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Natural but Not Harmless? Essential Oils, Endocrine Activity, and Gynecomastia in Boys

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ABSTRACT

Essential oils, extracted from a wide range of plants, are increasingly incorporated into cosmetics, personal care products, and aromatherapy preparations, and are often promoted as safe and natural choices for children and families. Among these, lavender (*Lavandula angustifolia*) and tea tree (*Melaleuca alternifolia*) oils are the most widely used. However, despite their popularity and perceived safety, limited and heterogeneous evidence has raised hypotheses regarding possible endocrine activity of these oils.Case reports have linked chronic topical exposure to prepubertal gynecomastia in boys, with complete regression of symptoms upon discontinuation, suggesting a possible but unconfirmed environmental association. Mechanistic in vitro studies provide biological plausibility under experimental conditionsby demonstrating that key constituents, including linalool, linalyl acetate, and terpinen-4-ol, activate estrogen receptors and inhibit androgen receptors, providing biological plausibility. While epidemiological studies have not consistently shown population-level effects, their methodological limitations preclude firm conclusions and although population-level associations have not been consistently demonstratedin susceptible subgroups. Regulatory oversight remains limited, as cosmetic products containing essential oils are not subject to comprehensive premarket toxicological testing, and labelling practices rarely disclose individual constituents.

Collectively, these findings challenge the assumption that "natural equals safe." The convergence of clinical evidence, mechanistic plausibility, and regulatory gaps highlights the need for expanded research to define safe exposure thresholds, identify vulnerable populations, and clarify long-term risks. Until such evidence is available, further well-designed clinical and epidemiological studies are required before risk-based recommendations can be made, particularly in products marketed for children.

Keywords: Essential oils, Lavender oil (*Lavandula angustifolia*), Tea tree oil (*Melaleuca alternifolia*), Endocrine disruption, Prepubertal gynecomastia, Estrogen receptor activation, Androgen receptor inhibition, Linalool, Linalyl acetate, Terpinen-4-ol, Cosmetic regulation

INTRODUCTION

Essential oils, derived from a wide variety of plants, have gained considerable popularity due to their natural origins and reputed therapeutic properties, including antimicrobial, anti-inflammatory, and

calming effects (1). They are widely promoted as safe and gentle, and are incorporated into personal care products, cosmetics, and aromatherapy preparations, many of which are marketed specifically for children and families. Among these, lavender (*Lavandula angustifolia*) and tea tree (*Melaleuca alternifolia*) oils are among the most commonly used, frequently included in shampoos, lotions, and skin creams (2).

Despite their popularity and the widespread perception of safety, emerging case-based and experimental evidence has raised questions regarding possible endocrine activity.Several case reports have documented prepubertal gynecomastia defined as benign breast tissue enlargement in boysassociated with topical exposure to these oils, with symptom resolution following discontinuation (3). While many cases of prepubertal gynecomastia remain idiopathic and self-limiting, these observations highlight a potentially modifiable environmental risk factor (4).

Over recent years, the use of essential oils in consumer products has risen sharply, driven by public interest in plant-based remedies and the perception that natural ingredients are inherently safe (1). Oils such as lavender (*Lavandula angustifolia*) and tea tree (*Melaleuca alternifolia*) are particularly widespread, incorporated into cosmetics, personal care items, and household products (5). Despite their natural origin, these oils are complex mixtures of bioactive compounds—including linalool, linalyl acetate, and terpinen-4-ol—that readily penetrate the skin and enter systemic circulation, raising concerns about their long-term biological effects (6).

Clinical concerns regarding endocrine effects first emerged with reports of prepubertal gynecomastia linked to topical essential oil exposure. In a seminal case series, Henley et al. (2007) described three boys who developed breast tissue enlargement that regressed after discontinuing lavender- or tea tree–containing products (3). Ramsey et al. (2019) later documented additional cases with similar reversibility, strengthening biological plausibility without establishing causality (4). These observations prompted mechanistic studies, which demonstrated that key constituents of lavender and tea tree oils exhibit estrogenic and anti-androgenic activities in vitro. Using MCF-7 and MDA-kb2 cell lines, Henley et al. showed estrogen receptor activation and androgen receptor inhibition (3).

