Chitosan-based Scaffolds, Suitable Structures for Wound Healing Dressing: A Short Review

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Introduction: Different kinds of substances has been used for wound dressing, however, some disadvantages such as unsatisfactory mechanical stability, poor flexibility, severe shrinkage, low porosity, hard separation from the wound site, and non-antibacterial activity, has been reported. Over the last two decades, much effort has been made to find suitable biopolymer materials for wound healing applications. Chitosan has revealed various biological properties like biodegradable, biocompatible, non-toxic and non-allergenic, antibacterial effects thus can be used for the production of biofilms and nano-scaffolds. The poor solubility and thermal properties of chitosan restrict its widespread uses, but this polysaccharide is highly compatible with other biopolymers, and researchers are using this property to improve the limitations of chitosan and produce various types of chitosan-based hybrids materials. The purpose of this study is to provide an overview of various chitosan-based nanoscaffolds as wound healing dressings. **Materials and Methods:** This narrative review was performed using ISI Web of Science, PubMed, SID, Scholar, Scopus, and Science Direct and articles published up to Jan 2020 were included. The keywords of chitosan, chitosan-based scaffolds, chitosan-based composite, and wound dressing were used. **Results:** Many researches have been accomplished to obtain chitosan-based scaffolds, including the construction of chitosan based blends and composite scaffolds and etc. The results of most of these researches showed positive effects of chitosan, and its nanocomposite scaffolds/biofilms in blood clotting, activated platelet activity, facilitated tissue regeneration and wound healing process. **Conclusion:** The use of chitosan-based scaffolds is effective in biological dressings and wound healing. Futuristic and innovative approaches in chitosan derivatives and nanocomposites can lead to the preparation of suitable co-polymers and the production of wound dressings with the desired properties. the authors hope that this review will be helpful to the researchers.

Keywords: Chitosan; Chitosan-based Scaffolds; Chitosan-based Composite; Biopolymer; Wound Dressing

Introduction

The skin wound is a type of injury that typically involves rupture of the integument or mucous membrane and usually damages the underlying tissues (1). Skin lesions treatment requires to find the temporary barriers that improve the recovery process and regeneration of the tissues and pain endured by the patient (2-4). Efforts to find a suitable dressing to cover the wound have grown over the years. An ideal wound dressing must allow protection of the damaged site, have adequate mechanical strength, inhibit bacterial/fungal growth, absorb wound secretions, promote cell proliferation, and accelerate the tissue repair process (1, 5, 6). Appropriate wound dressing should also be flexible, easy to use, non-allergenic, and non-toxic (7-9). The selection of wound healing material due to its interaction with the wound affects the healing process (10, 11). Commercially, various types of biopolymers for wound dressing have been distinguished; some are based on natural polymers, such as chitin, chitosan, alginate, cellulose, and some others on synthetic polymers polyvinyl alcohol, polycaprolactone, and polylactic acid (12-17).

Chitosan (CS) is a natural cationic polysaccharide composed of β-O-(1–4) - linked glucosamine (GlcN) and variable levels of

N-acetyl glucosamine (GlcNAc) (18, 19).

CS is derived from chitin, which can be obtained from the exoskeleton of shrimp, other sea crustaceans, and fungi (18). Because of various biological features like easy preparation, biodegradability, cytocompatibility, fat binding capacity, environmental safety, non-cytotoxicity, antibacterial/antifungal activity, hemostasis, non-carcinogenic, hydrophobic, and property to accelerate wound healing, CS and its derived are the most promising biomolecules material, widely investigated in tissue engineering fields, biomedicine, bone regeneration, and drug controlled release systems, as well as biochemical separation systems (12, 20-27). CS scaffolds are used to prepare various forms of the wound dressings, such as sponges, bandages, hydrogels, and membranes (3, 28, 29). CS shows positive effects at different stages of the wound improvement process (3, 29, 30). In the early stage of wound healing phase, Chitosan modulates surface-induced thrombosis and blood coagulation and can promote the activation of platelets and collagen fabrication of fibroblasts (31, 32). The hemostatic ability of CS does not depend on the host's coagulation path, and this is an advantage of CS dressing compared to Combat Gauze (33). Additionally, CS can re-epithelialize and regenerate the granular layer of the skin (34-36). CS exhibits rather broad immunomodulatory effects, by inducing innate immune cells to release a broad range of pro- and anti-inflammatory cytokines, chemokines, growth factors, and bioactive lipids (19).

Due to some of the limitations associated with using scaffolds synthesized from a single-phase biomaterial, a number of researchers have formed scaffolds that include two, or more, phases to combine the advantageous properties of each step (37, 38). Blending or combining of synthetic-natural polymers, natural and natural polymers as well as synthetic-synthetic polymers can result in the development of new polymeric materials that are both biocompatible and biodegradable (39). However, some of the limitation of pure CS, like its low mechanical properties (rigid crystalline structure), high destruction rate, and moderate Cell adhesion, can be overcome by cross-linking as well as mixing with other synthetic biodegradable polymers such as poly (ethylene glycol), poly-L-lysine, hyaluronic acid, hydroxyapatite, gelatin, laminin, and collagen type II/type IV (40-48). This study aims to overview and outline the different CS-based scaffolds for wound healing dressings.

Materials and Methods

This study is going to review and summarize information about CS-based scaffolds for wound dressing. In this study, the keywords searched included chitosan, chitosan-based scaffolds, chitosan-based composite, and wound dressing. We searched English reported and published articles in journals up to 2020 using various databases, including ISI Web of Science, SID, Google Scholar, PubMed, Scopus, and Science Direct. Then, the related articles were reviewed.

Results

Chitosan-based blend, nanocomposite scaffolds

Scaffolds are artificial, highly porous extracellular networks, used in applications such as delivering cells, drugs or genes selectively into the body. Different forms of scaffolds are available such as typical thermo-sensitive sol/gel transition hydrogels, 3D extracellular matrix scaffolds, nanofibrous scaffolds, etc. (37, 38). A scaffold provides appropriate material for different functions, cell attachment, proliferation, as well as cell migration. The biological materials used to make scaffold may be natural polymers such as CS, fibrin, curdlan, gelatin, galactan, gellan, emulsan, levan, dextran, pullulan, alginate, collagen, and albumin, or synthetic biodegradable polymers such as polyethylene oxide (PEO), polyvinyl pyrrolidone (PVP), and polyvinyl acetate (PVA) (37, 38).

There are several purposes for blending CS, which depend on the application. chitosan-based natural/synthetic or polymer/nanoparticle composite scaffolds can be used for several purposes such as increase hydrophilicity and improve blood, high water vapor transmission rate (WVTR), wound closure rate and enhance antibacterial and mechanical properties (26, 49). Chitosan-based scaffolds are used to prepare various forms of wound dressings, such as sponges, bandages, hydrogels, and membranes (13, 50-55).

