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

Liuyun Jiang · Zhihong Jiang · Bingli Ma · Yingjun Ma · Yue Wen · Na Zhang · Yan Zhang · Shengpei Su · Xionggui Tang · Xiang Hu

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Abstract Nano-hydroxyapatite/bamboo fiber (n-HA/BF) composite membranes were obtained by a simple casting technology. The mechanism of the membrane formation and the effects of different pre-drying conditions, drying methods and n-HA addition amounts on the properties of the n-HA/BF composite membranes 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 different preparation conditions did not affect the dispersity of n-HA nanoparticles in BF matrix, but determined the membrane appearances, owing to the different changes of hydrogen bond under different pre-drying temperatures. Moreover, the hydrophilicity of the composite membranes could be improved when the membranes were prepared at 70 °C and freeze-drying as well as n-HA high addition content, and the mechanical properties of the composite membranes depended on n-HA addition content. In vitro soaking behavior indicated that the corrosion properties and bone-like apatite deposition could be controlled by different preparation conditions. The cell proliferation results showed that the n-HA/BF composite membranes obtained in different preparation conditions were all non-toxic. The obtained results showed that the casting technique could be used to prepare n-HA/BF composite membranes, and the properties of the composite membranes could be controlled by adopting different preparation conditions, which would have a great potential for guide bone tissue regeneration (GBR) membranes, and the study would provide a new way for BF application in biomedical fields.

Graphical abstract In this manuscript, nano-hydroxyapatite/BF (n-HA/BF) composite membranes were prepared by casting method, and the membrane
forming mechanism and the effects of different pre-drying conditions, 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 changes. 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 obtained results indicated that the n-HA/BF composite membrane with 20% n-HA prepared at room temperature has a great potential as guide bone tissue regeneration (GBR) membrane, which would provide a new application for BF in biomedical field.

Keywords Bamboo fiber · Nano-hydroxyapatite · Composite membrane

Introduction

Guided bone regeneration (GBR) membranes are commonly used in bone defect repair. These membranes are placed on the bone defect area as barrier membranes for creating a singular space, so as to prevent epithelial cells from growing into the defect region, and permit osteoblasts to proliferate and form new bone to form (Niu et al. 2021; Li et al. 2015a, b, 2020). Based on the GBR membrane research results (Lee et al. 2016; Yu et al. 2020; Hoornaert et al. 2016), all GBR membranes, ideally, should have appropriate mechanical properties, space-retention ability, biocompatibility and biodegradability. To meet the above-mentioned requirements, natural biodegradable polymers have been widely studied by many researchers (Prajatelistia et al. 2021; Ma et al. 2019; Bierhalz and Moraes 2017), owing to the better biocompatibility and biodegradability, compared with the synthetic polymers.

Bamboo fibers (BFs) are extracted from natural bamboo and have high strength, biodegradability and low cost (Khalil et al. 2012; Liu et al. 2012). Therefore, BFs are usually used as a reinforcing agent for polymers, particularly for polylactic acid (Phuong et al. 2019; Long et al. 2019; Zuo et al. 2018). Our previous study also revealed that BFs have a remarkable reinforcement effect for the nano-hydroxyapatite/poly (lactide-co-glycolide) (n-HA/PLGA) composite (Li et al. 2015a, b; Jiang et al. 2017, 2018, 2019). In addition, we found that BFs could replace other polymers to develop n-HA/BF nanocomposite by co-precipitation, a method in which calcium and phosphorus for the preparation of n-HA were added into a BF aqueous dispersion, and the n-HA was deposited on the bamboo fibers, accordingly, n-HA/BF nanocomposite was obtained, which had a great potential...
as bone materials (Ma et al. 2020). Moreover, BF-reinforced electrospun membranes were studied (Chingakham et al. 2020; Cai et al. 2018). Unfortunately, it is known that electrospinning membranes have loose porous structures, which would display worse mechanical strength than casting membranes (Oksana et al. 2020). Consequently, we hold that simplex electrospinning membrane would be not suitable for GBR membranes. On the contrary, casting membranes can be prepared by a simple casting technology. Therefore, the reinforcement effect of carboxylated BF on chitosan-based casting membrane was investigated in our previous study (Tang et al. 2020). However, the preparation process of the carboxylated BF was very tedious. On the other hand, BFs in the above-mentioned study were usually added in the primeval state fiber form as reinforcement or polymer matrix, which would be adverse for the dispersion of the BFs, so it would be expected to explore a BF solution-based polymer membrane by a simple and green processing.