Among these constituents, monoterpenes such as linalool have attracted particular interest for their ability to interact with hormone receptors. Safety assessments indicate that linalool can engage estrogen receptors, potentially influencing endocrine signalling. Broader analyses of terpenes further support their capacity to modulate hormone pathways and impact endocrine health (7). Animal studies also report hormonal and reproductive changes after topical exposure, though findings vary depending on dose, timing, and duration (8).

The biological plausibility of essential oil–induced hormonal disruption is consistent with the established sensitivity of developing endocrine systems to low-level, chronic exposure to endocrine-disrupting chemicals (EDCs) (9). EDCs, whether synthetic or natural, interfere with hormone signalling by mimicking endogenous hormones or blocking their receptors (10). Historically, attention has centered on industrial chemicals such as phthalates and bisphenol A, but naturally derived compounds—including essential oil constituents—are increasingly recognized as potential disruptors.

Regulatory oversight of essential oils remains less rigorous than for synthetic ingredients. In the United States, for example, the FDA does not require premarket safety testing of cosmetics unless therapeutic claims are made. Consequently, many essential oil–containing products enter the market without systematic toxicological evaluation (11). Furthermore, labelling often omits disclosure of individual constituents,

limiting both consumer and clinician awareness of potential exposures (12).

Collectively, these findings challenge the assumption that natural products are inherently safe and highlight the need for systematic safety evaluation of essential oils, particularly in formulations intended for children. Strengthened public health awareness, clinical vigilance, and continued research are essential to establish exposure thresholds, identify vulnerable populations, and clarify the long-term health consequences of essential oil use. This narrative review critically explores the paradox of essential oils natural substances widely perceived as safe yet capable of disrupting hormonal balance during sensitive developmental stages. It synthesizes clinical evidence, examines underlying biological mechanisms, and evaluates implications for safety and regulatory oversight, with particular emphasis on paediatric populations.

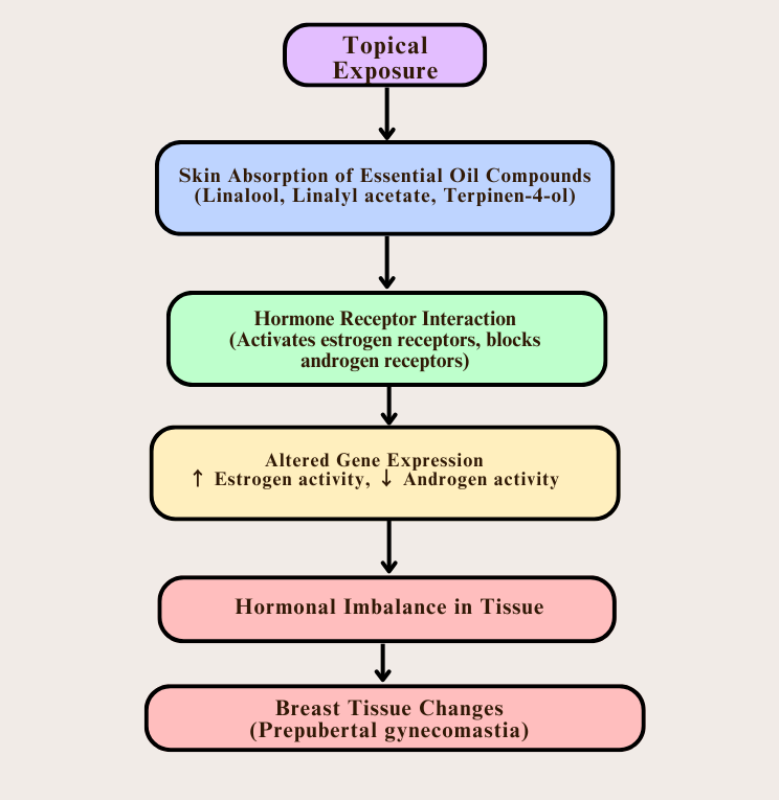

Figure 1: Following dermal absorption, constituents such as linalool, linalyl acetate, and terpinen-4-ol reach systemic circulation. In vitro work by Henley et al. (2007) showed these compounds activate estrogen receptors and inhibit androgen receptors, demonstrating receptor-level interactions under experimental conditions; these findings do not confirm in-vivo human effects.