Chitosan scaffolds with natural polymers

Alginate is a natural anionic and hydrophilic multifunctional polysaccharide. Alginate, due to its excellent biocompatibility, forming gel easily, is one of the important polymers, have increasingly used as attractive compounds in the biomedical applications (32, 56). The CS/alginate polyelectrolyte complex (CS-AL PEC) biofilms showed excellent *in vitro* biocompatibility with human and mouse fibroblasts and promoted accelerated healing of wounds compared with a

conventional gauze dressing. The results of these researches demonstrate that this membrane can be considered for wound dressing (57-59).

The super porous hydrogel composite of CS / alginate/curcumin / honey had a good fluid absorption capacity, excellent swelling capacity, water vapor transmission, bio-adhesion, and expandable strength. *In vivo* results showed that this wound dressing induced re-epithelialization. This composite contributed to impressive faster wound healing within one week (32, 60).

The high performance of biodegradable, biocompatible, and non-toxic CS/cellulose composite as a wound dressing is reported. This composite substantially protects wounds from dehydration and inhibited the growth of a broader range of bacteria such as S. aureus, E. coli, Vancomycin-resistant Enterococcus faecalis (VRE) and Methicillin-resistant S.aureus (MRSA) in the lesion site. Fibroblasts continue to survive, and proliferate in the presence of composites. These results indicated that this blend membranes might be appropriate to be used as a wound dressing (61-64).

Straccia *et al.*, examined the effect of N-Succinyl chitosan (NSC)/sodium alginate/micro-cellulose on wound dressings. This hydrogel had antimicrobial effect against S. aureus and E. coli, ameliorated swelling grade, and water vapor transmission rate and stability. This biomaterial was suitable to hold a moist environment in the wound site to increase regeneration and re-epithelization (65).

Flexible sponge composite, CS/sodium alginate (SA)/ curcumin, was used to repair dermal lesions in rats. The results obtained from this compound indicated the ability of *in vitro* drug release, swelling capability, as well as *in vivo* formation of the collagen. *In vivo* tests showed that this compound was more effective than cotton gauze, and the presence of curcumin in this compound increases the therapeutic healing effect (66).

CS/sericin composite nanofibers displayed good compatibility to tissues for wound dressing applications. These biocompatible composite nanofibers showed a bactericidal effect against gram-negative and gram-positive bacteria and could promote cell proliferation. The researchers showed that the combination of the two substances improved the biological response ability through their synergistic biological effects; therefore it could function as a good candidate for wound dressings (28, 67).

The use of CS and silk fibroin (SF) showed an antibacterial effect on gram-negative bacteria *E. coli,* enhanced cell attachment and proliferation. The results of the experiments in rats showed a rapid improvement in skin regeneration without tolerogenic. Taken together, these results indicate that composite might be a promising biohybrid material for wound dressing (68, 69).

Type I collagen and chitosan, due to their cell-related signaling activity including survival, proliferation, and migration have been broadly used to make scaffolds for wound dressing and restoring the damaged tissue (70). CS/collagen and its derivatives hydrogel demonstrated well wound repairing potential. These scaffolds had a good anti-inflammatory effects, re-epithelialization ability, and considerable accelerated diabetic wound healing (70, 71). Ma *et al.*, produced CS/collagen sponge for skin tissue rengineering. They added Glutaraldehyde (GA) to this composite to improve their biostability. The results of using this treated scaffold on human skin fibroblasts culture showed accelerated cell infiltration and proliferation. Satisfactory *in vivo* tests results were also obtained. All these results suggested that the collagen/CS/GA scaffold may be a potential candidate for skin regeneration with increased biocompatibility and good biostability (72).

Chitosan/fibrin bandages, when tested in rats, showed high cell viability, adhesion compared to chitosan-only groups. In rats, due to an increased blood clotting, enhanced percentage of wound closure was seen in lesion treated with this dressing compare to chitosan-only bandages. It was proposed that the biodegradation chitosan/fibrin bandages, might produce an additive effect on wound healing. It was suggested that the biodegradation chitosan/fibrin bandages, might generate an increasable impact on wound healing (73).

In vitro and *in vivo* result of novel fibrous scaffold CS/salmon fibrinogen showed a good mimic of the native extracellular matrix (ECM). Progressive proliferation of human skin fibroblasts cultured on this scaffold was seen. Wound healing in the group that used this scaffold was far better than the control group. As a result, researchers proposed this scaffold for use in tissue regeneration, surgery, and other injuries dressing (74).

Kweon *et al.*, used water-soluble CS (WSC)/heparin (CH) ointment to make an accelerator in the wound healing process. Heparin was used in this structure due to its ability to increase stabilization and concentration of growth factors in the wound site. The use of this structure showed approximately full regeneration in the dermis of the lesion area (28, 75).

Hyaluronic acid (hyaluronan) due to its capability to promote epithelial and mesenchymal cells migration, differentiation, enhancing collagen deposition is a suitable biomaterial for

wound dressing (76, 77). Studies involving the use of chitosan/HA hydrogels, aldehyde 1-amino-3,3-diethoxy-propane–HA–chitosan, and HA/poly(vinyl phosphonic acid)/chitosan hydrogels in wound healing with satisfactory results have been reported (32, 78).

Blazevic *et al.*, proposed a new strategy to deliver melatonin locally at the lesion site utilizing CS /lecithin nanoscaffold. These nanoparticles showed a good effect on the keratinocyte migration/proliferation. The use of CS/melatonin nanoscaffold caused accelerated wound epithelialization and closure (79).

Carboxymethyl-chitosan / gelatin hydrogels and CS/gelatin/epigallocatechin gallate hydrogels displayed positive antibacterial activity, an effective promoting cell proliferation, easily remove from the wound and accelerate the wound healing process (80,81). The CS/gelatin (GE)/nanofiber membranes with Fe3O4 nanoparticles with mechanical and antibacterial properties appeared as a promising wound dressing substance (82).

Natural polymers (from plant extracts)

The use of a combination of plant extracts with CS has an important role in nanotechnology. Researchers believe that the incorporating of plant extracts into some structures such as CS could provide better performance and synergistic effect for wound healing as well as great potential as a biodegradable and antibacterial blend for wound dressing applications. These outcomes have been widely supported by the results of cell viability and proliferation of fibroblast cells (30, 83). Lawsonia inermis leaves extract, Melilotus officinalis extract, Tridax procumbens leaves extract, Senna auriculata extract, Achyranthes aspera extract, Radix Salviae miltiorrhizae extract, Ocimum basilicum extract, Bletilla striata extract, Passiflora edulis extract, Morus alba leaves extract and several other plants have shown great potential for use in the skin wounds dressing (83-91).