BFs could be directly dissolved to be a homogeneous solution, correspondingly, the casting membrane would be formed. However, pure BF membranes lack osteoconductivity, which would be detrimental to guide bone tissue regeneration. Complementarily, n-HA has good osteogenic activity because of the similarity of inorganic component with natural bone, which could endow polymers with better biological performances (Li et al. 2021; Macuvele et al. 2017). However, whether n-HA could be homogeneously dispersed in the BF solution and replace other polymers to obtain a n-HA/BF composite membrane by the solution blending method, and what effects of the different preparation conditions would produce on the properties of the n-HA/BF membrane, including different pre-drying conditions, drying methods and n-HA addition amounts, and whether the n-HA/BF membrane could be used as GBR membranes, none of the above-mentioned aspects has been reported, which is worth exploring.

Based on these, in this work, we attempt to study the fabrication of the n-HA/BF composite membrane, in which BFs were dissolved as polymer matrix rather than in primeval state fiber form as a reinforcement, and n-HA was added into the BF solution to obtain a homogeneous solution. Then, n-HA/BF composite membranes were prepared by a casting method, and the effects of the different preparation conditions including pre-drying conditions (at r. t. and at 70 °C), different drying methods (at r. t., at 70 °C, in freeze-drying) and different n-HA addition contents (10, 20, 30 and 40%) on the properties of the n-HA/BF composite membranes were studied by Fourier Transform infrared spectroscopy (FT-IR), X-ray diffraction (XRD), scanning electron microscopy (SEM), contact angle, electromechanical universal tester. Moreover, the erosion behavior of the n-HA/BF composite membranes were 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 an excellent GBR membrane with a low cost by making full use of natural biomass resources.

**Experiment section**

**Materials**

BFs were provided by Zhejiang A&F University, whose size was 0.03–0.2 mm in diameter and 6–10 cm in length. Dimethylacetamide (DMAc, AR) and LiCl (AR) were purchased from Aladdin. n-HA was prepared in our laboratory. Other agents were analytical grade.

**Preparation of the n-HA/BF composite membranes**

BFs were dissolved in DMAc/LiCl system with the concentration of 1.3 wt%. A certain amount of n-HA was dispersed in DMAc by the ultrasonic treatment, which was slowly added into the bamboo fiber solution with the magnetic stirring, and the evenly dispersed mixture solution was poured on a clean and dry glass plate, and the thickness of the membrane was adjusted by a glass rod with two copper rings. Then, the glass plate covered with the n-HA/BF mixture solution was placed at r. t. or at 70 °C to pre-dry film, and a part of solvent was left in the membrane. Afterwords, the membrane was dried at r. t., at 70 °C or freeze drying, aimed to completely volatilize the solvent, thus, n-HA/BF composite membranes with 20% n-HA were obtained by six methods, and the membranes were noted as r. t.–r. t., r. t.–70 °C, r. t.-freeze drying, 70 °C–r. t., 70–70 °C and
70 °C-freeze drying, respectively. Moreover, n-HA/ BF composite membranes with n-HA contents of 10, 20, 30 and 40% were prepared by r. t.–r. t. method in the similar procedure.

Characterization of the composite membranes

The appearances of the membranes acquired by the two different preparation methods of r. t. – 70 °C and 70–70 °C were given as examples, and the appearance photos were 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, and the scanning speed was 5°/min at 40 kV and 45 mA, and the range of 20 was 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 samples of the n-HA/BF composite membranes were put on the slide, and the distilled water was dropped onto the membrane surface by a 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 five specimen for each sample.

In vitro erosion of the composite membranes

The erosion of n-HA/BF composite membranes in vitro were studied by soaking in SBF, whose ion concentration was very similar to that of human plasma, and it was obtained according to the related reference (Soares et al. 2012), that is, NaHCO₃ (0.350 g), NaCl (7.996 g), KCl (0.224 g), K₂HPO₄·3H₂O (0.228 g), CaCl₂ (0.278 g), Na₂SO₄ (0.071 g), MgCl₂·6H₂O (0.305 g) were sequentially dissolved in deionized water, and buffered with trimethylolmethylaminomethane (6.057 g) and hydrochloric acid to adjust the solution to physiological pH = 7.40 at 37 °C (± 0.5 °C). The samples were taken out from SBF at 2, 4 and 8 weeks, and the membrane surface was gently washed with water, and the residue water was absorbed with a filter paper. The weight loss ratio and water absorption ratio were calculated as follows.

\[
\text{Weight loss ratio/\%} = \frac{W₁ - W₃}{W₁} \times 100\%
\]

\[
\text{Water absorption ratio/\%} = \frac{W₂ - W₃}{W₃} \times 100\%
\]

In vitro cell biocompatibility of the composite membranes

Bone mesenchymal 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 undisturbedly placed in a 96-well plate with the density of 4000 cells/well in an incubator for 3 h, then an additional 1 mL culture medium was added into each well.

