International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 05 May 2023
DOI: 10.47191/ijcsrr/V6-i5-42, Impact Factor: 6.789
IJCSRR @ 2023
www.ijcsrr.org

The Expanding Scope of Emulgels: Formulation, Evaluation and Medical Uses

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ABSTRACT: Emulgels are semi-solid emulsions that combine the benefits of both emulsions and gels. They provide enhanced stability, sustained release and improved cosmetic properties. Emulgels can be fabricated using a variety of emulsification techniques and gelling agents like carbopol, hydroxypropyl cellulose. Characterization of emulgels includes evaluation of particle size, viscosity, pH, spreadability and drug release. Emulgels have promising applications in topical delivery of drugs and cosmetics, parenteral delivery of drugs and as emulsion-based oral drug delivery systems. Topical emulgels are used in skin care, hair care and cosmetics to provide moisturization, hydration, etc. Parenteral emulgels can deliver drugs in a sustained manner. Oral emulgels improve the absorption of some drugs. Several advantages of emulgels include sustained and controlled release of actives, improved solubility of both hydrophilic and lipophilic drugs, protection from degradation, and enhanced cosmetic elegance. However, emulgel formulation requires specialized emulsification equipment, and they have lower drug loading capacity compared to other semi-solid systems. Emulgels combine the benefits of emulsions and gels, providing a versatile drug and cosmetic delivery platform with unique advantages. Improvements in emulsification techniques, identifying newer gelling agents and permeation enhancers can further enhance the potential of emulgel systems. With growing research on emulgels, these systems are poised to make a significant impact on topical, parenteral and oral delivery in the coming years. Emulgels thus present an exciting prospect for developing innovative and improved formulations.

KEYWORDS: Cosmeceuticals, Emulgels, Emulsifying agents, Microemulsions, Rheology, Topical drug delivery

INTRODUCTION

Emulgels are novel colloidal delivery systems that combine the properties of emulsions and gels. They exhibit both fluid and semi-solid properties, providing interesting possibilities for drug delivery and other applications. Emulgels can encapsulate both hydrophilic and lipophilic actives and provide controlled release [1]. They also demonstrate enhanced stability compared to emulsions alone. Emulgels represent an exciting new class of delivery vehicles, and this review explores their potential and future prospects [2]. Despite their promise, emulgels have not been extensively reviewed in the literature. This article aims to provide a comprehensive overview of emulgels, focusing on their formulation, characterization, and applications.

DEFINITION, CHARACTERISTICS AND COMPONENTS

A. Definition

Emulgels are semisolid emulsions that contain both emulsion and gel components. They exhibit characteristics of both emulsions and gels, combining the benefits of these delivery systems [3]. Emulgels are hydrophilic lipid structures that provide sustained and controlled release of incorporated active pharmaceutical ingredients.

B. Characteristics

Emugels are unique in sense that they combine the properties of emulsions and gels. Fine tuning their internal and external phases make them more adaptable for loading any kind of drug. The key characteristics and techniques used for the preparation of emulgels are shown in Figure 1.

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www.ijcsrr.org

Figure 1. Characteristics and preparation techniques for emulgels

Some key characteristics [5] of emulgels include:

Hydrophilic-lipophilic balance (HLB): The HLB of emulsifiers used determines the type of emulsion formed (oil-in water or water-in-oil).

Viscosity: Imparts emulgel-like consistency and prevents separation of phases. This is provided by thickeners in the aqueous phase.

pH: The pH of emulgels depends on the compounds used and impacts skin irritation, drug stability and permeation. Most emulgels have a pH in the range of 5 to 8.

Spreadability: Emulgels must have a smooth and spreadable consistency for easy application and release of actives.

A. Components

The key components [4] used in emulgels are listed in Table 1.

