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Review Article

RECENT RESEARCH ON FORMULATION DEVELOPMENT OF BCS CLASS II DRUGS – A REVIEW

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Abstract: BCS class II drugs pose challenging problems in their pharmaceutical product development process because of their low solubility and dissolution rates. They require enhancement in solubility and dissolution rate in their formulation development especially solid dosage forms such as tablets and capsules. Several conventional methods and new emerging technologies have been developed for formulation development of BCS class II drugs. Literature on these methods as well as recent research on formulation development of BCS class II drugs is reviewed in this article.

Key**words:** BCS class II drugs, Formulation development, Recent research

INTRODUCTION

Therapeutic effectiveness of a drug depends upon the bioavailability and ultimately upon the solubility and dissolution rate of drug molecules. Solubility and dissolution rate are the important parameters to achieve desired concentration of drug in systemic circulation for pharmacological response to be shown. The Biopharmaceutical Classification System (BCS) is an experimental model that measures permeability and solubility under prescribed conditions.

Biopharmaceutical Classification System

Biopharmaceutical Classification System[1] (BCS) guidance was provided by US Food and Drug Administration (FDA), to improve the efficiency of drug product development process. According to which drugs are grouped into four major classes basing on their solubility and permeability.

Class I: High Permeability and High Solubility
Propranolol, Metoprolol, Diltiazem, Verapamil

Class II: High Permeability and Low Solubility
Ketoconazole, Mefenamic acid, Nifedipine, Nicardipine, Felodipine, Piroxicam

Class III: Low permeability and High solubility
Acyclovir, Neomycin B, Captopril, Enalaprilate, Alendronate

Class IV: Low permeability and Low solubility
Chlorthiazide, Furosemide, Tobramycin, Cefuroxime

A drug substance is considered highly soluble when the highest dose strength is soluble in < 250 ml water over a pH range of 1 to 7.5 and it is considered highly permeable when the extent of absorption in humans is determined to be > 90% of an administered dose, based on mass-balance or in comparison to an intravenous reference dose. A drug product is considered to be rapidly dissolving when > 85% of the labeled amount of drug substance dissolves within 30 minutes using USP apparatus I or II in a volume of < 900 ml buffer solutions.

The rate limiting process for drug absorption and bioavailability (rate and extent of absorption) is either the release (or dissolution) of drug substances from the dosage form or its permeation through the intestinal membrane. If permeation through intestinal membrane is rate limiting, dissolution properties may be of negligible importance. Class I drugs behave in vivo like an oral solution. Dissolution and bioavailability is very rapid for these drugs. If the Class I drug substance is released from the dosage form very rapidly in vivo, gastric emptying will become the rate limiting process for drug absorption. Whereas for drugs having high permeability and low solubility (Class II), dissolution or release from the dosage form occurs slowly and the dissolution rate will become the rate limiting factor for drug absorption. These drugs exhibit variable bioavailability and need enhancement in dissolution rate for increasing bioavailability. Permeation through the intestinal membrane forms the rate-limiting step for absorption of drugs of Class III and bioavailability is independent of drug release from the dosage form. These drugs generally exhibit low bioavailability and need enhancement in permeability. Class IV drugs exhibit poor and variable bioavailability. Several factors such as dissolution rate, permeability, gastric emptying form rate limiting steps for absorption of these drugs.

Formulation Development Techniques for BCS Class II Drugs

BCS class II drugs pose challenging problems in their pharmaceutical product development process. As the dissolution rate forms the rate limiting step in their bioavailability, enhancement of dissolution rate and achieving the target dissolution is a critical step in their formulation development. Several conventional methods such as micronization, chemical modification, use of surfactants and solubilizers, solid dispersion and a few new emerging technologies such as cyclodextrin complexation, mucoadhesive microspheres, nanoparticles, nanosuspensions, micro emulsion and self-emulsifying systems are available to enhance the bioavailability of BCS Class II drugs. The more industrially useful techniques are as follows

Particle size reduction:

Particle size reduction can be achieved by micronisation and nanosuspension. Each technique utilizes different equipments for reduction of the particle size.