The cell proliferation was evaluated by MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl-2H- tetrazolium bromide) assay, and the procedure was carried out according to the similar references (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% CO₂ for at least 4 h, 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. Three specimen for each sample were used and the average value was given.

Results and discussion

Characterization of surface-modified n-HA

Appearances of the membranes

Figure 1 shows the n-HA/BF composite membrane appearances. It can be seen that the membrane pre-dried at r. t. showed thicker appearance with smaller area than that pre-dried at 70 °C, which was mainly caused from the different changes of the hydrogen bonds between the bamboo fiber molecules. At r. t., the bamboo fiber solution was very sensitive to the moisture in air, and the absorbed water would make DMAC/LiCl solution diffuse from the edge, which made the hydrogen bond of bamboo fiber molecules reproduce. Thus, the bamboo fiber was gelled and the bamboo fiber membrane was formed, resulting in a thicker membrane with smaller area. While temperature was at 70 °C, there was little water for dissolved bamboo fiber in DMAC/LiCl solution before the formation of bamboo fiber membrane, in which the hydrogen bond between the bamboo fiber molecules was destroyed, so the bamboo fiber molecular chain was stretched during the solvent volatilization, resulting in a thinner membrane with larger area.

IR analysis

Figure 2 describes the FT-IR spectra of the different n-HA/BF composite membranes obtained by different methods and different n-HA addition contents. The characteristic peaks of 2920 cm<sup>-1</sup> and 2846 cm<sup>-1</sup> corresponded to the tensile vibration of C-H bond on methylene of BFs existed in n-HA/BF composite membranes (Fig. 2c–h). In addition, the characteristics peaks at 3567.2 cm<sup>-1</sup> attributed to the tensile vibration of OH<sup>-</sup> and the peaks at 1095, 604 and 565 cm<sup>-1</sup> of PO<sub>4</sub><sup>3-</sup> were related to n-HA (Fig. 2a) (Chesley et al. 2020). The peak position did not shift obviously when n-HA was added into BFs, which stated that n-HA was simply blended with BFs without chemical bond interaction (Fig. 2c–h). Additionally, for the different n-HA/BF composite membranes with different n-HA contents, the characteristics peak intensity of n-HA with high content (Fig. 2D) was sharper than that of n-HA with lower content (Fig. 2A).

XRD investigation

To further understand the phase structure of the 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, showing that the two components of n-HA and BF were only blended. Similarly, the crystallization peaks of n-HA in Fig. 3f, g, h were also obviously weaker than those in Fig. 3c, d and e, which might be related with the content of n-HA in the membrane. At r. t., n-HA tended to agglomerate during the BFs gelling process, so n-HA content in the membrane was more than that in the thinner membrane pre-dried at 70 °C for the same size of samples, and the less n-HA in the composite membrane would be weaker crystal peak. With the increase of n-HA
content, the characteristic peak and its crystallinity of n-HA in different membrane increased (Fig. 3D), which further confirmed that n-HA and BF were only blended without chemical reaction.

**SEM observation**

Figure 4 shows the SEM micrographs of n-HA/BF composite membranes achieved by different methods. 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 BF's matrix, and the n-HA was relatively more uniform at 70 °C (Fig. 4d, e, f) than at r. t. (Fig. 4a, b, c), which was caused by the different changes of hydrogen bond between molecules during the pre-drying process. At 70 °C, bamboo fiber molecular chains kept stretching state, so n-HA could be dispersed more uniform till the solvent of DMAc was evaporated. While at r. t., the absorbed water made bamboo fiber form gel in a short time, which led to worse dispersion of n-HA.