Table 1. Key components of emulgels

Sl. No.	Components	Examples
01	Oil phase	Lipophilic solvents Ex. mineral oil, olive oil Lipids Ex. waxes, triglycerides Oils Ex. castor oil, coconut oil
02	Aqueous phase	Hydrophilic solvents Ex. water, glycols, Humectants Ex. glycerin, propylene glycol Polymers Ex. carbomer, hydroxypropyl cellulose
03	Emulsifiers	Non-ionic Ex. cetostearyl alcohol, cetearyl macromonium chloride, Anionic Ex. sodium lauryl sulfate, Cationic Ex. cetrimonium bromide
04	Surfactants	Fluorosurfactants, Polysorbates, Span 80, Tween 80
05	Gelling agents	Natural Ex. gelatin, starch, carbomer Synthetic Ex. carbomer, acrylates/C10-30 alkyl acrylate crosspolymer
06	Penetration enhancers	Ex. urea, propylene glycol
07	Preservatives	Parabens, Formaldehyde, Phenoxyethanol
08	pH modifiers	Citric acid, sodium hydroxide

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FORMULATION OF EMULGELS

Emulgels contain several excipients that aid in their formulation and improve their properties. The key excipients [6] used in emulgels include:

Emulsifiers: Help in emulsifying the immiscible oil and water phases. Common emulsifiers include sorbitan esters (Span), glyceryl esters (Glyceryl Monooleate), cetostearyl alcohol, etc. The HLB value determines whether an emulsifier will produce O/W or W/O emulsion.

Co-emulsifiers: Used along with emulsifiers to improve emulsion formation and stability. Examples include polyethylene glycol, propylene glycol, ethanol, etc. They help in solubilizing ingredients and decreasing interfacial tension.

Thickeners: Provide viscosity and gel-like consistency to emulgels. Common thickeners are carbomer, hydroxypropyl cellulose, xyanthan gum, etc. The thickener type and concentration determines whether a fluid, soft solid or firm solid emulgel is obtained.

Polymers: Synthetic (carbomer, acrylates) or natural (xanthan gum, guar gum) polymers are used as thickeners, emulsifiers and to improve release control in emulgels. They absorb water and form hydrogels.

Surfactants: Used in addition to emulsifiers to improve wetting, solubilization and stability. Examples include cetyl alcohol, cetostearyl alcohol, etc. Anionic, cationic or nonionic surfactants are used depending on the emulsion type.

Solvents: Used to dissolve oils, increase solubility and modify release. Common solvents for emulgels include water, alcohol, propylene glycol, glycerin, etc. They modify properties like spreadability, drying time, etc.

Penetration Enhancers: Substances that increase the permeability of skin or other tissues. Examples for emulgels include ethanol, propylene glycol, oleic acid, etc. They improve the release of incorporated actives.

Preservatives: Prevent the growth of microbes in emulgel formulations. Common preservatives are methyl paraben, propyl paraben, benzyl alcohol, etc. They maintain sterility, stability and prevent irritation when applied to skin or mucous membranes.

pH Modifiers: Acids (citric acid or phytic acid) or bases (triethanolamine) are added to adjust the pH of emulgels. The pH impacts properties like viscosity, emulsification, stability, Skin irritation etc. Most emulgels have a pH in the range 5 to 8.

PREPARATION OF EMULGELS

B. Preparation techniques

There are several methods for preparing emulgel formulations. The method selected depends on the type of emulgel, ingredients used and objectives [7]. Some of the main techniques and their characteristic features are discussed below:

***Low energy emulsification*:**

- Also known as solubilization- dispersion technique.
- Requires weak emulsifiers that can solubilize ingredients with mild agitation.
- Commonly used for microemulsions.
- Provides ultrafine droplets.

***High Pressure Homogenization*:**

- Uses high pressure valve homogenizers or microfluidizers to subject the formulation to intense shearing forces. Produces very fine droplets, around 0.2 μm.
- Requires use of high HLB emulsifiers.
- Limited by energy input and heat generation.

***Microemulsion technique*:**

- Requires appropriate HLB of emulsifiers and oils.
- Formulation of oil-in-water (O/W) or water-in-oil (W/O) microemulsions that are thermodynamically stable, iso-tropic and have a droplet size below 100 nm.
- Provides high stability and encapsulation.
- Limited by types of emulsifiers and APIs that can be incorporated.

