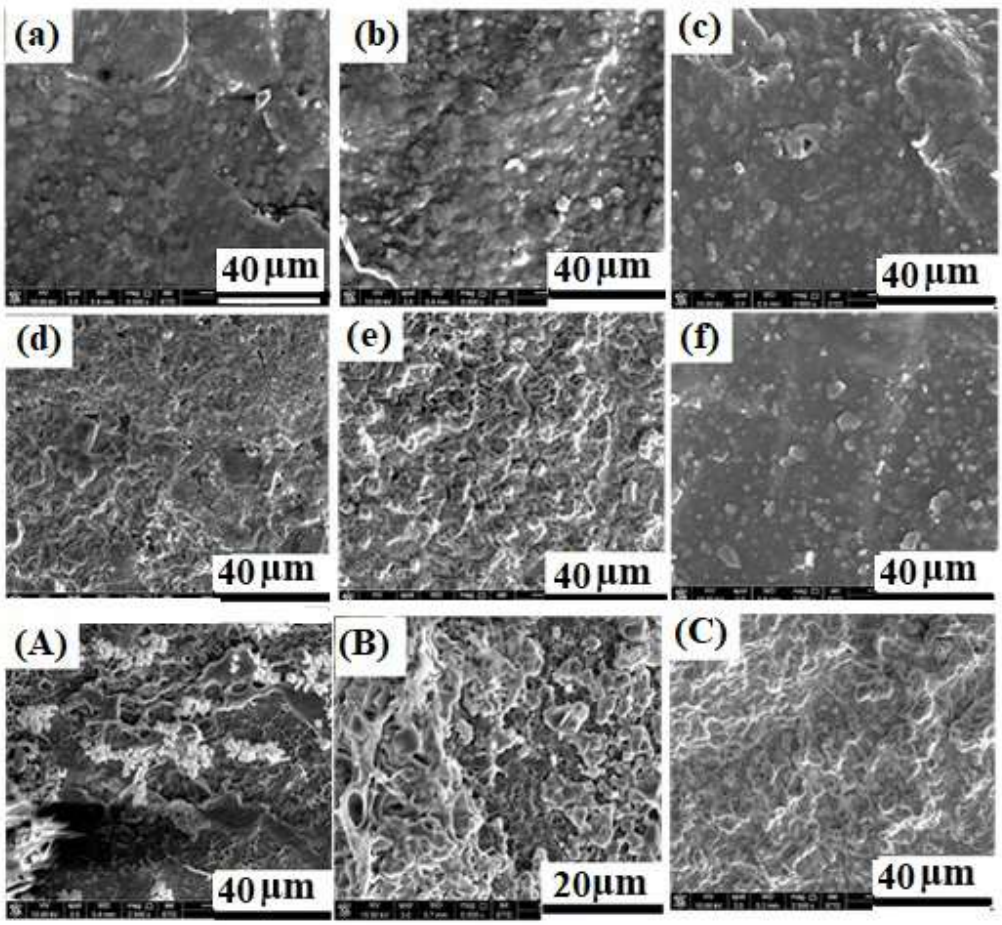

Fig. 9. SEM micrographs of samples after soaking for 8 weeks. (a) Air-Air, (b) Air-oven, (c)Air-freeze drying, (d) Oven-air, (e) Oven-oven, (f) Oven-freeze drying, (A)10% n-HA/BF, (B) 30% n-HA/BF, (C)40% n-HA/BF.

For the composite membrane with different n-HA contents of 10%, 30% and 40% n-HA (seen Fig.9(A), (B), (C)), respectively. From the 10% n-HA/BF composite membrane, it can be seen that there were pores on the surface of bamboo fiber (Fig.9(A)), which indicated that bamboo fiber could be degraded during soaking. With the increase of n-HA content, the more bone-like apatite was deposited, which further demonstrated that the n-HA in composite membrane could induce bone-like apatite deposition, and the results were consistent with the previous analysis.

MTT test of cell culture

The cell proliferation results of BMSC cultured on the surface of n-HA/BF composite membrane for 1, 2 and 3 days are given in Fig. 10.

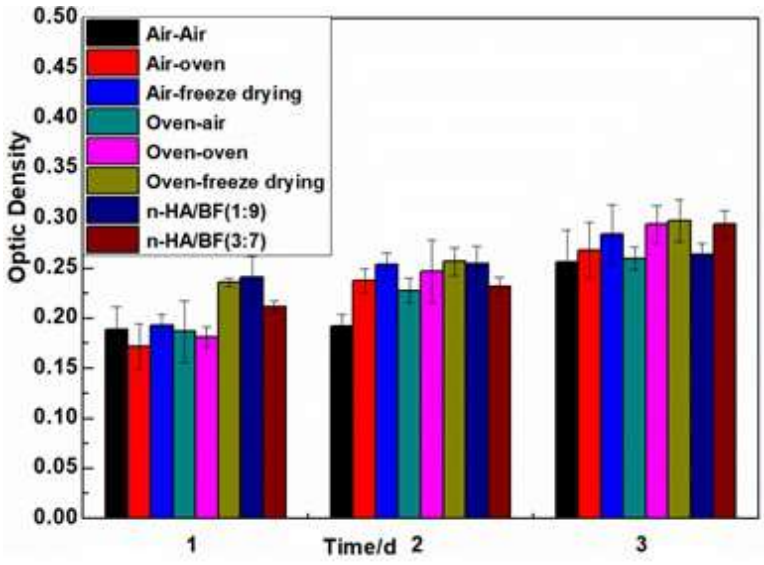

Fig. 10. MTT value of cell culture on sample surface.