Micronization:

The solubility of drug is often intrinsically related to drug particle size. By reducing the particle size, the increased surface area improves the dissolution properties of the drug. Conventional methods of particle size reduction, such as comminution and spray drying, rely upon mechanical stress to disaggregate the active compound. The micronisation is used to increased surface area for dissolution[2]. Micronisation increases the dissolution rate of drugs through increased surface area; it does not increase equilibrium solubility[3]. Micronization of drugs is done by milling techniques using jet mill, rotor stator colloid mills etc. Micronization is not suitable for drugs having a high dose number because it does not change the saturation solubility of the drug.

Nanosuspension:

Nanosuspensions are sub-micron colloidal dispersion of pure particles of drug, which are stabilized by surfactants. The advantages offered by nanosuspension is increased dissolution rate is due to larger surface area exposed, while absence of Ostwald ripening is due to the uniform and narrow particle size range obtained, which eliminates the concentration gradient factor. Techniques for the production of nanosuspensions include Homogenization and wet milling. Active drug in the presence of surfactant is defragmented by milling. Other technique involves the spraying of a drug solution in a volatile organic solvent into a heated aqueous solution. Rapid solvent evaporation produces drug precipitation in the presence of surfactants. The nanosuspension approach has been employed for drugs including tarazepide, atovaquone, amphotericin B, paclitaxel and bupravaquone. All the formulations are in the research stage. One major concern related to particle size reduction is the eventual conversion of the high energy polymorph to a low energy crystalline form, which may not be therapeutically active one[4]. Drying of nanosuspensions can be done by lyophilisation or spray drying.

Sonocrystallisation:

Recrystallization of poorly soluble materials using liquid solvents and antisolvents has also been employed successfully to reduce particle size[5]. The novel approach for particle size reduction on the basis of crystallisation by using ultrasound is Sonocrystallisation. Sonocrystallisation utilizes ultrasound power characterised by a frequency range of 20–100 kHz for inducing crystallisation. It's not only enhances the nucleation rate but also an effective means of size reduction and controlling size distribution of the active pharmaceutical ingredients.8 Most applications use ultrasound in the range 20 kHz-5 MHz.

Supercritical fluid process:

A SCF exists as a single phase above its critical temperature (Tc) and pressure (Pc). SCFs have properties useful to product processing because they are intermediate between those of pure liquid and gas (i.e.,liquid-like density, gas-like compressibility and viscosity and higher diffusivity than liquids). Moreover, the density, transport properties (such as viscosity and diffusivity), and other physical properties (such as dielectric constant and polarity) vary considerably with small changes in operating temperature, pressure, or both around the critical points. Hence, it is possible to fine tune a unique combination of properties necessary for a desired application. These unique processing capabilities of SCFs, long recognized and applied in the food industry, have recently been adapted to pharmaceutical applications[6].

Solid Dispersion:

Solid dispersion is defined as a dispersion of one or more active ingredients in an inert carrier or matrix at solid state prepared by the melting (fusion), solvent, or melting-solvent method[7]. In melting method carrier is melted and drug is added with stirring and melted until homogenous melt is obtained which is then cooled to room temperature while in solvent method drug and carrier is dissolved in minimum amount of solvent and solvent is removed by evaporation under reduced pressure[8]. Solid dispersions are also prepared by dissolving drug and carrier in a common solvent followed by evaporation of the solvent. Melting-solvent method involves use of heating and solvent action to dissolve the drug and carrier in solvent followed by evaporation of the solvent. Solid dispersion technique improves the solubility, dissolution rate, and as a result the bioavailability of poorly water-soluble drugs[9].

The higher dissolution rates of solid dispersions can be ascribed to a number of factors which includes:

1. The formation of higher energy metastable states of the components as a function of the carrier system being used and the proportion of carriers present[10].
2. The reduction of particle size to nearly a molecular level[11]. As the soluble carrier dissolves, the insoluble drug is exposed to dissolution medium as very fine particles leading to an increase in both surface area and solubilization for fast dissolution and absorption[7].
3. Formation of amorphous forms of drug and carriers[12].
4. The presence of carrier may also prevent aggregation of fine drug particles, thereby providing a larger surface area for dissolution. The wetting properties are also greatly increased due to the surfactant property of the polymer, resulting in decreased interfacial tension between the medium and the drug, hence higher dissolution rates. The presence of carrier polymers also inhibits crystal growth of the drug which facilitates faster dissolution[10].
5. Cosolvent effect on the drug by the water soluble carriers [12].
6. Intermolecular hydrogen bonds between drug and carrier[13].
7. Local solubilization effect of carrier at the diffusion layer[8].