***Hot and Cold method*:**

- Heating the oil phase separately and then cooling and mixing with the aqueous phase under high speed stirring.
- Followed by increasing homogenization at low temperature.
- Produces medium sized droplets.

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IJCSRR @ 2023
www.ijcsrr.org

- Simple but time consuming process.

C. Factors affecting emulgel formulation and stability

Various factors [8,9] affecting the formation and stability of emulgels are:

HLB Value: Appropriate HLB of emulsifiers is critical for emulsion formation and stability. HLB 12-18 produces O/W emulsions while HLB 4-6 gives W/O emulsions.

Oil and Water Solubility: Emulsifiers must solubilize both oil and water phases efficiently for stable emulsification.

Emulsifier Concentration: Optimal amount needed to coat the droplets and prevent coalescence. Too high or too less can destabilize the emulsion.

Temperature: Low temperatures favor W/O emulsions while O/W emulsions are favored at higher temperatures. Temperature affects solubility, viscosity and kinetic energy of molecules.

Agitation: sufficient agitation is required to overcome the interfacial tension between oil and water phases. High agitation produces smaller droplets.

Additives: Surfactants, co-emulsifiers, electrolytes, gels and polymers can improve emulsion stability by increasing charge, decreasing surface curvature, and providing viscosity.

CHARACTERIZATION OF EMULGELS

Several parameters [10,11] are evaluated to characterize emulgel formulations are discussed below.

A. Droplet Size Analysis: The droplet size of dispersed phase in emulgels is determined by photon correlation spectroscopy, laser diffraction, or scanning electron microscopy. Smaller droplet sizes provide larger surface area and better release. Droplet size ranges from 10-1000 nm for microemulsions to 0.1-100 µm for macroemulsions.

B. Viscosity: The viscosity of emulgels is measured using viscometers like Brookfield viscometer, cone and plate viscometer, etc. High viscosity provides emulgel-like consistency while low viscosity yields liquid-like formulations. Viscosity depends on the type and concentration of thickener used. It ranges from 100-1000000 cP for emulgels [12].

C. pH: The pH of emulgels influences properties like stability, irritancy, release and permeation. It is measured using a pH meter or pH strips. Most emulgels have a pH in the range of 5 to 8. Acids or bases can be used to adjust the pH [13].

D. Spreadability: Spreadability is assessed by determining the time taken for emulgel to spread over a fixed area on a non-adhesive substrate. It depends on the viscosity, oil content and emulsifier type. Emulgels with good spreadability have a prolonged and uniform spread with less mess [14].

E. Drug Release: The release of incorporated actives from emulgels is evaluated using Franz diffusion cells, dialysis membrane method, etc. Factors affecting release include droplet size, viscosity, pH, solubility, etc. Sustained and controlled release over prolonged periods is desirable for most emulgel applications [15].

Release kinetics can be zero-order, first-order, Higuchi, Korsmeyer-Peppas, etc. Release compounds with different solubility, molecular weight and dose are commonly used. Release assessment of emulgels provides valuable insights into optimizing formulation and application.

The details of complete evaluation tests, their significance and techniques used for characterization of emulgels are listed out in Table 2.

Table 2. Significance and methods of different emulgel characterization parameters

Sl. No.	*Parameter*	*Significance*	*Technique*
01	Particle size	Indicates stability and dispersion. Smaller sizes have higher stability	Measured using photon correlation spectroscopy, laser diffraction, scanning electron microscopy.
02	Viscosity	Relates to spreadability and gel strength. Higher viscosity signifies stronger gel with lower spreadability	Evaluated using rotational viscometers, Brookfield viscometer