Also, chitosan hydrogels in combination with hemigraphis, nerolidol or apigenin, which found in several plants, displayed the antimicrobial effect and healing properties (91-93).

Chitosan scaffolds with synthetic polymers

Polyethylene oxide (PEO) is a hydrophobic polymer used in the manufacture of nanofibers. PEO was reported to reduce viscosity due to changes in the internal and molecular interactions of CS chains. PEO also led to an increase in the hydrophilic property of the nano CS scaffold and better wound dressing. Therefore, CS/PEO scaffold is a good candidate for wound dressing usages due to its non - cytotoxicity, great antibacterial properties, and biocompatibility (4, 94, 95).

CS-based nanoscaffolds have been used as an anti leishmaniasis wound dressing. The CS/PEO/berberine (BBR) nanofibers were prepared with the aim to obtain a suitable nanofiber for leishmania lesions dressing in mice. Results showed that this nano bandage has a positive effect on the rapid healing of lesions (4).

Polyvinyl Alcohol (PVA) has good physical and chemical properties such as nontoxic, water-soluble polymer, biodegradable, as well as excellent film-forming properties. Therefore, PVA is widely used to support natural polymers in tissue engineering and wound dressing (96). According to some investigations, intermolecular and intramolecular hydrogen bonds between CS and PVA chains resulted in an easier electrospinning process. Furthermore, the use of CS/PVA nanofibers on open wound healing in mice was useful. Results of mechanical stability and histopathological examination indicated that this matrix was impressive as a wound healing accelerator (97-101).

The use of chitosan/PVA hydrogel in experimental burn rats showed that the wound was healed earlier than those cured with cotton and paraffin gauze (102). Exciting results were that after adding bee venom or honey to this compound, the anti-inflammatory and antibacterial properties of this hydrogel was increased. These results showed chitosan/ PVA compound has good potential as wound healing dressing (32, 103, 104)

The PVA/CS/Starch nanofiber could provide proper handling of wound exudates, accelerate wound healing, and efficiently protect the wound against E. coli and S.aureus (36). Another study on wound healing properties of CS/ PVA/ starch membrane with nano Zinc oxide showed that this membrane was effective as a wound dressing and that the gel can be used in topical applications, which required a broad spectrum of antimicrobial activity; for example, as a bandage for wound dressing (12).

The CS/PVA/montmorillonite (MMT) nanocomposite hydrogels were recommended as a suitable wound dressing, due to good mechanical properties, biocompatibility, biodegradability, blood clotting ability, and antibacterial effect (105).

Poly (ethylene glycol) (PEG) is a hydrophilic and flexible polymer that has been widely used in pharmaceutical industries for its low toxicity, flocculation ability, and thermoplasticity. CS/ PEG diacrylate blend biofilms showed good *in vitro* biocompatibility and no cytotoxicity toward the growth of

mouse fibroblasts and have the potential to be applied as wound dressing substance (106, 107).

Acrylic acid, a common hydrogel-forming monomer, has been used in the copolymerization with CS/chitin to enhance its hydrophobicity. The results of the combination of poly (acrylic acid) (PAA) with chitin or CS showed that not only this compound improved the water sorption of the dressing but also caused growth and migration of fibroblasts to the wound site. After 14 days, the morphological and biological conditions of the cell on this film returned to normal (108).

Chitosan-based scaffold as a drug delivery system / antimicrobial agents

The use of silver nanoparticles has an important role in nanotechnology because of its physical, biological, and functional applications. Nanosilver incorporated and CS scaffolds have shown antibacterial effect against gram-negative and gram-positive bacteria, excellent blood clotting ability, and nontoxic effect toward Vero cells. In another study, the results of the antibacterial tests showed that fabricated composite scaffolds CS/cellulose (CE)/silver (Ag) could find potential usage against different bacterial strains, including antibiotic-resistant strains and could be applied as wound dressing materials. Also, cellular response data showed that NIH3T3 fibroblastic cells have adhered and proliferated into all composite scaffolds. These satisfactory results predict a good future for the use of these nanoparticles in the biomedical field, especially for wound dressing materials (30, 109-114).

In this regard, Rahimi *et al*., revealed that a bioactive quaternized chitosan and its silver-containing nanocomposites could be considered as a biomaterial for wound dressing applications (113).

The bionanocomposite CS/ZnO due to water absorption, cytocompatibility, antibacterial effect, thermal stability, as well as biodegradability, was introduced for use in wound dressing (115, 116).

CS–polyacrylamide (PAM) and other chitosan hydrogel scaffolds were produced to deliver piperacillin/tazobactam, norfloxacin, minocycline, gentamicin/ ciprofloxacin, and gentamycin sulfate, sulfadiazine, amikacin, tetracycline hydrochloride. The results of these studies have shown the good effect of antimicrobial agents in chitosan-based dressings for decreasing infection load and accelerating wound healing (117-124).

Thiolated CS/poly (N-isopropyl acrylamide)/ ciprofloxacin film showed antibacterial properties. This composite was easily removed from the lesion site by lowering the temperature without causing any pain (28, 125).

After using hydrolyzed curdlan /chitosan membranes, improved elongation-at-break and water vapor transmission rate in high temperature (90 ◦C) were observed. Curdlan, a microbial linear polysaccharide produced by a strain of Alcaligenes faecalis(126, 127). The results of using curdlan/CS membranes showed a well antibacterial effect against Klebsiella pneumoniae, Escherichia coli, Pseudomonas aeruginosa and Staphylococcus aureus. The use of this substance as a wound dressing requires more time and studies (126).

Chitosan-based scaffold with growth factor releasing nanoparticles

Growth factors are soluble regulatory signaling polypeptides synthesized by fibroblasts, epithelial cells, endothelial cells, inflammatory cells, and platelets. These factors can stimulate cell migration, cellular growth, proliferation, cellular differentiation and healing (32, 128, 129).

The use of growth factors incorporated into CS has also shown good results for use in wound healing. The most important of these factors are fibroblast growth factor-2 (FGF-2), platelet-derived growth factor (PDGF), basic fibroblast growth factor (bFGF), vascular endothelial growth factor (VEGF), epidermal growth factor (EGF), and transforming growth factor-beta (TGF-b) (130-136).

Conclusion

Despite a large number of wound dressings in the medical world, efforts to find the superior product for a variety of wounds are continuing. Therefore, finding a suitable substance for wound dressings that guide and accelerates the wound healing process will help patients and physicians. Chitosan has been shown to be important biopolymers to be used in wound dressing due to its biodegradability, biocompatibility and antibacterial, anti-inflammatory, non-cytotoxicity activity. Satisfactory results from CS and modified CS (blends/composites) on healing and regeneration wound tissues, have increased researchers' efforts to find cost-effective and better compounds for the treatment of acute and chronic wounds. For this reason, the present study is focused on the introduction of synthetic/natural polymers and other metabolites with different properties as the additives to CS-based wound dressing's substances. The purpose of this

review was to collect the best work in this field and provide information to help the researcher.