Various factors affecting dissolution of drug from solid dispersion includes the method of preparation of the solid dispersion, amount and properties of the polymer carriers, drug polymer contact and drug-polymer interactions [14].

Inclusion Complexation:

This is most widely used method to enhance water solubility and increase stability of hydrophobic drugs by using cyclodextrins. Solid inclusion complexes can be prepared by using following methods:

a) **Kneading Technique**: In this technique, cyclodextrin (CD) is impregnated with water and converted to paste. Drug is then added and kneaded for specified time. The kneaded mixture is then dried and passed through sieve if required.[15]

b) **Coprecipitation:** The required amount of drug is added to the solution of β-CD. The system is kept under magnetic agitation with controlled process parameters and protected from the light. The formed precipitate is separated by vacuum filtration and dried at room temperature in order to avoid the loss of the structure water from the inclusion complex [16].

c) **Neutralization:** Drug is added in alkaline solution like sodium hydroxide, ammonium hydroxide. A solution of β- Cyclodextrin is then added to dissolve the joined drug. The clear solution obtained after few seconds under agitation is neutralized using HCl solution until reaching the equivalence point. At this moment, the appearance of a white precipitate could be appreciated, corresponding to the formation of the inclusion compound. The precipitate is then filtered and dried[17].

d) **Co-grinding:** Drug and cyclodextrin are mixed and the physical mixture is introduced in a suitable mill like oscillatory mill and grinded for suitable time [16].

e) **Spray-Drying Method:**Drug is dissolved in suitable solvent and the required stoichiometric amount of carrier material like β cyclodextrin is dissolved in water. Solutions are then mixed by sonication or other suitable method to produce a clear solution, which is then spray dried using spray dryer [16].

f) **Microwave Irradiation Method:** Drug and cyclodextrins mixture is reacted in microwave oven to form inclusion. It is a novel method for industrial scale preparation due to its major advantage of shorter reaction time and higher yield of product[18].

Cogrinding / Comicronization:

Cogrinding of a poorly water-soluble drug with water-soluble polymers like hydroxypropyl methylcellulose (HPMC), poly vinyl alcohol (PVA) etc in the presence of small amount of water is extremely effective to improve its apparent solubility with maintenance of drug crystallinity to some extent[20]. Small particles produced by milling or micronization have increased surface area and expected to have enhanced dissolution rate. However, energy added to reduce particle size results in increased van der Waal's interactions and electrostatic attraction between particles leading to reduce effective surface area due to agglomeration thus decreasing dissolution rate. Comicronization of drugs by using excipients like microcrystalline cellulose can be used as an alternative to reduce or eliminate cohesive and electrostatic forces. This approach increases apparent surface area available for drug dissolution by creating an ordered mixture, thereby causing a reduction in particle-particle agglomeration or by reducing van der Waal's interactions. Increase in true surface area of the ordered powdered mixture is expected due to the inherent surface roughness and porosity of the microcrystalline cellulose-drug mixture[21].

Lipid-based formulations:

Lipid-based delivery systems like emulsions, microemulsions, liposomes, microspheres, solid-lipid nanoparticles, etc have ability to avoid resistant chemical and physical barriers to oral absorption and are most successful in enhancing the bioavailability of molecules that are poorly water-soluble but highly permeable drug molecules (BCS class II). Some proposed mechanisms of action of lipid-based systems to enhance oral bioavailability of compounds include [22]:

a) Particle size reduction to molecular size yielding a solid-state solution within the carrier.

b) Enhanced wetting of hydrophobic solids resulting in enhanced dissolution.

c) Increased rate of dissolution into aqueous environment from oil droplets of high surface area.

d) Promotion of absorption via intrinsic lipid pathways.

e) Enhanced thermodynamic activity via supersaturation of the aqueous environment of the gastrointestinal tract.