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03	pH	Important for stability, drug compatibility and skin irritation. Range of 4-8 is usually acceptable for topical use.	Determined using pH meters, pH strips or indicators
04	Spreadability	Indicates flow behavior and patients' acceptance. Emulgels should spread easily and retain form	Assessed using slips and slides method or cone penetration method.
05	Drug release	Reflects sustained release ability and effectiveness. Slower release over longer period is desirable	Studied using diffusion cells, dialysis bags, Franz diffusion cells.
06	Spreading coefficient	Provides insight into spreadability and adhesion to skin. Higher positive values indicate better spreadability and adhesion.	Calculated using interfacial tension measurements
07	Zeta potential	Gives information about surface charge and stability. Values around ±30 mV denote acceptable stability.	Measured using laser doppler electrophoresis, electrophoretic light scattering.
08	Rheological behavior	Provides viscosity profiles under steady and dynamic conditions. Pseudoplastic, thixotropic or viscoelastic behavior is expected.	Evaluated using concentric cylinders, plate-plate or tube viscometers under increasing shear rates.
09	Drug permeation	Determines penetration of actives into skin and effectiveness. Enhanced permeation leads to improved activity.	Assessed using ex-vivo or in-vivo experiments on skin or using synthetic membrane.

APPLICATIONS OF EMULGELS

A. Topical Applications

Skin Care: Emulgels are used as moisturizers, emollients and for treating conditions like roughness, dullness, irritation, etc. Ingredients like glycerin, cetyl alcohol, chamomile extract, aloe vera, etc. are incorporated [16].

Hair Care: Emulgels containing proteins, oils, keratin, etc. are used as conditioners, styling agents, treatment for dandruff, etc. Coconut oil and glycerin are commonly used [17].

Cosmetics: Emulgels are used as foundations, lip balms, sunscreens, etc. Ingredientsinclude pigments, waxes, silicones, emulsifiers, etc. for desired effects. Sun protection factor depends on the emulgent and sunscreens used [16].

B. Parenteral applicaitons

Emulgels provide sustained release of drugs through injection. They release drugs over prolonged periods, reducing dosing frequency and maintaining adequate drug levels. Water soluble corticosteroids and antibiotics are commonly incorporated [18].

C. Oral Applications

Emulsion-based oral drug delivery systems include:

Emulgels: Emulgels contain both emulsions and gels for controlled release of drugs. Oil-in-water or water-in-oil emulsions are used based on solubility of drug [12].

Liquid filled gelatin capsules (LFGCs): Emulsions contained within gelatin capsules. LFGCs provide floating, sink-ing or remained buoyant to release drug at specific sites. Used for site-specific release [10].

Self-emulsifying drug delivery systems (SEDDS): Contain emulsifiers and solvents to produce fine O/W or W/O emulsions upon dispersion in aqueous media with low energy. Improve solubility, absorption and bioavailability of drugs [19].

Microemulsions: Thermodynamically stable, isotropic and have a droplet size below 100 nm. Microemulsions pro-vide maximum surface area for absorption and enhance solubility. They are suitable for lipophilic, amphiphilic and hydrophilic drugs [20].

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Benefits of oral emulgel systems include improved solubility, absorption, sustained release, reduced dosing frequency and improved patient compliance. However, formulating challenges exist for emulsion-based systems. More research is needed to realize their full potential in drug delivery. Various applications of emulgels in skin care, hair care, and other cosmetic products are listed out in Table 3. The applications of emulgels in parenteral controlled drug delivery are listed out in Table 4 while their applications in oral drug delivery is shown in Table 5

Table 3. Applications of topical emulgels (skin care, hair care, cosmetics)

