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A Prospective Insight Into The Therapeutic Potential Of Snail Mucin In Pancreatic Cell Protection And Regeneration

Mrs Sathi Paul Mondal[1], B. Ramya[2], K.Trinadh[3], G.Jaya Lakshmi[4], G.H.Raj Kumar[5]

Abstract

The pancreas is a vital organ in a body which is responsible for the release of multiple hormones which are necessary to carry out the tasks of the body like glucose regulation in blood and hunger hormones and metabolism. But due to different circumstances be it dietary, lifestyle, trauma or habitat the pancreatic cells are prone to stress and inflammation due to which the chances of pancreatic cells dysfunction or damage is observed. This ultimately leads to conditions like diabeties, pancreatitis, pancreatic adenocarcinoma. Though research on the possible treatments are going on but there is still no complete curative treatment.but the research for a complete cure like by using stem cells have a high probability of replacing and repairing the damaged pancreatic cells. So this paper is about the emerging snail mucin extract which has a lot of compounds like glycosaminoglycans, peptides, glycolic acid, hyaluronic acid, and other trace elements due to which it shows antioxidant, anti microbial, anti inflammatory, regenerative properties so it is used in cosmetic products. Bioprospecting this snail mucin if it has the potential in preventing or protecting the pancreatic cells from conditions which cause it to deteriorate. And for that purpose understanding the snail mucin and pancreatic cells and designing a proper plan to conduct a research is thhe main objective of this paper.

Keywords: Pancreatic cell dysfunction, Diabetes and pancreatitis, Snail mucin, Glycosaminoglycans, Antioxidant and anti-inflammatory properties, Stem cell therapy, Bioprospecting for pancreatic protection.

1. Introduction

Pancreatic disorders, particularly diabetes and pancreatitis, pose significant health burdens globally. Current pharmacological interventions often target glycemic control and inflammation but fall short in pancreatic tissue regeneration. Snail mucin, a secretion with established wound-healing and anti-inflammatory properties, has yet to be extensively explored in pancreatic pharmacology. This review examines its molecular interactions, potential mechanisms of action, and the future scope of bioprospecting research in pancreatic cell therapy, with an emphasis on experimental validation.

2. Pancreatic cells: structure and functions

Pancreas is a pinkish tan organ located in the upper reached of the abdominal cavity in a retroperitoneal position. It weighs 100g in males and and 85g in females and about 5g in newborns. This organ in its adult form is about 14-18cm long, 2-9cm wide and 2-3cm thick which is divided into 4 regions - head,neck,body,tail. This pancreas can be broadly categorized into exocrine and endocrine cells. The exocrine cells consists of ductal and acinar cells(zymogen granules). The exocrine cells in pancreas are responsible for the storage of digestive enzymes. Whereas the endocrine cells consists of 5 types of cells namely Beta(β) cells, Alpha(α) cells, Delta (δ) cells, Epsilon(ε) cells and pancreatic polypeptide(pp) cells. These cells each produce hormones like beta cells produce insulin which plays a primary role in lowering of blood glucose levels, alpha cells produce glucagon which raises blood glucose levels, delta cells produce somatostatin which regulates insulin and glucagon secretion, epsilon produces ghrelin which influences hunger and metabolish and pp cells help regulate thepancreatic secretion and digestion. When any of these cells malfuncton they may cause disorders or diseases like pancreatisis, diabetes or even cancer.

3. Snail mucin: composition and bioactivity

With respect to pancreas now coming to snail mucin which is also known as snail secretions filtrate is a mucin gel like substance which is produced by snail. This mucin is an emerging biosubstance which is bioprospected to be very useful in various fields of medicine and cosmetics due to its composition of various key biomolecules. These mucins primarily consists 90-99% water based on the species of the snail and the remaining consists of bioactive compounds like glycosaminoglycans, proteoglycans, antimicrobial peptides, glycolic acid, hyaluronic acid and other trace elements. Due to the presence of these molecules the snail mucin has different pharmacological activities. Because the glycosaminoglycans and glycoproteins are known for cellular adhesion and repair mechanisms, hyaluronic acid promotes tissue hydration and wound healing, antioxidants and enzymes neutralize oxidative stress and modulate inflammatory pathways, wheras immunomodulatory peptides regulate the immune and cytokine acivity. Due to its properties the snail mucin is used in skin cosmetic preparations and it has the potential in pharmaceuticals too. Pancreatic diseases are mostly caused due to the

inflammation,oxidative, trauma etc.. so when there is a high chance of snail mucin being able to protect the pancreas against the inflammation and oxidative stress.

