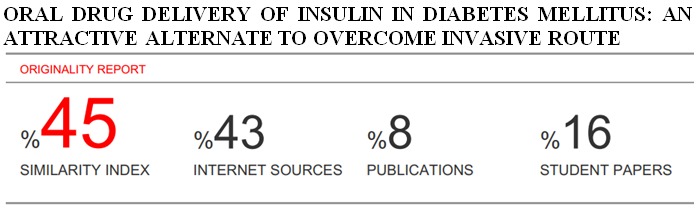
**Reviewer’s Comments**

****

**ORAL DRUG DELIVERY OF INSULIN IN DIABETES MELLITUS: AN ATTRACTIVE ALTERNATE TO OVERCOME INVASIVE ROUTE**

**ABSTRACT**

The subcutaneous injection of insulin for the treatment of diabetes mellitus can lead to patient non-compliance, Diabetes discomfort, pain and local infection is a chronic metabolic health disease affecting the homeostasis of blood sugar levels in human beings. Oral route of drug delivery system has been the most widely accepted means of drug administration other than invasive drug delivery systems. For the development of an oral insulin delivery system, we have to focus on overcoming the various gastro-intestinal barriers for insulin uptake from the gastrointestinal tract. To overcome these barriers, various types of formulations such as insulin conjugates, micro/nanoparticles, liposomes, hydrogel, capsule, and tablets are designed to deliver insulin orally. Various potential ways to administer insulin orally has been explored over years but a fluctuating level of insulin release have been recorded. A number of advancement has taken place in the recent years for understanding the needs of improved oral delivery systems of insulin. This review article concentrates on the challenges for oral drug delivery of insulin as well as various carriers used for the oral drug delivery of insulin and also provides the relevant information about the clinical tested formulations of oral insulin and its patents.

**Keywords:** Insulin, formulation technology, oral drug delivery, patient compliance,

**INTRODUCTION**

The effective treatment of diabetic person with insulin require a route of administration that is painful to the patient. Although invasive routes are poorly acceptable by the diabetics but other noninvasive routes of administrations are highly expedient1. Administration of drugs by oral route is the most acceptable route of administration, but it is difficult to deliver peptide and protein drugs by this route. Presystemic enzymatic degradation and poor penetration of the intestinal membrane are the main reasons for the low oral bioavailability of peptide and protein drugs2. Oral bioavailability of insulin is below 1% so there is a big challenge to improve it upto 30%–50%3. A number of polymers both biodegradable and non-biodegradable polymers have been studied for non-invasive delivery of insulin (provide references). Non-biodegradable polymers possess problems of toxicity, difficulty in eviction and also sustained release of insulin cannot be attained using these polymers. Biodegradable polymers favour the uptake of insulin through intestinal cells by shielding the encapsulated drug from the external harsh conditions. Biodegradable polymeric particles protect the peptide from the peptidases, enhancing uptake by enterocytes. Polymeric particles will slowly degrade after absorption depending on the nature of the polymer; provide a sustained and controlled release of the drug4.Various strategies have to be implemented to maximize oral insulin bioavailability to overcome GI barriers, and to bring safe and effective oral dosage form to the market5. In order to attain an ideal oral peptide drug delivery system, some alternates will be required to encapsulate the insulin6.For the oral delivery of peptide and protein drugs, nanocarriers have shown great potential with improved pharmacokinetics and pharmacodynamics of insulin. Nanocarriers or nanoparticles can stabilize these macromolecular drugs by providing insulation from the harsh GI conditions and accelerating their transport across the absorptive epithelia7. The new strategies for products that are tried before include water-soluble, long-acting insulin derivative, [(2-Sulfo)-9-fluorenylmethoxycarbonyl]3-insulin, vitamin B12-dextran nano particles, lipid nano particles and PEGylated calcium phosphate nanoparticles etc as oral drug delivery carriers for insulin8.

**VARIOUS CHALLENGES TO ORAL INSULIN DRUG DELIVERY**

**Absorption across GIT membrane**

General route for absorption of drug molecules is the Paracellular and the transcellular route. Hydrophilic molecules having mol. Wt. less than 500 Da are absorbed by Paracellular route. The molecules having high molecular weight like insulin (about 6KDa) cannot absorb via this route. Absorption of insulin by transcellular route is restricted because of its molecular size, its charge, and its hydrophilicity9. To increase the GI uptake of orally poorly absorbed insulin is their binding to colloidal particles that can safeguard the insulin from degradation in the GI tract and encourage the transport of poor-absorbable molecules into systemic circulation10.