Skin care	*Hair care*	*Cosmetics*
Moisturizers: Hydration, soothing and softening dry skin. Emulgels contain humectants, emollients and hydrating polymers. **Emollients:** Reducing roughness, softening skin and relief from scaling/itching. Oil and wax emulgels are effective emollients. **Protectants:** Forming barrier against environmental aggressors like sun, wind, pollution etc. Emulgels contain UV absorbers, antioxidant emulgels. **Calming agents:** Reducing inflammation, soothing irritation and relieving pain. Emulgels contain corticosteroids, lidocaine, aloe vera etc. **Scrubs:** Gentle exfoliation and purification of skin. Emulgels contain abrasives (ground nut shells, oatmeal), surfactants and detergents in proper proportions.	**Conditioners:** Improving manageability, reducing static and detangling hair. Emulgels contain hydrating polymers, silicones, dimethicone etc. **Styling agents:** Providing hold, shape and volume without stiffening hair. Emulgels contain polymers, wax emulsions, plant extracts (carnauba wax). **Treatments:** Penetrating deeply to strengthen hair, stimulate hair follicles and promote growth. Emulgels contain vitamins A, E, amino acids, caffeine, peptides etc.	**Foundations:** Covering skin imperfections and providing even tone and texture. Emulgels provide oil control, non-greasy feel with emollients, silicones, dimethicone. **Primers:** Filling fine lines and pores, providing smooth base for makeup application. Emulgels contain silicones, dimethicone, cyclomethicone for mattifying and smoothing effect. **Highlighters:** Enhancing natural glow and highlighting features. Emulgels contain micronized pigments, pearlescent agents, diethylhexyl 2,6-naphthalate etc for highlighting effect. **Lip products:** Plumping lips, protecting and hydrating. Emulgel lipsticks and balms contain emollients, humectants, wax emulsions, botanical extracts etc. **Nail paints:** Coloring nails with chip-resistant and long-lasting polish. Emulgel nail polishes provide smooth and even application with quick drying.

Table 4. Applications of parenteral emulgels (controlled drug delivery)

Sl.No.	*Parenteral emulgels*	*Applications*
01	Sustained release injectables	Providing prolonged therapeutic effect with single administration. Emulgels contain water insoluble drugs, polymers for sustained release. Examples include norethindrone emulsions, testosterone emulsions etc.
02	Prolonged anesthetics	Emulgels containing local anesthetics like lidocaine provide pain relief for extended duration with single injection.
03	Anticancer emulges	Anti-cancer drugs like vincristine, methotrexate, hydroxycamptothecin etc. have been formulated in emulgel injectables for sustained, targeted and improved effectiveness

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04	Emulgels containing Neurological drugs	Drugs for disorders like Parkinson's disease (levodopa), epilepsy (valproic acid) have been developed as emulgel injectables for controlled release
05	Peptide/protein delivery	Emulgels provide stable environment and sustained release of therapeutic peptides, hormones, enzymes etc. preventing enzymatic degradation. Examples include insulin emulsions, growth hormone emulsions etc.
06	Vitamin emulgels	Parenteral emulsions of fat soluble vitamins A, D, E and K have been developed to provide adequate dosing of these vitamins which would otherwise be difficult to deliver through other routes.
07	Emulgels containing antibiotics	Antibiotics, antifungal and antiviral drugs have been formulated as emulgel injectables for site-specific delivery, sustained release and reduced toxicity. Examples include fluconazole emulsions, acyclovir emulsions etc.
08	Cosmeceuticals	Injectable emulgels containing hyaluronic acid, retinol, vitamin C, peptides etc. are used for anti-aging, skin rejuvenation and wrinkle reduction with prolonged and anti-aging effects.