REVIEW

1. Essential Oils: Between Natural Origins and Perceived Safety

There is a longstanding belief that natural products, such as essential oils, are inherently safe—an assumption reinforced by cultural traditions and marketing narratives (1,2). Lavender and tea tree oils, in particular, have become widely used in child- and family-oriented products for their calming and antimicrobial qualities (2,5). However, evidence from scientific and regulatory reports indicates that natural origin does not guarantee biological safety (13). Regulatory frameworks for essential oils are notably less stringent than those governing synthetic chemicals. For example, the U.S. Food and Drug Administration (FDA) does not mandate comprehensive premarket testing of cosmetic formulations containing essential oils, leaving potential risks insufficiently assessed (14,23). Inadequate regulation and incomplete labelling have contributed to

limited consumer awareness, as many products fail to disclose their full compositions (12). Regulatory gaps indicate limited premarket testing rather than evidence of demonstrated harm under normal conditions of use.

2. Clinical Evidence: Linking Lavender and Tea Tree Oils to Gynecomastia

The debate surrounding essential oils and endocrine disruption gained prominence following case reports of prepubertal gynecomastia linked to topical use of lavender- and tea tree–containing products. In a landmark case series, Henley et al. (3) described three prepubertal boys with breast enlargement, all of whom experienced complete regression after discontinuing essential oil exposure. Ramsey et al. (4) expanded these findings, reporting additional cases and reinforcing the reversibility of symptoms. Both case series are hypothesis-generatingdue to their temporal association, resolution upon withdrawal, and reported recurrence with re-exposure in uncontrolled observational settings. Nevertheless, critics highlight the limitations of small sample sizes and reliance on anecdotal reports, emphasizing the need for larger epidemiological studies (18,20). Interestingly, no comparable effects have been consistently documented in girls, raising questions about possible sex-specific vulnerability or differential hormonal sensitivity during prepubertal development (17).These reports lack exposure quantification, endocrine biomarker confirmation, and control for confounding variables, limiting causal inference.

3. Mechanistic Insights: Endocrine Disruption at the Molecular Level

Mechanistic studies provide crucial insights into how essential oils and their constituents may act as endocrine disruptors. Henley et al. (3) first demonstrated that lavender and tea tree oils, as well as their major monoterpenes—linalool, linalyl acetate, and terpinen-4-ol—exhibit both estrogenic and anti-androgenic activity in vitro, stimulating estrogen receptor responses and inhibiting androgen receptor signaling in MCF-7 and MDA-kb2 cell lines. These findings were later corroborated by Koyama & Heinbockel. (15), who confirmed receptor-mediated activity of lavender and tea tree oils in multiple human cell-based assays, and by Diaz et al. (22), who demonstrated estrogenic stimulation in MCF-7 proliferation assays alongside anti-androgenic effects in androgen-responsive reporter systems. Together, these studies support the ability of terpenes to interact with hormone receptors in vitro.However, critics argue that the concentrations used in vitro may not reflect real-world consumer exposure (16). In vitro receptor activity alone is insufficient to infer endocrine disruption in humans without exposure-relevant doses and demonstrated adverse outcomes.

Animal studies provide mixed and route-specific evidence on the endocrine effects of essential oils. In immature female Sprague–Dawley rats, percutaneous application of lavender oil at 20 or 100 mg/kg/day for 3 days produced no uterotrophic (estrogenic) effects, as measured by uterine weight in a validated bioassay (8). In contrast, prepubertal female rats exposed to lavender oil via inhalation exhibited earlier vaginal opening (at ~33.8 days vs 38.4 days in controls) and elevated luteinizing hormone levels (16). These findings underscore dose-, route-, and species-dependent variability, limiting direct extrapolation to human exposure scenarios, thereby limiting extrapolation of these findings to real-world human exposure scenarios