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References

1. Zarrintaj P, Moghaddam AS, Manouchehri S, Atoufi Z, Amiri A, Amirkhani MA, *et al.,* Can regenerative medicine and nanotechnology combine to heal wounds? The search for the ideal wound dressing. Nanomedicine (Lond). 2017;12(19):2403-22.
2. Abdelrahman T, Newton H. Wound dressings: Principles and practice. Surgery (oxford). 2011;29:491-5.
3. Miguel S, Moreira A, Correia I. Chitosan based-asymmetric membranes for wound healing: A review. International Journal of Biological Macromolecules. 2019;127.
4. Seyyed Tabaei SJ, Rahimi M, Akbaribazm M, Ziai SA, Sadri M, Shahrokhi SR, *et al.,* Chitosan-based nano-scaffolds as antileishmanial wound dressing in BALB/c mice treatment: Characterization and design of tissue regeneration. Iranian Journal of Basic Medical Sciences. 2020;23(6):788-99.
5. Boateng JS, Matthews KH, Stevens HN, Eccleston GM. Wound healing dressings and drug delivery systems: a review. Journal of pharmaceutical sciences. 2008;97(8):2892-923.
6. Sarabahi S. Recent advances in topical wound care. Indian journal of plastic surgery : official publication of the Association of Plastic Surgeons of India. 2012;45:379-87.
7. Ong S-Y, Wu J, Moochhala S, Tan M, Lu J. Development of a chitosan-based wound dressing with improved hemostatic and antimicrobial properties. Biomaterials. 2008;29:4323-32.
8. Paul W, Sharma C. Chitosan and Alginate Wound Dressings: A Short Review. Trends in Biomaterials and Artificial Organs. 2004;18.
9. Berger J, Reist M, Mayer J, Felt O, Gurny R. Structure and interactions in chitosan hydrogels formed by complexation or aggregation for biomedical applications. European journal of pharmaceutics and biopharmaceutics : official journal of Arbeitsgemeinschaft für Pharmazeutische Verfahrenstechnik eV. 2004;57:35-52.
10. Branski L, Gauglitz G, Herndon D, Jeschke M. A review of gene and stem cell therapy in cutaneous wound healing. Burns : journal of the International Society for Burn Injuries. 2008;35:171-80.
11. K S, Kim H, P.s S, Chun B-S, Kang HW. Fabrication of multifunctional chitosan-based nanocomposite film with rapid healing and antibacterial effect for wound management. International Journal of Biological Macromolecules. 2018;118.
12. Baghaie S, Khorasani MT, Zarrabi A, Moshtaghian J. Wound healing properties of PVA/ starch /chitosan hydrogel membranes with nano Zinc oxide as antibacterial wound dressing material. Journal of Biomaterials Science, Polymer Edition. 2017;28:1-40.
13. Burkatovskaya M, Castano AP, Demidova-Rice TN, Tegos GP, Hamblin MR. Effect of chitosan acetate bandage on wound healing in infected and noninfected wounds in mice. Wound repair and regeneration : official publication of the Wound Healing Society [and] the European Tissue Repair Society. 2008;16(3):425-31.
14. Ishihara M, Nakanishi K, Ono K, Sato M, Kikuchi M, Saito Y, *et al.,* Photocrosslinkable chitosan as a dressing for wound occlusion and accelerator in healing process. Biomaterials. 2002;23(3):833-40.
15. Lin J, Li C, Zhao Y, Hu J, Zhang LM. Co-electrospun nanofibrous membranes of collagen and zein for wound healing. ACS Appl Mater Interfaces. 2012;4(2):1050-7.
16. Charernsriwilaiwat N, Opanasopit P, Rojanarata T, Ngawhirunpat T. Lysozyme-loaded, electrospun chitosan-based nanofiber mats for wound healing. International journal of pharmaceutics. 2012;427(2):379-84.
17. Luo Y, Luo G, Gelinsky M, Huang P, Ruan C. 3D bioprinting scaffold using alginate/polyvinyl alcohol bioinks. Materials Letters. 2017;189:295-8.
18. Sudhakar YN, Selvakumar M, Bhat DK. Chapter 2 - Methods of Preparation of Biopolymer Electrolytes. In: Sudhakar YN, Selvakumar M, Bhat DK, editors. Biopolymer Electrolytes: Elsevier; 2018. p. 35-52.
19. Fong D, Hoemann CD. Chitosan immunomodulatory properties: perspectives on the impact of structural properties and dosage. Future science OA. 2018;4(1):Fso225.
20. Ge J, Cui Y, Yan Y, Jiang W. The Effect of Structure on Pervaporation of Chitosan Membrane. Journal of Membrane Science - J MEMBRANE SCI. 2000;165:75-81.
21. Hu Y, Jiang X, Ding Y, Ge H, Yuan Y, Yang C. Synthesis and characterization of chitosan-poly(acrylic acid) nanoparticles. Biomaterials. 2002;23(15):3193-201.
22. Shi XY, Tan TW. Preparation of chitosan/ethylcellulose complex microcapsule and its application in controlled release of vitamin D2. Biomaterials. 2002;23(23):4469-73.
23. Madhumathi K, Shalumon KT, Rani VV, Tamura H, Furuike T, Selvamurugan N, *et al.,* Wet chemical synthesis of chitosan hydrogel-hydroxyapatite composite membranes for tissue engineering applications. Int J Biol Macromol. 2009;45(1):12-5.
24. Li X, Kong X, Zhang Z, Nan K, Li L, Wang X, *et al.,* Cytotoxicity and biocompatibility evaluation of N,O-carboxymethyl chitosan/oxidized alginate hydrogel for drug delivery application. Int J Biol Macromol. 2012;50(5):1299-305.
25. Luca L, Rougemont AL, Walpoth BH, Boure L, Tami A, Anderson