Table 5. Applications of oral emulgels

Sl. No.	***Category***	***Applications***
01	Lipid insoluble drugs	Emulgels improve absorption of drugs having low lipid solubility and high hydrophobicity which cannot be absorbed easily through GIT. Examples include carbamazepine, nimodipine, coenzyme Q10 etc.
02	Peptides and proteins	Emulgels protect peptides and proteins from enzymatic degradation and improve their absorption in intact form. Examples include insulin, calcitonin, enzyme replacements etc.
03	Photosensitive drugs	Light sensitive drugs get protection from degradation in emulgels. Examples include carotenoids, chlorophyll, flavonoids etc.
04	Poor membrane permeability	Emulgels aid in absorption of drugs that cannot permeate through intestinal membranes easily. Examples include poorly absorbed NSAIDs, antihistamines etc.
05	Improved oral bioavailability	Emulgels enhance absorption of many drugs leading to better therapeutic effect with same dose. This results in decreased dosage and side effects. Examples of drugs with improved bioavailability through emulgels include paclitaxel, atorvastatin, fenofibrate etc.
06	Treatment of gallstones	Oral emulgels containing bile salts help in dissolving gallstones slowly and preventing their recurrence. They maintain supersaturation of bile salts for prolonged period
07	Treatment of infections	Antibacterial, antifungal and antiviral drugs have been formulated in emulgels to improve absorption, reduce toxicity and achieve better patient compliance through decreased dosage frequency. Examples include fluconazole, terbinafine, acyclovir etc.
08	Improved nutrition	Fat soluble vitamins A, D, E and K as well as certain minerals have been delivered through emulgels to counter their deficiencies and improve nutritional status.
09	Anti-cancer activity	Certain anti-cancer emulgel formulations help in achieving higher drug concentrations at the site of tumor for improved therapeutic effect. Examples include coenzyme Q10, tea polyphenols etc.

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www.ijcsrr.org

ADVANTAGES AND CHALLENGES OF EMULGEL SYSTEMS

D. Advantages

Emulgel systems offer several advantages over conventional delivery systems [4,10]. However, they also pose some challenges in formulation and application.Some of the advantages of emulgel Systems are discussed below:

Sustained and Controlled Release: Emulgel droplets and high viscosity provide sustained release of incorporated actives over prolonged periods. This reduces dosing frequency and maintains therapeutic drug levels.

Improved Solubility: Hydrophilic drugs can be solubilized in the aqueous phase while lipophilic drugs dissolve in the oil phase. This enhances the solubility of poorly soluble drugs.

Enhanced Stability: Emulgel structure protects light sensitive, oxygen sensitive or microbe sensitive drugs from degradation. The aqueous and oil phases also provide separate environments for compatibility.

Improved Cosmetic Elegance: Emulgel semisolid consistency provides a pleasant feel and non-greasy texture suitable for cosmetic and topical applications.

Flexibility: Various grades of viscosity and spreading can be obtained by modifying the thickener concentration and type. This flexibility allows developing emulsions, creams, gels or pastes.

The key advantages and challenges of emulgel systems are shown in Table 7

Table 7. Key advantages of emulgel systems

Sl.No.	*Characteristic*	*Advantages*
01	Controlled and sustained release	Emulgel matrix releases the incorporated drugs in a controlled manner over prolonged period. This results in sustained therapeutic effect, reduced dosing frequency and improved patient compliance.
02	Solubilization of poorly soluble drugs	Hydrophilic-lipophilic balance in emulgels helps in solubilizing drugs with poor aqueous solubility. This enhances absorption and bioavailability of such drugs.
03	Protection from degradation	Emulgel formulation provides a stable environment protecting labile drugs, peptides and proteins from degradation. This helps improving their effectiveness and stability.
04	Improved cosmetic appeal	Emulgel bases provide a smooth, cushioned and emollient feel. This leads to better cosmetic elegance, spreadability and non-greasy feel which enhances patients' acceptance
05	Site-specific delivery	Emulgels can be designed to release drugs at specific sites like transdermal, intra-articular, intra-nasal etc. This achieves high local concentrations with minimal systemic absorption and side effects.
06	Improved penetration	Some emulgels facilitate penetration of drugs into skin, hair follicles and other layers. This allows enhanced therapeutic effects for conditions affecting these layers.
07	Anti-irritation	Emulgel formulations help in masking bitter taste, irritation and unpleasant smell of certain drugs. They provide soothing and cooling sensation.
08	Flexible dosing	Emulgels can be designed as solid, semi-solid or liquid formulations based on required consistency and dose. This permits flexible choices of dosage forms for various applications.
09	Combination of drugs	Emulgel matrix allows incorporation of drugs with synergistic effects or different mechanisms of action. This provides combined therapeutic benefits in single formulation.
10	Improved patient compliance	Advantages of emulgels like sustained release, reduced dosing frequency, improved taste masking, flexible dosing etc. enhance patients' acceptance and compliance. This leads to better therapy outcomes.