Melt-Granulation:

In this technique powdered drugs are efficiently agglomerated by the use of a meltable binder which can be a molten liquid, a solid or a solid that melts during the process usually in high shear mixers, where the product temperature is raised higher than the melting point of the binder either by a heating jacket or, when the impeller speed is high enough, by the heat of friction generated by the impeller blades[23]. In this technique no water or organic solvents are needed and there is no drying step therefore the process is environmentally safe, less time consuming and uses less energy than conventional wet granulation[24]. Polyethylene glycol is widely used as a molten binder due to its complimentary solution properties, low melting point, rapid solidification rate, low toxicity and little cost[23]. The increase in dissolution rate can be described to the hydrophilic character of the system due to the presence of water-soluble carriers and the fact that the drug forms monotectic mixtures with PEG[24].

Direct Compaction:

In this process polymer like hydroxypropyl methylcellulose and drug is dry-blended, compressed into

slugs and then milled into a granular powder. The process results in enhanced dissolution rate of poorly water-soluble drugs without the use of solvent or heat addition to overcome the disadvantages of solid dispersion by these methods. This process is also cost effective and quicker. The compaction processes are believed to be particularly effective at enhancing the rate of drug dissolution because the drug particles are maintained in direct contact with the polymer particles during drug dissolution, in contrast with a physical mixture where the drug and polymer particles may rapidly disperse and be separated in the dissolution medium [25].

Solvent Evaporation by Ultra-Rapid Freezing (URF):
This process involves freezing a drug contained in a polymer solution onto the surface of a cryogenic substrate with a thermal conductivity (k) between 10 and 20 W/(m K), collecting the frozen particles and removing the solvent. Because of rapid conductive heat transfer, resulting in high supersaturation and nucleation rates, the URF technology has the potential to create powders with superior physicochemical properties, similar to those produced by other rapid freezing technologies. As in other freezing technologies, the rapid freezing of the drug/polymer composition is decisive in preventing phase separation during freezing, allowing for the active to be molecularly dispersed with the polymer. Recrystallization of the drug is avoided by the inclusion of high glass-transition temperature (Tg) polymers such as PVP or hypromellose (HPMC). This technique is widely applicable to enhance in-vivo absorption for the BCS class II compounds[26].

Ordered/Interactive Mixing:
Ordered mixing is described as method to prepare ordered units in the mix such that the ordered unit will be the smallest possible sample of the mix and will be of near identical composition to all the other ordered units in the mix. Ordered mixing yields nearly the perfect mix and may be obtained in a number of ways like mechanical means, adhesion, coating and other methods[28]. Prerequisite for fast dissolution from an ordered mixture includes that the carrier particle should dissolve rapidly, delivering a fine particulate suspension of drug particles[29]. Higher concentration of drug shows reduced dissolution rates particularly at loadings above monolayer coverage because high concentration of drug forms agglomerates rather than discrete particles with resulting decreased surface area and thicker diffusional layers causing reduction in dissolution rates[30]. In an ordered powder mix fine drug particles are distributed fairly evenly on coarse carrier particles. The drug powder is therefore deagglomerated in the dry state. This may be used to increase the dissolution rate of drug powders because a larger contact surface area is exposed to the dissolution medium [29].

Adsorption of Drugs onto High Surface Area Carriers:
In this technique drug is absorbed onto carriers having large surface area (like crosslinked polyvinylpyrrolidone, Kollidone) from solutions of the drug in appropriate solvents like methanol, polyethylene glycol, and 2-pyrrolidone. The dissolution rate of drug increases due to increase in surface area and drug particles have good wettability due to the surrounding solubilising materials[31].

Liquisolid Compacts:
Liquid Compacts are compressible powdered forms of liquid medications. The term "liquisolid medication" implies oily liquid drugs and solutions or suspensions of water insoluble drugs carried in suitable non volatile solvent systems. Using this technique, a liquid medication may be converted into a dry, non-adherent, free flowing and compressible powder by a simple blending with selected powder excipients such as the carrier and coating material. Surfactants like tweens are used to improve aqueous solubility of poorly soluble drugs [32].

Solvent Deposition /Evaporation:
In this technique drug is dissolved in a solvent like methylene chloride to produce a clear solution. The carrier is then dispersed in the solution by stirring and the solvent is removed by evaporation under temperature and pressure. The resultant mass is then dried, pulverized, and passed through a sieve. The Increase in the dissolution rate is described to the reduced particle size of the drug deposited on the carrier and enhanced wettability of the particles brought about by the carrier[32].