JM, *et al.,* Injectable rhBMP-2-loaded chitosan hydrogel composite: osteoinduction at ectopic site and in segmental long bone defect. Journal of biomedical materials research Part A. 2011;96(1):66-74.
26. Archana D, Dutta J, Dutta PK. Evaluation of chitosan nano dressing for wound healing: characterization, *in vitro* and *in vivo* studies. Int J Biol Macromol. 2013;57:193-203.
27. Dai T, Tegos G, Burkatovskaya M, Castano A, Hamblin M. Chitosan Acetate Bandage as a Topical Antimicrobial Dressing for Infected Burns. Antimicrobial agents and chemotherapy. 2008;53:393-400.
28. Ahmed S, Ikram S. Chitosan Based Scaffolds and Their Applications in Wound Healing.Achievements in the Life Sciences. 2016;10(1):27-37.
29. Patrulea V, Ostafe V, Borchard G, Jordan O. Chitosan as a starting material for wound healing applications. Eur J Pharm Biopharm. 2015;97(Pt B):417-26.
30. Ahmed S, Ahmad M, Swami BL, Ikram S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. Journal of Advanced Research. 2016;7(1):17-28.
31. Mattioli-Belmonte M, Zizzi A, Lucarini G, Giantomassi F, Biagini G, Tucci G, *et al.,* Chitin Nanofibrils Linked to Chitosan Glycolate as Spray, Gel, and Gauze Preparations for Wound Repair. Journal of Bioactive and Compatible Polymers. 2007;22(5):525-38.
32. Liu H, Wang C, Li C, Qin Y, Wang Z, Yang F, *et al.,* A functional chitosan-based hydrogel as a wound dressing and drug delivery system in the treatment of wound healing. RSC Advances. 2018;8:7533-49.
33. Khan MA, Mujahid M. A review on recent advances in chitosan based composite for hemostatic dressings. International Journal of Biological Macromolecules. 2019;124:138-47.
34. Jayakumar R, Prabaharan M, Sudheesh Kumar PT, Nair SV, Tamura H. Biomaterials based on chitin and chitosan in wound dressing applications. Biotechnology advances. 2011;29(3):322-37.
35. Jayakumar R, Prabaharan M, Nair SV, Tamura H. Novel chitin and chitosan nanofibers in biomedical applications. Biotechnology advances. 2010;28(1):142-50.
36. Adeli H, Khorasani MT, Parvazinia M. Wound dressing based on electrospun PVA/chitosan/starch nanofibrous mats: Fabrication, antibacterial and cytocompatibility evaluation and *in vitro* healing assay. Int J Biol Macromol. 2019;122:238-54.
37. Garg T, Singh O, Arora S, Rayasa M. Scaffold: A Novel Carrier for Cell and Drug Delivery. Critical reviews in therapeutic drug carrier systems. 2012;29:1-63.
38. Vishal P. Scaffolds: Porous Scaffold for Modulated Drug Delivery. Austin Therapeutics. 2016;3:1027.
39. Jawaid M, Abdul Khalil HPS. Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate polymers. 2011;86(1):1-18.
40. Huang Y, Onyeri S, Siewe M, Moshfeghian A, Madihally SV. *In vitro* characterization of chitosan–gelatin scaffolds for tissue engineering. Biomaterials. 2005;26(36):7616-27.
41. Anderl J, Beckstead B, Brown C, Hoffman A, Giachelli C. Adhesive protein interactions with chitosan: Consequences for valve endothelial cell growth on tissue-engineering materials. Journal of biomedical materials research Part A. 2003;67:538-47.
42. Ragetly G, Griffon D, Lee H, Chung Y. Effect of collagen II coating on mesenchymal stem cell adhesion on chitosan and on reacetylated chitosan fibrous scaffolds. Journal of materials science Materials in medicine. 2010;21:2479-90.
43. Cuy JL, Beckstead BL, Brown CD, Hoffman AS, Giachelli CM. Adhesive protein interactions with chitosan: consequences for valve endothelial cell growth on tissue-engineering materials. Journal of biomedical materials research Part A. 2003;67(2):538-47.
44. Mingyu C, Kai G, Jiamou L, Yandao G, Nanming Z, Xiufang Z. Surface modification and characterization of chitosan film blended with poly-L-lysine. Journal of biomaterials applications. 2004;19(1):59-75.
45. Zhang M, Li XH, Gong YD, Zhao NM, Zhang XF. Properties and biocompatibility of chitosan films modified by blending with PEG. Biomaterials. 2002;23(13):2641-8.
46. Zhang J, Nie J, Zhang Q, Li Y, Wang Z, Hu Q. Preparation and characterization of bionic bone structure chitosan/hydroxyapatite scaffold for bone tissue engineering. Journal of biomaterials science Polymer edition. 2014;25(1):61-74.
47. Yamane S, Iwasaki N, Majima T, Funakoshi T, Masuko T, Harada K, *et al.,* Feasibility of chitosan-based hyaluronic acid hybrid biomaterial for a novel scaffold in cartilage tissue engineering. Biomaterials. 2005;26(6):611-9.
48. Gomes SR, Rodrigues G, Martins GG, Roberto MA, Mafra M, Henriques CM, *et al., In vitro* and *in vivo* evaluation of electrospun nanofibers of PCL, chitosan and gelatin: a comparative study. Materials science & engineering C, Materials for biological applications. 2015; 46:348-58.
49. Elhefian E. Chitosan-Based Polymer Blends: Current Status and Applications. Journal- Chemical Society of Pakistan. 2014; 36:11-27.
50. Miguel SP, Ribeiro MP, Brancal H, Coutinho P, Correia IJ. Thermoresponsive chitosan-agarose hydrogel for skin regeneration. Carbohydrate polymers. 2014; 111:366-73.
51. Anisha BS, Biswas R, Chennazhi KP, Jayakumar R. Chitosan-hyaluronic acid/nano silver composite sponges for drug resistant bacteria infected diabetic wounds. Int J Biol Macromol. 2013;62:310-20.
52. Li D, Diao J, Zhang J, Liu J. Fabrication of New Chitosan-Based Composite Sponge Containing Silver Nanoparticles and Its Antibacterial Properties for Wound Dressing. Journal of nanoscience and nanotechnology. 2011; 11:4733-8.
53. Li D, Diao J, Zhang J, Liu J. Fabrication of new chitosan-based composite sponge containing silver nanoparticles and its antibacterial properties for wound dressing. J Nanosci Nanotechnol. 2011; 11(6):4733-8.
54. VandeVord PJ, Matthew HW, DeSilva SP, Mayton L, Wu B, Wooley PH. Evaluation of the biocompatibility of a chitosan scaffold in mice. Journal of biomedical materials research. 2002; 59(3):585-90.