4. Pharmacological Hypothesis: Interaction of snail mucin with pancreatic cells

Based on its bioactive composition, snail mucin could influence pancreatic cells through:

4.1. **Antioxidant activity:** Oxidative stress and apoptosis is one of the most common reasons for the beta cell damage and cell dysfunction which can lead to conditions like diabetes. This is because pancreatic beta cells are particularly suceptible to oxidative stress due to their high endogenous production of reactive oxygen species(ROS) and their low antioxidant capacity suggesting that it plays a important role in beta cells failure. At basal level, ROS in fact plays a crucial role in insulin secretion. It has been demonstrated by Llanos et al. that the ROS generation alongside the moderate Ca2+ influx after glucose stimulation is required for RyR channel activation. Once activated, these channels provide the intracellular Ca2+ increase required for insulin secretion. Moreover, H2O2 treatment of islet cells under basal glucose level resulted in augmented insulin secretion, further supporting the concept that ROS plays a critical role in insulin secretion. However, under pathological conditions, the build-up of ROS results in oxidative stress. The major contributor of ROS production is the mitochondrial electron transport chain (ETC). Under hyperglycemic and hyperlipidemic conditions, the increased nicotinamide adenine dinucleotide and flavin adenine dinucleotide levels result in augmented production of ROS through overloading the ETC and causing electrons to leak from complex I and III. The electrons react with molecular oxygen to form O2 ,which is quickly converted to H2O2. Left undetoxified, the accumu lated H2O2 then could be converted into highly reactive hydroxyl radical and OH by the Fenton reaction in the presence of higher concentrations of transition metals Cu2+ and Fe2+. cells have several antioxidant defense systems including catalase (CAT), glu tathione peroxidase (GPx), thioredoxin (TXN), and periredoxins, which play a significant role in the conversion of H2O2 into H2O and O2.There are several reports describing a potential usefulness of antioxidants in treatment of type 2 diabetes.antioxidants pre served glucose-stimulated insulin secretion with mod erately decreased blood glucose levels.Histologic analyses of the pancreas revealed that the beta cell mass was significantly larger in the pancreas treated with the antioxidants. These results may indicate that the antioxidant treatment prevented apoptotic death of beta cells without changing the rate of beta cell proliferation. The antioxidant treatment also preserved the amounts of insulin content and insulin mRNA, and histologically insulin degranulation was less evident. Furthermore, the PDX-1 expression was more clearly visible in the nuclei of the islet cells treated with antioxidants.Due to this the snail mucin wich has the antioxidant properties due to the presence of glycosaminoglycans, enzymes such as glutathione peroxidase, peptides and trace elements can help in preventing the oxidative stress and help in scavenging reactive oxygen species(ROS).

4.2. **Anti-inflammatory activity:-** Some conditions like diabetes mellitus, pancreatitis are closely linked to inflammation and apoptosis. Inflammation in the pancreas, or pancreatitis, can arise through several mechanisms, notably involving the activation of nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB). NF-κB is a protein complex that controls the transcription of DNA, playing a pivotal role in regulating the immune response to infection. When activated in the pancreas, NF-κB can induce both local and systemic inflammatory responses.The mechanism involved is various stimuli, such as oxidative stress, cytokines, and microbial infections, can activate NF-κB in pancreatic cells. Once activated NF-κB leads to the production of cytokines like tumor necrosis factor-alpha (TNF-α), interleukins (e.g., IL-1β, IL-6), and chemokines. Due to this the Bax(pro-apoptic) and Caspase-3 are upregulated and Bcl-2(anti-apoptic) is downregulated which promotes cell death further exposing intracellular components to immune system aggravating inflammation. These molecules amplify the inflammatory response by recruiting immune cells to the pancreas. The recruited immune cells, including macrophages and neutrophils, exacerbate inflammation by releasing additional cytokines, reactive oxygen species (ROS), and proteolytic enzymes. This can result in tissue damage and further activation of NF-κB, creating a vicious cycle of inflammation. Persistent activation of NF-κB and continuous inflammatory responses can lead to chronic pancreatitis. Over time, this may cause fibrosis (scarring of pancreatic tissue), impairing pancreatic function and potentially contributing to the development of pancreatic cancer. Based on the inflammation caused the snail mucin is proven to have anti inflammatory activity. Because it is proven to show inhibition of pro inflammatory cytokines like TNF-α (Tumor Necrosis Factor-alpha), IL-1β (Interleukin-1 beta), IL-6 (Interleukin-6). Along with that The nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) pathway plays a central role in regulating immune response and inflammation. Snail mucin inhibits the activation and nuclear translocation of NF-κB, thereby blocking transcription of inflammatory genes.