However, for the three different dry methods, n-HA particles were well embedded in the BF matrix without visible gaps and cracks, and there was no obvious difference for the surfaces of at r. t. and at
70 °C, which showed that drying method of at r. t. or at 70 °C had little effect on the membrane morphology after the formation of the n-HA/bamboo fiber composite membrane, and the compact structure would ensure the membranes have better mechanical properties. While for the freeze-drying method, there were some closed pores on the surface of freeze-drying membrane (Fig. 4c, f), which was originated from the pores left by the sublimation of water molecules, and the porous structure of the membrane surface was conducive for cell adhesion for guided bone regeneration. Additionally, for the composite membranes with
different n-HA contents, the white particles got more and more on the surface of the membrane with the increase of n-HA content, but there was no obvious agglomeration phenomenon, and there was no cavity between n-HA and BF, which implied 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 membranes 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 membranes. Comparing with the membranes obtained by different methods, it could be found that the drying method had little effect on the contact angle of the membrane adopted the same pre-drying condition (Fig. 5a–b, d–e), except the freeze-dried membrane had lower contact angle because of the rough membrane surface with the porous structure (Fig. 5c and 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 pre-dried at 70 °C had lower contact angle than that of the membrane pre-dried at r. t. (Fig. 5d < Fig. 5a, e < Fig. 5b), and the reason was that the hydrogen bonds between the bamboo fibers molecules were destroyed during the formation membrane stage at 70 °C, and the surface tension was reduced, which would have the lower contact angle for hydrophilic surfaces. In addition, for the n-HA/BF composite membranes with different n-HA contents, the contact angle gradually decreased with the increase of n-HA content, suggesting that the higher n-HA content endowed the membrane with better hydrophilicity.

Tensile strength test

Figure 6 illustrates the tensile strengths of all the n-HA/BF composite membranes. It could be found that the mechanical strength of the membrane pre-dried at r. t. was higher than that of the membrane pre-dried at 70 °C. Moreover, for the three pre-dried at r. t. membranes (Fig. 6a, b, c), the post-drying by
freeze-drying method produced the lowest tensile strength, while post-drying at r. t. method improved the tensile strength by 69.64%, and dried at 70 °C method increased the tensile strength by 51.7%, respectively. Likely, for the three membranes pre-dried at 70 °C (Fig. 6d, e and f), the tensile strengths of the membranes dried at r. t. and at 70 °C were improved by 23.89% and 5%, respectively, compared with that of the membrane post-dried by freeze-drying. The reason was that the freeze-drying membrane was porous structure, easily leading to weak tensile strength of the membrane. The pre-drying or dry at 70 °C caused the destruction of intermolecular hydrogen bond during the solvent volatilization, so the tensile strength of the membrane was worse than that of the membrane dried at r. t. For the n-HA/BF composite membranes with different n-HA contents, the tensile strength increased at first but decreased with the increase of n-HA content, and the 20% n-HA/BF composite membrane presented the highest tensile strength, meaning that n-HA could enhance the mechanical properties of polymers, and the addition of 20% n-HA might be an appropriate amount, but excessive addition would weaken its mechanical properties, which was accord with the principle of nanoparticles fillers reinforce polymer (Yadav et al. 2020). According to the relative report of PCL-based GBR membrane (Castro et al. 2018), we think the mechanical strength of n-HA/BF composite membrane with 20% n-HA could meet the application requirement of GBR membranes.

**In vitro erosion and cell culture**

**Weight loss ratio of the composite membrane after soaking**

Figure 7 gives the weight loss ratio of the n-HA/BF composite membranes. It can be seen that the weight loss ratios of the composite membranes first decreased and then increased within 8 weeks. During the first 4 weeks, the weight loss ratios were negative value continuously, implying that the mass of composite membrane did not decrease but increased after immersion, which reflected that the weight loss amount was smaller than the weight gain of apatite deposition on
the surface of the membrane, so that the total mass of composite membrane was greater than that before immersion. At 4-8 weeks, the weight loss ratio exhibited an upward trend, that is, the total weight increase was less. However, as we know, apatite deposition would get more with the extension of immersion time, and the weight increase should be more. Comprehensive consideration of the weight change originated from both deposition and erosion, we speculated that the weight loss amount got more than that the first 4 weeks immersion, suggesting that the erosion started to play a more important role at 4–8 weeks. However, weight loss ratio was still negative value, which signified that the weight loss amount was less than weight increase, so it could be concluded that the n-HA/BF composite membranes corroded slowly, which might keep space-retention ability longer on the bone defect as barrier membrane in body. For the different composite membranes, the weight loss ratio of the membranes obtained by 70 °C-freeze drying method changed the most among the membrane different methods, which testified that bone-like apatite deposited the most owing to the porous structure, and the more apatite deposition would bring about better biological activity. Moreover, for the composite membranes with different n-HA contents, the higher the n-HA content was, the greater the negative value of weight loss ratio was, which revealed that the higher content of n-HA was more favorable for the bone-like apatite deposition, and the phenomenon was similar to the soaking results of PCL/PLA/PEG/N-HA composites (Fong et al. 2021).