55. Silva SS, Popa EG, Gomes ME, Cerqueira M, Marques AP, Caridade SG, *et al.,* An investigation of the potential application of chitosan/aloe-based membranes for regenerative medicine. Acta biomaterialia. 2013; 9(6):6790-7.
56. Szekalska M, Puciłowska A, Szymańska E, Ciosek P, Winnicka K. Alginate: Current Use and Future Perspectives in Pharmaceutical and Biomedical Applications. International Journal of Polymer Science. 2016; 2016:7697031.
57. Yan XL, Khor E, Lim L. Chitosan-alginate films prepared with chitosans of different molecular weights. Journal of biomedical materials research. 2001; 58:358-65.
58. Meng X, Tian F, Yang J, He C-N, Xing N, Li F. Chitosan and alginate polyelectrolyte complex membranes and their properties for wound dressing application. Journal of materials science Materials in medicine. 2010; 21:1751-9.
59. Yan X, Khor E, Lim L. PEC Films Prepared from Chitosan-Alginate Coacervates. Chemical & pharmaceutical bulletin. 2000; 48:941-6.
60. Momin M, Kurhade S, Khanekar P, Mhatre S. Novel biodegradable hydrogel sponge containing curcumin and honey for wound healing. Journal of Wound Care. 2016; 25:364-72.
61. Tran C, Duri S, Harkins A. Recyclable synthesis, characterization, and antimicrobial activity of chitosan-based polysaccharide composite materials. Journal of biomedical materials research Part A. 2013; 101A.
62. Harkins A, Duri S, Kloth L, Tran C. Chitosan-cellulose composite for wound dressing material. Part 2. Antimicrobial activity, blood absorption ability, and biocompatibility. Journal of biomedical materials research Part B, Applied biomaterials. 2014; 102.
63. H.P.S AK, Saurabh C, Adnan A, Fazita M, Syakir MI, Davoudpour Y, *et al.,* A review on chitosan-cellulose blends and nanocellulose reinforced chitosan biocomposites: Properties and their applications. Carbohydrate polymers. 2016; 150.
64. Wu Y-B, Yu S-H, Mi F-L, Wu C-W, Shyu S-S, Peng C-K, *et al.,* Preparation and characterization on mechanical and antibacterial properties of chitsoan/cellulose blends. Carbohydrate polymers. 2004; 57:435-40.
65. Straccia M, Romano I, Oliva A, Santagata G, Laurienzo P. Cross linker effects on functional properties of alginate/N-succinylchitosan based hydrogels. Carbohydrate polymers. 2014; 108:321-30.
66. Dai M, Zheng X, Xu X, Kong X, Xingyi L, Guo G, *et al.,* Chitosan-Alginate Sponge: Preparation and Application in Curcumin Delivery for Dermal Wound Healing in Rat. Journal of biomedicine & biotechnology. 2009; 2009:595126.
67. Zhao R, Li X, Sun B, Zhang Y, Zhang D, Tang Z, *et al.,* Electrospun chitosan/sericin composite nanofibers with antibacterial property as potential wound dressings. International journal of biological macromolecules. 2014; 68:92-7.
68. Cai Z-X, Mo X-M, Zhang K-H, Fan L-P, Yin A-L, He C-L, *et al.,* Fabrication of chitosan/silk fibroin composite nanofibers for wound-dressing applications. International journal of molecular sciences. 2010; 11(9):3529-39.
69. Bhardwaj N, Kundu SC. Silk fibroin protein and chitosan polyelectrolyte complex porous scaffolds for tissue engineering applications. Carbohydrate polymers. 2011; 85(2):325-33.
70. Sanchez R, Martínez-Arredondo E, Martínez-López V, Melgarejo-Ramírez Y, Molina AM, Lugo H, *et al.,* Development of Hydrogel with Anti-Inflammatory Properties Permissive for the Growth of Human Adipose Mesenchymal Stem Cells. Journal of Nanomaterials. 2016; 2016:1-8.
71. Xiao Y, Reis LA, Feric N, Knee EJ, Gu J, Cao S, *et al.,* Diabetic wound regeneration using peptide-modified hydrogels to target re-epithelialization. Proceedings of the National Academy of Sciences of the United States of America. 2016; 113(40):E5792-e801.
72. Ma L, Gao C, Mao Z, Zhou J, Shen J, Hu X, *et al.,* Collagen/chitosan porous scaffolds with improved biostability for skin tissue. Biomaterials. 2003; 24:4833-41.
73. Madasamy P, Lokhande G, Singh A, Gaharwar A. Engineered Nanomaterials for Infection Control and Healing Acute and Chronic Wounds. ACS Applied Materials & Interfaces. 2016; 8.
74. Laidmäe I, Ērglis K, Cēbers A, Janmey PA, Uibo R. Salmon fibrinogen and chitosan scaffold for tissue engineering: *in vitro* and *in vivo* evaluation. J Mater Sci Mater Med. 2018; 29(12):182-.
75. Kweon D-K, Song S-B, Park Y-Y. Preparation of water-soluble chitosan/heparin complex and its application as wound healing accelerator. Biomaterials. 2003; 24(9):1595-601.
76. Galeano M, Polito F, Bitto A, Irrera N, Campo G, Avenoso A, *et al.,* Systemic administration of high-molecular weight hyaluronan stimulates wound healing in genetically diabetic mice. Biochimica ET biophysica acta. 2011; 1812:752-9.
77. Uppal R, Ramaswamy G, Arnold C, Goodband R, Wang Y. Hyaluronic acid nanofiber wound dressing--Production, characterization, and *in vivo* behavior. Journal of biomedical materials research Part B, Applied biomaterials. 2011; 97:20-9.
78. Chang Q, Gao H, Ge L, zhong W, Lu F, Xing M. Injectable aldehyded 1-amino-3, 3-diethoxy-propane hyaluronic acid-chitosan hydrogels as carrier of adipose derived stem cells to enhance angiogenesis and promote skin regeneration. J Mater Chem B. 2015; 3.
79. Blažević F, Milekic T, Duvnjak M, Juretić M, Pepić I, Filipovic-Grcic J, *et al.,* Nanoparticle-mediated interplay of chitosan and melatonin for improved wound epithelialisation. Carbohydrate polymers. 2016; 146.
80. Huang X, Zhang Y, Xu L, Chen X, Wei S. Influence of radiation crosslinked carboxymethyl-chitosan/gelatin hydrogel on cutaneous wound healing. Materials science & engineering C, Materials for biological applications. 2013; 33:4816-24.
81. Lin Y-H, Lin J-H, Li T-S, Wang S-H, Yao C-H, Chung W-Y, *et al.,* Dressing with epigallocatechin gallate-nanoparticles for wound regeneration. Wound Repair and Regeneration. 2015; 24: n/a-n/a.
82. Cai N, Li C, Han C, Luo X, Shen L, Xue Y, *et al.,* Tailoring mechanical and antibacterial properties of chitosan/gelatin nanofiber membranes with Fe3O4 nanoparticles for potential wound dressing application. Applied Surface Science. 2016; 369:492-500.
83. Yousefi I, Pakravan M, Rahimi H, Bahador A, Farshadzadeh Z, Haririan I. An investigation of electrospun Henna leaves extract-loaded