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E. Challenges

Challenges [2] involved in the formulation and development of emulgel systems are:

Difficult emulsification: Emulsification requires high-energy inputs and specialized equipment. It is time consuming and can lead to over-processing damaging heat sensitive compounds.

Limited drug loading: The space occupied by oil droplets and thickener phases reduces the amount of drug that can be loaded compared to liquid or semisolid systems.

Irritation: Some emulsifiers and penetration enhancers used in emulgels can irritate the skin in high concentrations. Proper selection and testing can minimize but not completely eliminate irritation.

Phase Separation: In spite of emulsification, limited stability may allow separation of phases over longer storage periods, especially for W/O emulsions. Continuous agitation or using stabilizing agents helps prevent separation.

Altered drug release: While sustained release is an advantage, the release profile of drugs can get modified from that of conventional dosage forms. This may not be desirable for all drugs and therapeutic objectives.

The challenges faced in the development of emulgels are shown in Table 8

Table 8. Limitations and challenges with emulgel preparation and use

Sl. No.	**Parameter**	**Limitations/Challenges**
01	High equipment cost	Specialized equipment like high shear homogenizers, microfluidizers, ultrasonicators etc. are required for preparing emulgel formulations which adds to the total cost. This can limit large scale production of emulgel formulations.
02	Lower drug loading	Only a fraction of the total formulation composition can be allocated for the drug due to gel matrix formation and increased aqueous content in emulgels. This results in lower drug loading compared to other semi-solid or liquid formulations. Higher doses may be needed to achieve desired therapeutic effect.
03	Stability issues	The emulsified system and gel matrix can make emulgels more prone to instability issues like creaming, sedimentation, phase separation, flocculation etc. Proper selection and optimization of emulsifiers and gelling agents are required to overcome stability challenges which can be difficult to achieve.
04	Difficulty in sterilization	The susceptibility of emulgel components like emulsifiers, gelling agents, drugs etc. to high temperatures or radiation makes sterilization a challenging task. Sterilization is critical for parenteral applications but can deteriorate product quality. Alternative sterilization techniques may need to be explored.
05	Skin irritation	Although emulgels minimize irritation in comparison to liquid systems, they may still cause irritation or sensitization to certain components like surfactants, preservatives etc. especially with prolonged and repeated use. Irritation liability needs to be properly assessed during formulation and evaluation.
06	Drug incompatibility	Although emulgel matrix provides some protection, it may not prevent all types of interactions between co-administered drugs or drugs and other emulgel components. Drug compatibility needs to be confirmed to avoid any physicochemical or biological incompatibility.
07	Long term effects	The effects of prolonged use or exposure to certain emulgel components are not fully known, especially for components used at high concentrations. This can be an important concern, especially for formulations applied topically or injected parenterally. Long term safety needs to be ensured before marketing.

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FUTURE PERSPECTIVES

Emulgels are promising semi-solid systems that combine the advantages of emulsions and gels. They offer enhanced stability, sustained release, improved cosmetic properties and versatile applications in topical, parenteral and oral drug delivery [21]. The promising areas of research and development for emulgels are illustrated in Figure 2

Figure 2. Promising areas of research and development for emulgels

Emulgels can be formulated using different emulsification techniques like high shear homogenization, ultrasonication, microemulsification etc. along with various gelling agents such as carbopol, hydroxypropyl cellulose, gelatin etc. Proper selection of emulsifiers, surfactants and gelling polymers can help achieve the desired physicochemical proper-ties and release kinetics for different applications [22]. Besides characterization of particle size, viscosity, pH, spreadability and drug release, evaluating factors like drug loading, drug permeation and skin hydration can provide useful insights into the performance of emulgel formulations. Topical emulgels are promising for skin care, hair care and cosmetics. Parenteral emulgels can deliver drugs in a controlled manner for systemic effects. Oral emulgels can improve absorption of both hydrophilic and lipophilic drugs [23]. Key advantages of emulgels include sustained release, solubilization of both hydrophilic and lipophilic drugs, protection from degradation, improved cosmetic appeal and flexible dosing. However, emulgel preparation requires specialized equipment and they have lower drug loading compared to other semisolid systems. The potential benefits for exploring future perspectives on emulgels are listed out in Table 9.