**Presystemic enzymatic degradation**

Pepsin is present inside the stomach as a group of aspartic proteases. Pancreatic proteases existing in small intestine comprising the serine endopeptidase (trypsin, α-chymotrypsin, elastase and exopeptidases, carboxypeptidase A, and carboxypeptidase B) which is accountable for the degradation of proteins. The order of enzymatic degradation of insulin in the small intestine is duodenum > jejunum > ileum9. Insulin can be available for absorption through GIT when the enzymatic attack is either diminished or overcome11.Although Insulin is not subject to proteolytic breakdown by brush border enzymes12.

**Poor Intestinal transport of insulin**

The anatomy of insulin is very exquisite. Insulin is susceptible to oxidative damage when it react with amino acids9. In other words we can say that insulin has low permeability via intestinal mucosa11.

**Dosage form stability**

Proteins changes its conformation, size, shape, surface properties, and bioactivity upon development into different formulations. Changes in conformation, size, shape can be detected by use of spectrophotometric techniques, X-ray diffraction, differential scanning calorimetery, light scattering, electrophoresis, and gel filtration12.(Figure 1)

**FEATURES OF AN ABSOLUTE ORAL INSULIN CARRIER**

An absolute carrier for insulin:

■ should be pH sensitive.

■ should provide a biocompatible and stable environment to ensure that the active part of insulin will remain biologically active after encapsulation.

■ should reduce or avoid enzyme degradation and increase insulin permeability across the intestinal membrane.

■ the permeability of the mucosal epithelium to enhance the absorption of insulin and provide the intact insulin to the blood circulation.

■ must be safe after oral administration.

■ Insulin should be available for interaction with cell surface receptors and captured by lymphatic cells, or pass through or be entrapped in the lymph nodes or transferred to the systemic circulation, provided that the particles remain as such and particle size within acceptable limit13.

**DIVERSE CARRIERS USED FOR NON INVASIVE DRUG DELIVERY OF INSULIN**

**Insulin-loaded Bioadhesive PLGA Nanoparticles for Oral Drug Delivery**

PEGylation play an important role in increasing the stability of several therapeutic proteins14**.**For the drug delivery system of proteins and peptides Poly (D, L-lactide-co-glycolide) nanoparticles (PLGA-NP) have been used extensively. Chitosan PLGA nanoparticle has some attractive properties, such as a mucosal adhesion, positive charge, and absorption enhancement, which increase the duration of residence of insulin in-vitro and improve its bioavailability in-vivo for oral delivery15.The negative surface charge present on PLGA nanoparticles tends to reduce the oral bioavailability by limiting the diffusion of insulin nanoparticle across the mucus layer. Cationic chitosan can be used to coat and modify the surface charge of PLGA nanoparticles16.

**Polymeric Hydrogels for Oral Insulin Delivery**

Nature of the polymer might enhance the residence time of a drug delivery system inside the GI tract17.Polymerichydrogels protect insulin from enzymatic degradation in acidic environment of stomach and delivers insulin effectively in the intestinal region. Swelling and de-swelling mechanisms of the hydrogel under different pH conditions of the body control the release of insulin. A Combination of enzyme inhibitors and polymeric systems have potentialto increase the potency of orally given insulin15.

**Acrylic Polymers for Oral Insulin Delivery**

Acrylic polymers are synthetic mucoadhesive polymers, basically intended for oral drug delivery. Various techniques used to generate synthetic polymers are Nano precipitation, solvent evaporation, freeze–drying, spray drying of emulsions and supercritical fluid technology15. Methacrylic acid or acrylic acid are used as copolymer because of their pH-sensitive nature and ability to bind calcium, and poly (ethylene glycol) because of its ability to stabilize and protect proteins18.

**Aerosolized Liposomes for Pulmonary Delivery of Insulin**

Pulmonary route for systemic delivery of peptides and proteins is paid more attention because it’s a non-invasive method of administrating insulin and it is valuable for the delivery of large molecular proteins14.This method is effective for both type 1(T1DM) and type 2 diabetes mellitus (T2DM)19. Generally lungs have large surface area (approximate about 100 square metres) and acts as an ideal target for insulin delivery20.