It can be seen that the OD value of each sample increased significantly with the extension of culture time, indicating that cells could normally grow and proliferate on different membrane surfaces. In addition, the OD values of freeze-dried composite membrane were significantly higher than those of the membrane dried in air or in oven, which further indicated that the porous

structure of freeze-dried composite membrane was more conducive for cell proliferation and possessed better biocompatibility (Ai et al., 2021). Comparing to the n-HA/BF membranes with 10%, 20% and 30%, the OD value enhanced significantly with the increase of n-HA content and the extension of culture time. The results illustrated that the cells proliferated rapidly on the surface of the membrane, suggesting that the n-HA/BF composite membrane had good biological properties (Bee et al., 2019). This was consistent with the previous *in vitro* immersion analysis.

Conclusions

In this study, the n-HA/BF composite membrane was successfully prepared by a simple casting technology, and the effects of different forming membrane, drying methods, and different n-HA contents on the properties of the composite membranes were studied. The results confirmed that there was no chemical bonding between n-HA and BF components, however, the membrane formed in air was thicker than that in oven, because the hydrogen bond shrinkage made the BF gel and DMAC/LiCl solution precipitated from the edge in air. Thus, the tensile strength of the membrane formed in air were higher than that of in oven, especially, the 20 % n-HA/BF composite membrane was the highest, but the tensile strength of freeze-dried composite membrane was the worst because of the porous structure. The contact angle test of the composite membrane confirmed that the composite membrane was hydrophilic, and the freeze-dried membrane exhibited better hydrophilicity owing to the rough surface and the small surface tension. SBF soaking results indicated that n-HA/BF composite membrane displayed different degradability behaviours, and the higher n-HA content in composite membrane possessed better bone-like apatite deposition. The cell proliferation results proved that the composite membranes had no cytotoxicity. This study would provide a new way for developing a novel GBR membrane

based on the utilization of natural BF.

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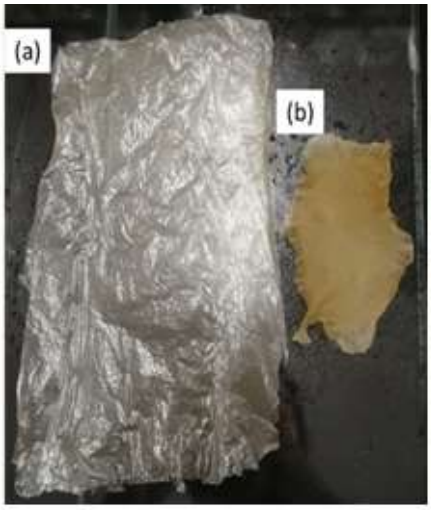
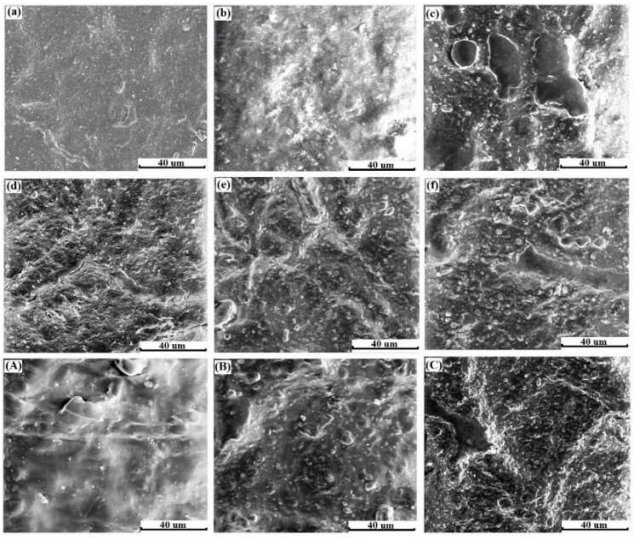
Graphical Abstract

In this manuscript, nano-hydroxyapatite/BF (n-HA/BF) composite membrane was prepared by casting method. and the membrane forming mechanism and the effects of different forming membrane methods, drying methods and n-HA amounts on the corresponding n-HA/BF membrane were investigated. Results demonstrated that the morphologies of membrane was determined by the different preparation conditions owing to different hydrogen bond shrinkage. Moreover, the hydrophilicity, the mechanical properties, the degradability and bone-like apatite deposition could be controlled by different preparation conditions, and all the n-HA/BF composite membranes were all non-toxic. The above results indicated that the n-HA/BF composite membrane have a great promising as guide bone tissue regeneration (GBR) membrane, which would provide a new application for BF in biomedical field.



Membrane appearances formed by different conditions. (a) in oven, (b) in air.



SEM micrographs of samples. (a)Air-Air, (b)Air-oven, (c)Air-freeze drying, (d)Oven-air, (e)Oven-oven, (f)Oven-freeze drying, (A)10%HA/BF, (B) 30%HA/BF, (C)40%HA/BF.