Table 9. Potential benefits of exploring future perspectives on emulgels

Sl. No.	Potential benefits	Future perspectives
01	Enhanced effectiveness	Exploring areas like newer gelling agents, emulsifiers, penetration enhancers etc. can lead to formulations with improved drug absorption, bioavailability and therapeutic effect. Use of nanotechnology and microemulsions can also enhance effectiveness.
02	Optimized and controlled release	Combining emulgels with intelligent polymers, stimuli responsive systems and touch activated nanoparticles can enable optimized release in response to external stimuli like pH, temperature, pressure etc. This allows activated release at specific sites or times.

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03	Sustained release for longer periods	Exploring longer acting gelling agents, wax emulsions and polymers can result in emulgels providing sustained release over weeks or months from a single administration. This can improve management of chronic conditions.
04	Wider applications	Emulgels can potentially be explored for applications beyond current topical, parenteral and oral use like buccal, nasal, rectal, intra-articular delivery etc. They can also be investigated for applications like tissue engineering, gene delivery etc.
05	Improved stability	Use of newer surfactants, polymers, ions etc. with improved emulsifying and gelling abilities can lead to emulgels with higher stability against creaming, sedimentation,phase separation etc. This can reduce wasted material and improve ease of use.
06	Reduced irritation	Exploring surfactants, polymers and other emulgel components with non-irritant and hypoallergenic properties can minimize potential for skin irritation, sensitization and other allergic reactions especially for topical use. This enhances safety, patient compliance and acceptability
07	Flexible and multifunctional formulations	Emerging areas like Janus particles, functional nanoparticles, temperature/pH responsive systems etc. can enable emulgels for flexible and combined functionalities like controlled release as well as targeting, imaging, therapy, testing etc. These "intelligent" formulations can revolutionize applications of emulgels.

There is immense scope for improving emulgel formulations by developing better emulsification techniques, identify-ing newer gelling agents, permeation enhancers and solubilizers. Combining emulgels with nanotechnology, micro-emulsions and hydrogels can generate synergistic formulations with enhanced effectiveness [17]. With growing research on preparation, characterization, applications and optimization of emulgel systems, these plat-forms are poised to make significant improvements in topical, parenteral and oral delivery of drugs and cosmetics. Emulgels thus present promising opportunities for developing innovative formulations with improved therapeutic and cosmetic benefits.

CONCLUSION

Emulgels are innovative semi-solid delivery systems that combine the benefits of emulsions and gels. They offer sus-tained release, improved stability, enhanced cosmetic properties, and versatile applications in drug and cosmetic deli-very. Emulgels can be tailored for optimal performance using different techniques and agents, but require specialized equipment and have lower drug loading. Continued research can help realize their true potential, including combining with nanotechnology, microemulsions, and hydrogels. Emulgels are poised to transform topical, parenteral, and oral delivery in the coming years, representing an exciting prospect for the healthcare and cosmetics industries. In sum-mary, emulgels are a remarkable delivery system that deserves further exploration for optimized therapeutic and cos-metic solutions.

ACKNOWLEDGEMENT

The authors would like to thank Dr. K. Ravishankar, Aditya College of Pharmacy, Surampalem for supporting this work.

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International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 06 Issue 05 May 2023
DOI: 10.47191/ijcsrr/V6-i5-42, Impact Factor: 6.789
IJCSRR @ 2023
www.ijcsrr.org

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Cite this Article: Prakash Nathaniel Kumar Sarella, Lakshmi Rama Krishna Pravallika Godavari (2023). The Expanding Scope of Emulgels: Formulation, Evaluation and Medical Uses. International Journal of Current Science Research and Review, 6(5), 3030-3041