Water absorption of the composite membrane after soaking

Figure 8 gives the water absorption of n-HA/BF composite membranes. The results reflected that the water absorption of most of n-HA/BF composite membranes had a similar trend during the immersion process, that is, the water absorption increased slightly at the initial erosion, and then decreased a little from 4 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 erosion, which would produce more micropores and bring more apatite depositions, and the deposited apatites would cover the micropore produced by erosion, so the water absorption would be lowest. In addition, the samples prepared by 70–70 °C emerged the lowest water absorption, which might be also attributed to the fast erosion. Similarly, for the composite membranes with different n-HA contents, the higher BF content was, the higher water absorption had, which was attributed to the water absorption of BF. In a word, the water absorption results further confirmed that the corrosion properties of the n-HA/BF composite membranes were not very fast (Tang et al. 2020), which would be beneficial to be used as GBR membranes.

SEM observation of composite membrane after soaking

Figure 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 apatites were deposited on the surfaces of the n-HA/BF composite membranes. However, comparing the different composite membranes, the composite membrane pre-dried at r. t. had less bone-like apatite (seen Fig. 9a, b, c) than the membrane pre-dried at 70 °C (seen Fig. 9d, e, f). The reason was that the hydrogen bond between bamboo fiber molecules reproduced at r. t., and most of n-HA particles were wrapped in the inner part of the membrane during the gelling process of bamboo fiber. However, when the composite membrane was pre-dried at 70 °C, the intermolecular hydrogen bond was broken during the formation membrane stage, and n-HA particles were dispersed on the surface of the membrane, which was more conducive for the deposition of
bone-like apatite on the surface of the membrane, especially for the freeze-drying membrane (Fig. 9f), it could be seen that a large amount of bone-like apatites existed in the micropores, which is an essential condition to grow bone-like apatite layer at the interface between the tissue-implant and its surrounding tissues, and it would greatly promote osteoblast adhesion and proliferation (Zhu et al. 2020). For the composite membranes with different n-HA contents of 10, 30 and 40% n-HA (seen Fig. 9A, B, C, respectively), it can be seen that there were pores on the membrane surface (Fig. 9A), which might be mainly caused from the erosion of bamboo fiber during soaking. In addition, with the increase of n-HA content, the more bone-like apatites were deposited, which further affirmed 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 membranes for 1, 2 and 3 days are given in Fig. 10. It can be seen that the OD value of each sample increased remarkably with the extension of culture time, meaning that cells could normally grow and proliferate on different membrane surfaces, that is to say, the membranes were nontoxic. In addition, the OD values of
the freeze-dried composite membranes were significantly higher than those of the membranes dried at r.t. or at 70 °C, which further indicated that the porous structure of freeze-dried composite membrane was more favourable for cell proliferation and possessed better biocompatibility (Ai et al. 2021).

Comparing the n-HA/BF membranes with 10% and 30%, the OD value enhanced dramatically with the increase of n-HA content. The results illustrated that the cells proliferated rapidly on sample surfaces, and the n-HA/BF composite membranes might be good biological properties (Bee et al. 2019). This was consistent with the previous in vitro immersion analysis.

Conclusions

In this work, the n-HA/BF composite membrane was successfully prepared by a simple casting technology, and the effects of different pre-drying conditions, drying methods and n-HA contents on the properties of the composite membranes were investigated. The results confirmed that there was no chemical bonding between n-HA and BF components, but the membrane pre-dried at r.t. was thicker than that at 70 °C, because the absorbed water made DMAC/LiCl solution diffuse from the edge, which made the hydrogen bond of bamboo fiber molecules reproduce, and the bamboo fiber was gelled. Thus, the tensile strengths of the membranes pre-dried at r.t. were higher than those of pre-dried at 70 °C. Especially, the tensile strength of 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 results of the composite membranes showed that the composite membranes were hydrophilic, and the freeze-dried membrane exhibited better hydrophilicity owing to the rough surface and the small surface tension. SBF soaking results stated that n-HA/BF composite membrane represented different erosion behaviors, and the higher n-HA content in composite membrane displayed 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 an excellent GBR membrane with a low cost based on the utilization of natural BF.

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Declarations

Conflict of interest

The authors declare that they have no conflicts of interest.

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