4.3. **Pancreatic cells regeneration:-** Pancreatic β-cell regeneration is a multifaceted process essential for maintaining glucose homeostasis and combating diseases like diabetes mellitus. This regeneration primarily occurs through the replication of pre-existing β-cells, a mechanism robust in younger individuals but diminished with age due to the upregulation of cell cycle inhibitors such as p27^Kip1 and p16^Ink4a. Critical growth factors including Epidermal Growth Factor (EGF), Transforming Growth Factor-α (TGF-α), Hepatocyte Growth Factor (HGF), Betacellulin, and Insulin-like Growth Factor-1 (IGF-1)—activate downstream signaling cascades like PI3K/Akt and MAPK, promoting β-cell proliferation and survival. In addition to replication, β-cell regeneration may arise from neogenesis, where pancreatic ductal or acinar progenitor cells differentiate into β-cells, often marked by the re-expression of the transcription factor Neurogenin-3 (Ngn3). Under conditions of extreme β-cell loss, transdifferentiation of α-cells

into insulin-producing β-cells can also occur, regulated by key transcriptional modulators such as Pax4 and Arx. In this regenerative context, snail mucin emerges as a promising natural biotherapeutic agent. Rich in glycosaminoglycans, glycoproteins, allantoin, hyaluronic acid, and antioxidant peptides, snail mucin has been extensively documented for its role in tissue repair, particularly in dermatology and wound healing. Its mechanisms ranging from the stimulation of fibroblast proliferation and extracellular matrix (ECM) remodeling to antioxidant and anti-inflammatory actions mirror several pathways involved in pancreatic regeneration. Notably, snail mucin upregulates regenerative growth factors such as TGF-β1 and VEGF, which are also implicated in β-cell neogenesis and islet vascularization. By protecting β-cells from oxidative stress and immune-mediated damage, snail mucin could stabilize the islet microenvironment, while concurrently activating progenitor pathways or enhancing β-cell replication through mechanisms analogous to those observed in epithelial healing. This integration of known pancreatic regeneration biology with the bioactive profile of snail mucin offers a novel bioprospecting framework, suggesting that mucin-based therapies could potentiate β-cell regeneration through both direct cellular support and modulation of the pancreatic niche. Such an approach paves the way for innovative, nature-inspired interventions in the treatment and management of diabetes.

Snail Mucin (GAGs, Allantoin, etc)

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Anti-inflammatory Action (↓TNF-α, IL-6)

↓

Antioxidant Protection (↓ROS-induced stress)

↓

↑ Growth Factor Expression (TGF-β1, VEGF)

↓

ECM Remodeling (↑Collagen, Hyaluronic Acid)

↓

Progenitor Cell Activation / β-Cell Support

↓

β-Cell Regeneration / Islet Neogenesis

5. Bioprospecting Approach For Future Research:-

So to validate the above hypothesis a structured experimental approach I necessary which should be divided into In-vitro and In-vivo studies.

5.1. In-vitro Studies:-

For the invitro studies cell culture models like culture pancreatic beta cell lines(eg: INS-1, MIN6) and primary islet cells can be preferred. Exposing these cells to the varying concentrations of purified snail mucin extract can help us understand the effects of mucin on pancreatic cells. For protectant activity the snail mucin is used and then the cell is exposd to stress or for the resistance and regenerative anti inflammatory study after applying stress exposint it to purified snail mucin can give certain results too so we can compare and study both the pre and post activities of the snail mucin with pancreatic cells. To identify and study the results obtained certain assays can be used like MTT assay for cell viability, ROS assays for oxidative stress measurement, ELISA test for the insulin secretion levels measurement, QPCR and Western blotting for inflammatory cytokine and growth factor expresion. When these assays arecarried out with the testing based on their results we can confirm whether the snail mucin has the ability to be used in the treatment of pancreatic disorders and if further research is required when such positive result is obtained then we can carry out the In-vivo studies for pancreatic cells and snail mucin.

5.2. In-vivo Studies:-

In the In-vivo studies of snail mucin and pancreatic cells we can prefer using animals like rodents. We can induce pancreatic conditions by artificially inducing pancreatic cellular stress using drugs like streptozocin(STZ). and by that when snail mucin extract is administered to the pancreas it is the studies for its pharmacokinetics and pharmacodynamical parameters which can help in studyng the mucin toxicological and undesired effects and formulate it in a way which can reach the pancreatic cells and then show its effects. For the studying of this the methods like tissue analysis and biochemical assays can be preferred by which we can compare the cells which are treated with snail mucin and cells which arent treated with snail mucin.

6. Challenges And Limitations:-

One of the major challenges are present in snail mucin , be it ethical considerations or the regulations. This is because the snail mucin has been used since ancient times but in modern day usage the snail mucin is still in a developing stages and it is still being researched. Though a part of the snail mucin has been researched and is being used in the cosmetics but majority of it is still used for the external applications. For the internal usage there arent any proper regulations provided by the regulatory bodies which leads us the ethical considerations and the hurdles in obtaining approval for snail mucin derived

pharmaceuticals. Along with this there is a lack of direct studies on pancreatic applications and no proper standardization of bioactive compounds for the reproducibility in pharmacological studies.

7. Conclusion and Future Directions:-

Most of the indian population is suffering from diabetic conditions. These conditions afre due to pancreatic cells exposed to oxidative and inflammatory stress leading to cellular damage ultimately leading to its dysfunction. So the snail mucin which has lots of desired properties can be a good bioprospected compound which with the future interdisciplinary collaborations between pharmacologists, molecular biologists and clinical researchers are crucial in advancing its field toward therapeutic applications and figure out new ways to repair pancreatic cellular damage and to prevent and protect the pancreas from deteriorating.

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