**Chitosan–zinc–insulin Complex**

Chitosan, a biodegradable polymer and a cationic polysaccharide, has been extensively known for the preparation of nanoparticles for oral controlled delivery. Derivatization of chitosan polymers afford improvement in drug retention capability, provide improved permeation, enhanced mucoadhesion and sustained release of therapeutic agents8.

**MARKET STATUS OF ORAL INSULIN FORMULATIONS**

In the recent years, the oral dosage form of insulin is at different clinical stages of development from pre-clinical testing to Phase II clinical trials21. Oralin has been successfully tried in Type 1 and Type 2 diabetic patients and when the results were compare with subcutaneous injection it was find appropriate for controlling blood glucose level22. A remarkable progress has been reported in the recent past years for the delivery of insulin by non-invasive routes. Some of other hormonal drugs, such as calcitonin and vasopressin, are available in the form of intranasal sprays. The field of oral insulin delivery took an enormous step ahead with the approval of Exubera® from Pfizer and Nektar Therapeutics5.(Table 1)

**CONCLUSION**

An extensive number of people especially in developed countries suffered from diabetes. The pharmacotherapy for T1DM and T2DM treatment is subcutaneous injection of insulin. Discomfort, pain and local infection are the main reasons for patient non-compliance. On the other hand, the development of oral dosage form of insulin formulation can improve patient acceptability. Painful administration and phobia from invasive routes have encourage scientists to research new possible methods for oral insulin delivery.

Various barriers to insulin uptake by oral routes have its own set of advantages and disadvantages. Over the last few years, researchers have focused on oral insulin delivery. Although, extensive human clinical studies are still the major requirement of oral insulin drug delivery and for the optimisation of physiochemical and pharmacokinetic parameters of insulin in drug carriers for diabetes treatment.

**REFERENCE**

1. Mariko Morishita, Isao Morishita, Kozo Takayama, Yoshiharu Machida, Tsuneji Nagai, Novel oral microsphere of insulin with protease inhibitor protecting from enzymatic degradation, International Journal of Pharmaceutics; 1992:78: 1-7.
2. Mariko Morishita, Nicholas A. Peppas. Is the oral route possible for peptide and protein drug delivery? Drug Discovery Today; 2006: 11: 905-907.
3. Arun Verma, Nitin Kumar, Rishabha Malviya, Pramod Kumar Sharma, Emerging trends in noninvasive insulin delivery, Journal of Pharmaceutics; 2014: 1-9.
4. T.A. Sonia, Chandra P. Sharma, An overview of natural polymers for oral insulin delivery, Drug Discovery Today; 2012: 17: 785-792.
5. El-Sayed Khafagy, Mariko Morishita , Yoshinori Onuki, Kozo Takayama, Current challenges in non-invasive insulin delivery systems: A comparative review, Advanced Drug Delivery Reviews; 2007: 59: 1521–1546.
6. Chun Y. Wong, Hani Al-Salami, Crispin R. Dass, Microparticles, microcapsules and microspheres: a review of recent developments and prospects for oral delivery of insulin, International Journal of Pharmaceutics; 2017: 1-45.
7. Wenji Deng, Qian Xie, Huan Wang, Zhiguo Ma, Baojian Wu, Xingwang Zhang

Selenium nanoparticles as versatile carriers for oral delivery of insulin, Nanomedicine: Nanotechnology, Biology, and Medicine; 2017: 1-39.

