

INTISARI

PENGEMBANGAN PERANCAH DAN GRANUL BERPORI BERBASIS KALSIMUM FOSFAT DARI STRUKTUR KERANGKA BULU BABI UNTUK REKAYASA JARINGAN TULANG

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Penelitian disertasi terkini melaporkan tentang telah selesainya fabrikasi dan karakterisasi perancah tiga dimensi (3D) dan material granul berpori berbasis struktur kerangka bulu babi. Penelitian ini dilatarbelakangi oleh kebutuhan akan material substitusi tulang yang lebih baik dalam meregenerasi tulang yang telah rusak, menggantikan *autologous bone graft* sebagai bahan klinis. Penelitian ini bertujuan untuk mengembangkan perancah 3D berbasis nanopartikel karbonat hidroksiapatit (nCHA) dari cangkang *Diadema setosum* dan granul berbasis kalsium fosfat bifasik terdoping magnesium (Mg-BCP) dari duri *Mesocentrotus nudus*. Penelitian ini memberikan manfaat dalam meningkatkan *green synthesis* berbasis *local wisdom* untuk mengembangkan material substitusi tulang yang lebih unggul daripada material komersil. Biokeramik nCHA disintesis melalui metode disolusi-presipitasi secara hidrotermal menggunakan nanopartikel hidroksiapatit (nHA), yang disintesis melalui metode hidrotermal menggunakan prekursor kalsium (Ca) berbasis cangkang *D. setosum*. Perancah berbasis nCHA difabrikasi melalui metode *freeze-drying* dengan penambahan polivinil alkohol (PVA) atau poli- ϵ -kaprolakton (PCL) serta inkorporasi nanofibril selulosa (CNF), yang disintesis melalui metode ultrasonikasi menggunakan selulosa mikrokristalin (MCC). Karakterisasi perancah dilakukan melalui uji fisis-kimia, mekanis secara kompresif, antibakteri secara difusi terhadap bakteri *P. aeruginosa*, *P. gingivalis*, dan *S. aureus*, dan *in vitro* terhadap sel *fibroblast* (NIH/3T3) dan *osteoblast* (MC3T3-E1). Uji fisis-kimia pada perancah meliputi sifat kristalografi, gugus fungsi, morfologi, kandungan unsur, perilaku *swelling*, biodegradasi, adsorpsi protein, dan biomineralisasi. Uji *in vitro* pada perancah meliputi viabilitas sel melalui 3-(4,5-dimethylthiazol-2-yl)-2,5 diphenyltetrazolium bromide (MTT) *assay*, proliferasi sel melalui cell counting kit-8 (CCK-8) *assay*, adhesi sel melalui *immunofluorescence staining*, dan migrasi sel melalui *scratch wound assay*. Material granul Mg-BCP difabrikasi melalui metode karbonasi dan fosfatasi menggunakan duri *M. nudus*. Karakterisasi granul dilakukan melalui uji fisis-kimia meliputi sifat kristalografi, gugus fungsi, morfologi, kandungan unsur, distribusi pori, dan laju pengisian granular, uji mekanis secara kompresif, dan *in vitro* melalui MTT *assay* terhadap sel MC3T3-E1. Inkorporasi CNF dalam perancah nCHA/PVA/CNF berpengaruh pada penurunan kristalinitas (75,3%), pembentukan makropori (<math><100 \mu\text{m}</math>) dan mikropori lamelar (1–20 $\mu\text{m}</math>), peningkatan aktivitas antibakteri, dan viabilitas sel NIH/3T3 mencapai 90,4% ($\text{IC}_{50} = 2732 \mu\text{g/mL}</math>). Inkorporasi nCHA dan CNF dalam perancah PCL/nCHA/CNF berdampak pada peningkatan porositas (sifat mekanis memenuhi tulang *cancellous*), aktivitas antibakteri, rasio *swelling*, laju degradasi, adsorpsi protein, biomineralisasi apatit,$$

dan proliferasi, adhesi, dan migrasi sel MC3T3-E1. Granul Mg-BCP berfasa bifasik HA/ β -TCP tersubstitusi Mg mempertahankan bentuk silinder (volume mikropori radial-uniaksial = $178,5 \pm 0,5 \text{ mm}^3/\text{g}$), menghasilkan sifat mekanis yang memadai, laju pengisian defek yang padat, dan sitokompatibilitas terhadap sel MC3T3-E1. Hasil penelitian di atas menyimpulkan bahwa perancah 3D dan material granul berbasis struktur kerangka bulu babi yang telah dikembangkan potensial untuk diaplikasikan sebagai material substitusi tulang yang mampu mendukung keberhasilan regenerasi tulang.