Carriers for Dissolution Enhancement:
Carriers, which are soluble and dissolve in water at a fast rate, are widely used in pharmaceutical formulations to enhance dissolution of drugs. The carriers which have been reported in literature are given in Table 1

Table 1: Summary of carriers for enhancing dissolution of BCS Class II drugs

S.No	Category	Example of carriers
1	Polymers	Polyvinylpyrrolidone, Polyvinylpolypyrrolidone, Polyvinyl alcohol, Polyethylene glycols, Hydroxypropyl methylcellulose, Hydroxypropyl cellulose, Poly (2-hydroxyethylmethacrylate), Methacrylic copolymers (Eudragit® S100 sodium salts and Eudragit® L100 sodium salts)
2	Superdisintegrants	Sodium starch glycolate, Croscarmellose sodium, Cross-linked polyvinylpyrrolidone, Cross-linked alginic acid, Gellan gum, Xanthan gum, Calcium silicate
3	Cyclodextrins	β-Cyclodextrins, Hydroxypropyl-β-cyclodextrins
4	Carbohydrates	Lactose, Soluble starch, Sorbitol, Mannitol, β-(1-4)-2-amino-2-deoxy-D-glucose (Chitosan), Maltose, Galactose, Xylitol, Galactomannan, British gum, Amylodextrin

5	Surfactants	Poloxamers (Lutrol® F 127, Lutrol® F 68), Polyglycolized glyceride (Labrasol), Polyoxyethylene sorbitan monoesters (Tweens), Sorbitan esters (Spans), Polyoxyethylene stearates, Poly (beta-benzyl-L-aspartate) -b- poly (ethylene oxide), Poly (caprolactone) -b- poly (ethylene oxide)
6	Hydrotropes	Urea, Nicotinamide, Sodium benzoate, Sodium salicylate, Sodium acetate, Sodium-o-hydroxy benzoate, Sodium-p-hydroxy benzoate, Sodium citrate
7	Polyglycolized glycerides	Gelucire 44/14, Gelucire 50/13, Gelucire 62/05
8	Acids	Citric acid, Succinic acid, Phosphoric acid
9	Dendrimers	Starburst® polyamidoamine (PAMAM)
10	Miscellaneous	Microcrystalline cellulose, Dicalcium phosphate, Silica gel, Sodium chloride, Skimmed milk Microcrystalline cellulose, Dicalcium phosphate, Silica gel, Sodium chloride, Skimmed milk

Recent Research on Formulation Development of BCS Class II Drugs

Recent research on formulation development of BCS class II drugs is summarized in Table 2.

Table 2: Summary of Recent Research on Formulation Development of BCS Class II Drugs

S. No	DRUG (Therapeutic Activity)	Polymer Employed	Technique Employed	Purpose	Reference
1	Pioglitazone (Antidiabetic)	Starch 1500, Lactose, DCP	Solid Dispersion	Dissolution rate enhanced in Lactose than the other two Polymers	33
2	Olanzapine (Antipsychotic)	Pregelatinised starch; Sodium starch glycollate	Solid Dispersion	Pregelatinised starch (PGS) and sodium starch glycollate (SSG) are effective carriers to improve the aqueous solubility of Olanzapine	34
3	Norethindrone (Oral contraceptive)	Lactose monohydrate, Maize starch, Crospovidone	Micronization	Improvement in in-vivo bioavailability	35
4	Megestrol acetate (Anti neoplastic)	Poloxamer 188	Nanonization	Enhanced dissolution rate and bioavailability	36
5	Nevirapine (Antiretroviral)	β-cyclodextrin, Polyvinylpyrrolidone	Solid complexes	Minimized the variable dissolution rates with increase in the oral bioavailability.	37
6	Diflunisal (Non opioid analgesic)	Supercritical Carbon Dioxide	SCF	Enhanced dissolution rate and bioavailability	38
7	Tinidazole (Antiprotozoal)	Polyethylene glycol; HP β-CD	Spray drying technique	Loss of drug crystallinity and increase in dissolution rate.	39
8	Salbutamol (Anti asthamatic)	Nicotinamide hydrotrope	Hydrotrophy	17-fold enhancement in aqueous solubility	40
9	Flutamide (Antiandrogen)	Salicylate hydrotrope	Hydrotrophy	More than a 27-fold enhancement in aqueous solubility	41
10	Telmisartan (Anti hypertensive)	Aerosil 200	solid self micro emulsifying drug delivery system	Enhanced dissolution rate and bioavailability.	42
11	Carvedilol (Anti hypertensive)	Tween 80	Using surfactant as coating material	Increase in the solubility of carvedilol	44
13	Tamoxifen citrate (Antiestrogen)	Avicel PH 102, Aerosil 200, Cross Carmellose	Liquisolid system	Increase in wetting properties and surface area of drug available for dissolution.	45