chitosan based nanofibrous mats for skin tissue engineering. Materials Science and Engineering: C. 2017; 75:433-44.
84. Mirzaei E, Sarkar S, Rezayat M, Faridi-Majidi R. Herbal Extract Loaded Chitosan-Based Nanofibers as a Potential Wound-Dressing. Journal of Advanced Medical Sciences and Applied Technologies. 2016;2:141.
85. Jayaram U, Sindhu R, Sakthivel S, Gurusamy A. HERBAL EXTRACT ENCAPSULATED IN CHITOSAN NANOPARTICLE: A NOVEL STRATEGY FOR THE TREATMENT OF UROLITHIASIS2018.
86. Chandrasekar S, Vijayakumar S, Rajendran R. Application of chitosan and herbal nanocomposites to develop antibacterial medical textile. Biomedicine & Aging Pathology. 2013; 4.
87. Zhao H-R, Wang K, Zhao Y, Pan L-Q. Novel sustained-release implant of herb extract using chitosan. Biomaterials. 2002; 23(23):4459-62.
88. Rasaee I, Ghannadnia M, Honari H. Antibacterial properties of biologically formed chitosan nanoparticles using aqueous leaf extract of Ocimum basilicum. Nanomedicine Journal. 2016; 3(4):240-7.
89. Bai L, Huang T-B. A Novel Wound Dressing Composed of Nonwoven Fabric Coated with Chitosan and Herbal Extract Membrane for Wound Healing. Polymer Composites. 2009; 31:1037-46.
90. Melo M. Chitosan membrane incorporated with Passiflora edulis Sims extract for potential application as wound dressing. Advances in Tissue Engineering & Regenerative Medicine: Open Access. 2019; 5.
91. Shukla R, Kashaw SK, Jain AP, Lodhi S. Fabrication of Apigenin loaded gellan gum-chitosan hydrogels (GGCH-HGs) for effective diabetic wound healing. Int J Biol Macromol. 2016; 91:1110-9.
92. Ferreira MOG, Leite LLR, de Lima IS, Barreto HM, Nunes LCC, Ribeiro AB, *et al.,* Chitosan Hydrogel in combination with Nerolidol for healing wounds. Carbohydrate polymers. 2016; 152:409-18.
93. Annapoorna M, Sudheesh Kumar PT, Lakshman LR, Lakshmanan VK, Nair SV, Jayakumar R. Biochemical properties of Hemigraphis alternata incorporated chitosan hydrogel scaffold. Carbohydrate polymers. 2013; 92(2):1561-5.
94. Emamgholi A, Rahimi M, Kaka G, Sadraie sh, Najafi S. Presentation of a novel model of chitosan- polyethylene oxide-nanohydroxyapatite nanofibers together with bone marrow stromal cells to repair and improve minor bone defects. Iranian journal of basic medical sciences. 2015; 18:887-93.
95. Yuan T, Jenkins P, Foushee A, Jockheck-Clark A, Stahl J. Electrospun Chitosan/Polyethylene Oxide Nanofibrous Scaffolds with Potential Antibacterial Wound Dressing Applications. Journal of Nanomaterials. 2016; 2016:1-10.
96. Abraham A, Soloman PA, Rejini VO. Preparation of Chitosan-Polyvinyl Alcohol Blends and Studies on Thermal and Mechanical Properties. Procedia Technology. 2016; 24:741-8.
97. Kang Y, Yoon I-S, Lee S, Kim D-D, Lee SJ, Park WH, *et al.,* Chitosan-coated poly (vinyl alcohol) nanofibers for wound dressings. Journal of biomedical materials research Part B, Applied biomaterials. 2009; 92:568-76.
98. Abdelgawad AM, Hudson SM, Rojas OJ. Antimicrobial wound dressing nanofiber mats from multicomponent (chitosan/silver-NPs/polyvinyl alcohol) systems. Carbohydrate polymers. 2014; 100:166-78.
99. Gonçalves R, Ferreira W, Gouvêa R, Andrade C. Effect of Chitosan on the Properties of Electrospun Fibers From Mixed Poly(Vinyl Alcohol)/Chitosan Solutions. Materials Research. 2017; 20.
100. Sambudi N, Park S, Cho K. Enhancing the mechanical properties of electrospun chitosan/poly(vinyl alcohol) fibers by mineralization with calcium carbonate. Journal of Materials Science. 2016; 51.
101. Zhou Y, Yang D, Chen X, Xu Q, Lu F, Nie J. Electrospun Water-Soluble Carboxyethyl Chitosan/Poly(vinyl alcohol) Nanofibrous Membrane as Potential Wound Dressing for Skin Regeneration. Biomacromolecules. 2008; 9:349-54.
102. Nacer Khodja A, Mahlous M, Tahtat D, Benamer S, Larbi Youcef S, Chader H, *et al.,* Evaluation of healing activity of PVA/chitosan hydrogels on deep second degree burn: pharmacological and toxicological tests. Burns. 2013; 39(1):98-104.
103. Lahooti B, Khorram M, Karimi G, Mohammadi A, Emami A. Modeling and optimization of antibacterial activity of the chitosan-based hydrogel films using central composite design. Journal of biomedical materials research Part A. 2016; 104(10):2544-53.
104. Amin MA, Abdel-Raheem IT. Accelerated wound healing and anti-inflammatory effects of physically cross linked polyvinyl alcohol-chitosan hydrogel containing honey bee venom in diabetic rats. Archives of pharmacal research. 2014; 37(8):1016-31.
105. Noori S, Kokabi M, Hassan ZM. Nanoclay Enhanced the Mechanical Properties of Poly (Vinyl Alcohol) /Chitosan /Montmorillonite Nanocomposite Hydrogel as Wound Dressing. Procedia Materials Science. 2015; 11:152-6.
106. Zhang X, Yang D, Nie J. Chitosan/polyethylene glycol diacrylate films as potential wound dressing material. International journal of biological macromolecules. 2008; 43(5):456-62.
107. Halabalová V, Šimek L. A Study of the Interaction between Chitosan and Poly (Ethylene Glycol) by Viscosity Method. International Journal of Polymer Analysis and Characterization. 2006; 11(3):185-95.
108. Tanodekaew S, Prasitsilp M, Swasdison S, Thavornyutikarn B, Pothsree T, Pateepasen R. Preparation of acrylic grafted chitin for wound dressing application. Biomaterials. 2004; 25:1453-60.
109. Ahmed S, Ikram S. Silver Nanoparticles: One Pot Green Synthesis Using Terminalia arjuna Extract for Biological Application. Journal of Nanomedicine & Nanotechnology. 2015; 6.
110. Vimala K, Mohan YM, Sivudu KS, Varaprasad K, Ravindra S, Reddy NN, *et al.,* Fabrication of porous chitosan films impregnated With silver nanoparticles: a facile approach for superior antibacterial application. Colloids and surfaces B, Biointerfaces. 2010; 76(1):248-58.