1. Subhashini Yaturu, Insulin therapies: Current and future trends at dawn, World J Diabetes; 2013:4(1): 1-7.
2. StrategiesRajashree S. Hirlekar, Esha J. Patil, Srinivas R. Bhairy,Oral Insulin Delivery: Novel strategies, Asian Journal of Pharmaceutics; 2017: 11 (3): 434-443.
3. Amulyaratna Behera, Satyajeet Biswal, Sunit Kumar Sahoo, Nanomedicine and type 2 diabetes: A review, Journal of Pharmacy Research; 2018:12 (3): 370-377.
4. Kinesh V.P., Neelam D.P.,punit B.P.,Bhavesh S.V., Pragna K.S., Novel approaches for oral delivery of insulin and current status of oral insulin products, international journal of pharmaceutical sciences and nanotechnology;2010:3(3):1-8.
5. Varshney H. M., Rajnish kumar, Shailender Mohan, Novel approaches for insulin delivery: current status, International Journal of Therapeutic Applications; 2012: 7: 25-31
6. Thundiparambil Azeez Sonia and Chandra P. Sharma, Oral Delivery of Insulin; 2014: 258
7. Kenneth D. Hinds et al, PEGylated insulin in PLGA microparticles. In vivo and in vitro analysis, Journal of Controlled Release; 2005: 104:447–460.
8. Yasmeen, T. Mamatha, Md. Zubair, Sana Begum, Tayyaba Muneera, Various Emerging Trends in Insulin Drug Delivery Systems, British Journal of Pharmaceutical Research; 2015: 5(5): 294-308.
9. Chun Y. Wong, Hani Al-Salami, Crispin R. Dass, Potential of insulin nanoparticle formulations for oral delivery and diabetes treatment, Journal of Controlled Release;2017:1-62.
10. Stacia Furtado, Danielle Abramson, Roxanne Burrill, Gloria Olivier, Celinda Gourd, Emily Bubbers, Edith Mathiowitz, Oral delivery of insulin loaded poly(fumaric-co-sebacic) anhydride microspheres, International Journal of Pharmaceutics; 2008: 347:: 149–155.
11. Aaron C. Foss, Takahiro Goto, Mariko Morishita, Nicholas A. Peppas, Development of acrylic-based copolymers for oral insulin delivery, European Journal of Pharmaceutics and Biopharmaceutics; 2004:57: 163–169.
12. Sosa George, Anitha Roy, Novel approaches in insulin drug delivery – a review, Int. J. Drug Dev. & Res.; 2013: 5 (4): 1-5.
13. S. Bala Murali Mohan\*1, Deepthi.B 1, Gourineny Bhanusree, Review of recent trends in non-invasive insulin therapy for diabetes mellitus, World Journal of Pharmacy and Pharmaceutical Sciences; 2017: 3(8): 1870-1884.
14. Kamlesh J Wadher,Ravi Kalsait, Milind Umekar,Oral Insulin Delivery: Facts, Developments and Challenges, Scholars Research Library; Der Pharmacia Lettre; 2009: 1 (2): 121-129.
15. Christiane Damge, Catarina Pinto Reis, Philippe Maincent, Nanoparticle strategies for the oral delivery of insulin, Expert Opin. Drug Deliv.;2008:**5**(1):45-68.

**Figure 1. Various challenges to oral insulTable 1. List of clinically tested oral insulin formulation9.**

|  |  |  |  |
| --- | --- | --- | --- |
| Company | Name | Product | Development phase |
| Biocon/Bristol‑Myers Squibb | IN‑105 | Conjugate Insulin | II |
| Access Pharmaceuticals, Inc | CobOral™ | Insulin coated insulin‑loaded nanoparticles | II |
| Aphios Corporation | APH‑0907 | Nanoencapsulated insulin/ biodegradable polymer nanospheres | PRECLINICAL |
| Diabetology Ltd | Capsulin™ OAD | Insulin with delivery system Axcess™ | II |
| Diasome Pharmaceuticals, Inc. | HDV‑Insulin | Hepatic‑directed vesicle‑insulin (nanocarrier) | III |
| Emisphere Technologies, Inc. | Eligen® insulin | Insulin with chemical delivery agents (Eligen®) | I |
| Jordanian Pharmaceutical Manufacturing Co. PLC | JPM oral | Liquid delivery system with insulin‑chitosan nanoparticles | I |
| Novo Nordisk A/S | NN1952 | Insulin analog with an oral delivery system GIPET® |  |
| Oramed, Inc. | ORMD‑0801 | Insulin with protein oral delivery system POD™ | II |
| Oshadi Drug Administration Ltd | Oshadi Icp. | Insulin, proinsulin, and C‑peptide in Oshadi carrier | II |
| NOD Pharmaceuticals, Inc./ Shanghai Biolaxy, Inc. | Nodlin | Insulin with bioadhesive nanoencapsulation (NOD Tech) | II |
| Transgene Biotek Ltd. | TBL1002OI | Proprietary nanotechnology Trabi‑Oral™ | PRECLINICAL |