		Sodium			
14	Flurbiprofen (NSAID)	Acetonitrile and methanol	Melt Sonocrystallization technique	Melt sonocrystallization improved flow properties and enhanced dissolution and bioavailability	46
15	Aceclofenac (Anti inflammatory)	sodium starch glycolate, camphor, lactose	Solvent deposition / MDT	Improved disintegration / dissolution of the drug in oral cavity	47
16	Clopidogrel (Platelet aggregation inhibitor)	Capmul MCM, Tween-80 and PEG 400	Microemulsion	Enhanced solubility by 80.66 folds, which may increase oral bioavailability	48
17	Aceclofenac (Anti inflammatory)	potassium ferricyanide, ferric chloride,	Co-crystallization	Enhancement in solubility	49
18	Aceclofenac (Anti inflammatory)	Sodium Starch Glycolate (SSG), mannitol, lactose	Solvent deposition	Enhanced solubility and dissolution rate.	50
19	Ziprasidone (Antipsychotic)	HPβ-CD, Lactose and HPMC	Co-grinding	Enhanced solubility and dissolution rate.	51
20	Famotidine (Antiulcer drug)	PEG 400, Tween 80, Span 80	Microemulsion	Faster rate of drug release into the aqueous phase	52
21	Valsartan (Anti hypertensive)	Skimmed milk powder	Solid Dispersion	Enhanced solubility and dissolution rate.	53
22	Spironolactone (Anti diuretic)	Poloxamer 407	Solid Dispersion By Co-Precipitation Method	Increased wetting properties and higher dissolution rates .	54
23	Telmisartan (Anti hypertensive)	SLS, PVP K30, PEG-4000, and Beta-CD	Solid dispersion	Higher dissolution rates	55
24	Raloxifene HCl (Antiosteoporosis)	Croscarmellose sodium, Sodium, starch glycolate, Crospovidone	co-grinding	Reduced the particle size	56
25	Simvastatin (Anti-hypertensive)	HPMCE3LV	physical mixture, co grinding and spray drying	Crystalline state converted into amorphous	57
26	Glipizide (Anti-Diabetic)	β-Cyclodextrin	Inclusion complex	Higher rates of dissolution	58
27	Etoricoxib (anti inflammatory)	Starch citrate	Solid Dispersion	Starch citrate was prepared, characterized and used in the formulation development of etoricoxib tablets with >85% dissolution in 30 min.	59
28	Albendazole (anthelmintic)	Sesame Labrasol, Captex 300 Low CC, Lutrol E300, Solutol HS15	self-microemulsifying drug delivery system	Increased dissolution rate and solubility	60
29	Atorvastatin (HMG-CoA reductase inhibitor)	Avicel PH 102, Explotab, Aerosil 200	liquisolid compacts	Improved dissolution and oral bioavailability	61
30	Etoricoxib (anti inflammatory)	Starch Phosphate	Solid Dispersion	Enhanced dissolution rate.	62

31	Efavirenz (anti retroviral)	Cyclodextrin, Polyvinyl pyrrolidone	Complexation	Combination of CDs (βCD and HPβCD) with PVP K30 resulted in enhancement in dissolution rate and dissolution efficiency of efavirenz tablets.	63

CONCLUSION

Several conventional methods such as micronization, chemical modification, use of surfactants and solubilizers, solid dispersion and a few new emerging technologies such as cyclodextrin complexation, mucoadhesive microspheres, nanoparticles, nanosuspensions, micro emulsion and self-emulsifying systems have been successfully developed for formulation development of BCS class II drugs. Though several studies are reported in this area, more intense research is needed to evolve new and novel formulation techniques for BCS class II drugs.

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