111. Madhumathi K, Sudheesh Kumar PT, Abhilash S, Sreeja V, Tamura H, Manzoor K, *et al.,* Development of novel chitin/nanosilver composite scaffolds for wound dressing applications. J Mater Sci Mater Med. 2010; 21(2):807-13.
112. Chen M, Yang Z, Wu H, Pan X, Xie X, Wu C. Antimicrobial activity and the mechanism of silver nanoparticle thermosensitive gel. International journal of nanomedicine. 2011; 6:2873-7.
113. Rahimi M, Ahmadi R, Kafil H, Shafiei Irannejad V. A novel bioactive quaternized chitosan and its silver-containing nanocomposites as a potent antimicrobial wound dressing: Structural and biological properties. Materials Science and Engineering C. 2019.
114. Haider A, Haider S, Kang I-K, Kumar A, Kummara MR, Kamal T, *et al.,* A novel use of cellulose based filter paper containing silver nanoparticles for its potential application as wound dressing agent. International Journal of Biological Macromolecules. 2017; 108.
115.Díez-Pascual A, Diez-Vicente A. Wound Healing Bionanocomposites Based on Castor Oil Polymeric Films Reinforced with Chitosan-Modified ZnO Nanoparticles. Biomacromolecules. 2015; 16.
116. Kumar PT, Lakshmanan VK, Anilkumar TV, Ramya C, Reshmi P, Unnikrishnan AG, *et al.,* Flexible and microporous chitosan hydrogel/nano ZnO composite bandages for wound dressing: *in vitro* and *in vivo* evaluation. ACS Appl Mater Interfaces. 2012; 4(5):2618-29.
117. Anjum S, Arora A, Alam MS, Gupta B. Development of Antimicrobial and Scar Preventive Chitosan Hydrogel Wound Dressings. International journal of pharmaceutics. 2016; 508.
118. Zhang D, Zhou W, Wei B, Wang X, Tang R, Nie J, *et al.,* Carboxyl-modified poly(vinyl alcohol)-crosslinked chitosan hydrogel films for potential wound dressing. Carbohydrate polymers. 2015; 125.
119. Pulat M, Kahraman A, Tan N, Gümüşderelioğlu M. Sequential antibiotic and growth factor releasing chitosan-PAAm semi-IPN hydrogel as a novel wound dressing. Journal of biomaterials science Polymer edition. 2013; 24:807-19.
120. Ngadaonye J, McEvoy K, Geever L, Brady D, Higginbotham C. Evaluation of Novel Antibiotic-Eluting Thermoresponsive Chitosan-PDEAAm Based Wound Dressings. International Journal of Polymeric Materials and Polymeric Biomaterials. 2014; 63:873–83.
121. El-Naggar M, Gohar Y, Sorour M, Rofeal M. Hydrogel dressing with a nano-formula against methicillin-resistant S. aureus and P. aeruginosa diabetic foot bacteria. Journal of microbiology and biotechnology. 2015; 26.
122. Sinha M, Banik R, Haldar C, Maiti P. Development of ciprofloxacin hydrochloride loaded poly (ethylene glycol)/chitosan scaffold as wound dressing. Journal of Porous Materials. 2013; 20.
123. Profire L, Pieptu D, Dumitriu R, Dragostin O, Vasile C. Sulfadiazine modified CS/HA PEC destined to wound dressing. Revista medico-chirurgicală a Societăţii de Medici şi Naturalişti din Iaşi. 2013; 117:525-31.
124. Mahmoud A, Salama A. Norfloxacin-loaded collagen/chitosan scaffold for skin reconstruction: Preparation, evaluation and in-vivo wound healing assessment. European Journal of Pharmaceutical Sciences. 2015; 83.
125. Radhakumary C, Antonty M, Sreenivasan K. Drug loaded thermoresponsive and cytocompatible chitosan based hydrogel as a potential wound dressing. Carbohydrate polymers. 2011; 83(2):705-13.
126. Sun Y, Liu Y, Li Y, Lv M, Li P, Xu H, *et al.,* Preparation and characterization of novel curdlan/chitosan blending membranes for antibacterial applications. Carbohydrate Polymers. 2011; 84:952-9.
127. McIntosh M, Stone BA, Stanisich VA. Curdlan and other bacterial (1→3)-β-D-glucans. Applied microbiology and biotechnology. 2005; 68:163-73.
128. Dvorak H. Vascular permeability to plasma, plasma proteins, and cells: An update. Current opinion in hematology. 2010; 17:225-9.
129. Guo S, DiPietro LA. Factors Affecting Wound Healing. Journal of Dental Research. 2010; 89(3):219-29.
130. Mizuno K, Yamamura K, Yano K, Osada T, Saeki S, Takimoto N, *et al.,* Effect of chitosan film containing basic fibroblast growth factor on wound healing in genetically diabetic mice. Journal of biomedical materials research Part A. 2003; 64(1):177-81.
131. Park C-J, Clark S, Lichtensteiger C, Jamison R, Wagoner Johnson A. Accelerated wound closure of pressure ulcers in aged mice by chitosan scaffolds with and without bFGF. Acta biomaterialia. 2009; 5:1926-36.
132. Alemdaroğlu C, Değim Z, Celebi N, Zor F, Oztürk S, Erdoğan D. An investigation on burn wound healing in rats with chitosan gel formulation containing epidermal growth factor. Burns: journal of the International Society for Burn Injuries. 2006; 32:319-27.
133. Obara K, Ishihara M, Fujita M, Kanatani Y, Hattori H, Matsui T, *et al.,* Acceleration of wound healing in healing-impaired db/db mice with a photocrosslinkable chitosan hydrogel containing fibroblast growth factor-2. Wound repair and regeneration: official publication of the Wound Healing Society [and] the European Tissue Repair Society. 2005; 13(4):390-7.
134. Gopal A, Kant V, Gopalakrishnan A, Tandan SK, Kumar D. Chitosan-based copper nanocomposite accelerates healing in excision wound model in rats. European journal of pharmacology.2014;731:8-19.
135. Judith R, Nithya M, Rose C, Mandal A. Application of a PDGF-containing novel gel for cutaneous wound healing. Life sciences. 2010; 87:1-8.
136. Frank S, Hübner G, Breier G, Longaker MT, Greenhalgh DG, Werner S. Regulation of vascular endothelial growth factor expression in cultured keratinocytes. Implications for normal and impaired wound healing. The Journal of biological chemistry. 1995; 270(21):12607-13.

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