Kata-kata kunci: struktur kerangka bulu babi, perancah 3D, material granul, rekayasa jaringan tulang.

ABSTRACT

DEVELOPMENT OF POROUS SCAFFOLDS AND GRANULES BASED ON CALCIUM PHOSPHATE FROM SEA URCHIN SKELETAL STRUCTURE FOR BONE TISSUE ENGINEERING

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Recent dissertation research reports on the completion of fabrication and characterization of three-dimensional (3D) scaffolds and porous granular materials based on sea urchin skeletal structures. This research is motivated by the necessity for better bone substitute materials to regenerate damaged bones and replace autologous bone grafts as clinical material. This study aims to develop 3D scaffolds based on carbonate hydroxyapatite (nCHA) nanoparticles from *Diadema setosum* shells and biphasic calcium phosphate-doped magnesium (Mg-BCP) granules from *Mesocentrotus nudus* spines. This research provides benefits in improving green synthesis based on local wisdom to develop bone substitute materials superior to commercial materials. The nCHA bioceramic was synthesized through a hydrothermal dissolution-precipitation method using hydroxyapatite (nHA) nanoparticles, which were synthesized through a hydrothermal method using calcium (Ca) precursors based on *D. setosum* shells. nCHA-based scaffolds were fabricated by freeze-drying with the addition of polyvinyl alcohol (PVA) or poly- ϵ -caprolactone (PCL) and incorporation of cellulose nanofibrils (CNF), which were synthesized by ultrasonication using microcrystalline cellulose (MCC). Scaffold characterization was carried out through physical-chemical, mechanical compressive, antibacterial diffusion tests against *P. aeruginosa*, *P. gingivalis*, and *S. aureus* bacteria, and in vitro against fibroblast (NIH/3T3) and osteoblast (MC3T3-E1) cells. Physical-chemical tests on the scaffolds included crystallographic properties, functional groups, morphology, element content, swelling behavior, biodegradation, protein adsorption, and biomineralization. In vitro tests on the scaffolds included cell viability through 3-(4,5-dimethylthiazol-2-yl)-2,5 diphenyltetrazolium bromide (MTT) assay, cell proliferation through cell counting kit-8 (CCK-8) assay, cell adhesion through immunofluorescence staining, and cell migration through scratch wound assay. Mg-BCP granule material was fabricated through carbonation and phosphatization methods using *M. nudus* spines. Granule characterization was carried out through physical-chemical tests, including crystallographic properties, functional groups, morphology, element content, pore distribution, and granular filling rate, compressive mechanical tests, and in vitro through MTT assay on MC3T3-E1 cells. The incorporation of CNF in the nCHA/PVA/CNF scaffold resulted in a decrease in crystallinity (75.3%), the formation of macropores ($<100 \mu\text{m}$) and lamellar micropores ($1\text{--}20 \mu\text{m}$), an increase in antibacterial activity, and the viability of NIH/3T3 cells reached 90.4% ($\text{IC}_{50} = 2732 \mu\text{g/mL}$). The incorporation of nCHA and CNF in PCL/nCHA/CNF scaffolds resulted in increased porosity (mechanical properties that fill cancellous

bone), antibacterial activity, swelling ratio, degradation rate, protein adsorption, apatite biomineralization, and proliferation, adhesion, and migration of MC3T3-E1 cells. Furthermore, Mg-BCP granules with biphasic phases of Mg-substituted HA/ β -TCP maintained a cylindrical shape (radial-uniaxial micropore volume = $178.5 \pm 0.5 \text{ mm}^3/\text{g}$), resulting in adequate mechanical properties, dense defect filling rate, and cytocompatibility to MC3T3-E1 cells. The results of the above study conclude that the 3D scaffold and granule material based on the sea urchin skeleton structure that have been developed are potential for application as bone substitute materials that can support successful bone regeneration.

Keywords: sea urchin skeletal structure, 3D scaffold, granular material, bone tissue engineering.