Precision Drug Delivery and Anti-Contamination Strategies in Oily Topical Liquid Formulations: A Narrative Review

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Abstract: This review aims to summarize the key challenges and improvement strategies for precise delivery and contamination control in oily topical liquid formulations. Based on published literature, it examines formulation properties, dispensing variability, user-related factors, post-opening contamination risks, packaging design, and protective technologies. The review shows that dose inconsistency is influenced by viscosity, temperature, container structure, bottle angle, applied force, skin spreading, and patient handling. Repeated use may also increase contamination risk through finger contact, environmental exposure, poor storage, and contaminated dispensing interfaces. Current strategies, including metered-dose delivery, applicator-guided systems, single-dose packaging, improved multidose containers, preservative optimization, and compatibility-aware packaging, may improve dose reproducibility and safety. Overall, oily topical liquid formulations should be managed as integrated product systems. Optimizing formulation, container, dispensing interface, packaging protection, and user instructions is essential to support safer, more accurate, and patient-centered topical therapy.

***Keywords*:** oily topical liquid formulations, topical drug delivery, dose reproducibility, contamination control, packaging safety, patient-centered administration

1. Introduction

Topical therapy depends on active ingredient and vehicle [1-3]. Oily topical liquids are used for localized symptom relief, barrier support, wound care, and some herb-derived therapies [4-6]. Compared with many semisolids, they are harder to deliver reproducibly because dispensed volume, spreading, and residual loss vary in routine use [2,3,7]. Repeated-use safety is also vulnerable to handling, reuse, environmental exposure, and poor storage [8-10].

2. Characteristics and barriers to precise delivery

These formulations contain an oil-dominant or lipophilic phase governing spreading, skin residence, and solubilization [4,6]. They include medicated oils, oil solutions, oil-rich suspensions, biphasic systems, and preparations with essential oils or other lipophilic constituents [4,11]. Their value lies in accommodating poorly water-soluble ingredients and prolonging local skin contact, but performance depends on formulation properties and instability of some volatile or oxidation-sensitive constituents [4,7,11,12]. Precision is difficult because the final cutaneous dose depends on formulation, container, user handling, body site, and post-dispensing behavior [2,3,13]. Dispensed volume varies with viscosity, temperature, bottle angle, opening geometry, and applied force [2,7]; delivered dose varies further because oily liquids spread rapidly or remain on fingers and applicators [1,3]. Routine use adds visual estimation, site variation, and difficulty in vulnerable users [13-17]. Precision is therefore a product-system property rather than a formulation attribute alone [2,3,13,15-17].

3. Post-opening contamination risk and protective strategies

After opening, safety depends on handling, storage, repeated exposure, and the dispensing interface rather than on initial quality alone [9,10]. Contamination may be introduced through repeated opening, finger contact, environmental exposure, or poor storage [9,10]. Evidence from in-use eye drops shows that dropper tips and caps are common contamination sites, indicating that the dispensing interface is part of the therapeutic system [18]. Oily formulations may also deteriorate through oxidation, volatilization, or phase instability, and packaging configuration can affect in-use performance [11,12,19,20]. With reduced preservative content, safe repeated use depends even more on dispenser design and package protection [21]. Protection requires integrated control of package design, preservative choice, material compatibility, and user behavior [24-27]. Exposure can be reduced by single-dose units or multidose containers that limit re-entry [24]. Preservative selection must be formulation-specific [25-27]. Compatibility also matters because light, oxygen, excipients, and container materials

can alter stability, while lipophilic constituents may interact with internal surfaces [27]. Even with better protection, poor handling, incomplete recapping, unsuitable storage, and use beyond the intended period can still compromise safety [24-27].

4. Precision technologies, clinical translation

Metered and applicator-guided systems aim to reduce variability during dispensing and transfer [22,23]. Their practical performance still depends on package design, discharge behavior, and user interaction [19,20,23]. Oily topical liquids should therefore be evaluated as product systems integrating formulation, container, interface, package protection, and instructions. Conventional quality assessment does not fully capture dose reproducibility or post-opening safety [9,10,19,21]. Future development should emphasize dose standardization, improved dispensers and applicators, stronger in-use protection, compatibility-aware packaging, and realistic instructions [22-27].

5. Conclusion

Oily topical liquid formulations remain useful for localized external therapy, but their real-world performance is limited by imprecise administration and repeated-use safety risk. More reliable use will depend on integrated control of formulation, dispensing, package protection, compatibility, and handling conditions.

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