4. Trends and Contradictions: Interpreting the Body of Evidence

The existing literature presents both consensus and controversy. Clinical evidence raises hypotheses regarding possible risk of endocrine disruption, particularly under conditions of chronic exposure (3,4,18). Conversely, some researchers argue that the rarity of reported cases suggests a low overall risk, potentially confined to genetically susceptible individuals or those exposed to unusually high concentrations (17). Systematic

reviews emphasize that while associations between essential oil exposure and gynecomastia have been described, methodological shortcomings: including limited sample sizes, lack of controls for confounding factors, and absence of direct measurements of systemic absorption—render current conclusions tentative (18,20). Another dimension of debate lies in the broader context of endocrine disruption. Essential oil constituents are biologically active, but similar or greater risks have long been associated with synthetic endocrine-disrupting chemicals (EDCs) such as phthalates and bisphenol A (10,19). Recognition that naturally occurring compounds may also interfere with hormonal pathways expands the discussion beyond essential oils and challenges regulatory and public health frameworks that have historically focused primarily on synthetic agents (9,19).

5. Implications for Safety, Public Health, and Regulation

The convergence of clinical, mechanistic, and regulatory evidence supports proportionate risk communication and continued scientific surveillance., particularly when essential oils are marketed for paediatric use or intended for chronic dermal application (11,13,21). Current regulatory systems do not require systematic premarket toxicological evaluation of products containing essential oils (14,23), an oversight that risks underestimating potential harms. Policy reforms aimed at improving labelling practices, mandating disclosure of individual constituents, and requiring targeted safety assessments are essential (12,21). Additionally, increased clinician and caregiver awareness can help minimize paediatric exposure to potential endocrine disruptors (9,10,17).

DISCUSSION

This review underscores the paradox that natural products, widely assumed to be safe, may exert measurable endocrine effects in vulnerable populations. Case reports by Henley et al. (3) and Ramsey et al. (4) provide temporal associations and reversibility of prepubertal gynecomastia with lavender and tea tree oil exposure. However, the evidence base remains limited in scope and methodology. Mechanistic studies reinforce biological plausibility, with lavender and tea tree oil constituents—linalool, linalyl acetate, and terpinen-4-ol—shown to activate estrogen receptors and inhibit androgen receptors in vitro (22,23). Nonetheless, questions remain regarding real-world exposure levels and dose–response relevance (16).

At the population level, available epidemiological studies have not demonstrated a consistent increase in paediatric endocrine disorders linked to essential oils. Systematic reviews by Hawkins et al. (18) and prevalence analyses (20) concluded that current evidence from larger cohorts is insufficient to establish causality. Yet, the rarity of reported cases, variability in product formulations, and limited data on real-world exposures make it challenging to reach definitive conclusions. The lack of consistent epidemiological signals suggests low population-level risk under typical exposure conditions, while acknowledging data limitations, recognizing that absence of evidence is not the same as evidence of safety (19),while acknowledging that available epidemiological data do not demonstrate population-level harm.

From a regulatory standpoint, oversight of essential oils in cosmetics and personal care products remains minimal. In the United States, the FDA does not mandate comprehensive premarket toxicological testing for cosmetics unless therapeutic claims are made (11,14,24). Incomplete labelling of individual constituents further restricts consumer awareness and clinical guidance (12).

This gap highlights the need for clearer labelling, standardized toxicological testing of bioactive constituents, and targeted safety evaluations for products marketed to children (13,21). Key limitations include reliance on case reports, in-vitro exposure mismatch, absence of pharmacokinetic correlation, and limited real-world exposure data.

Future research priorities should include:

(i) well-designed epidemiological studies with robust exposure assessment (18,20),

(ii) mechanistic studies clarifying dose–response thresholds (23,24), and

(iii) identification of subgroups with heightened susceptibility to endocrine disruption (17,19). Clinicians, meanwhile, should adopt a precautionary stance, counseling caregivers about prudent use and maintaining vigilance for paediatric endocrine changes (9,10,21).

However, systematic reviews and prevalence studies have not demonstrated a consistent causal or population-level association between essential oil exposure and paediatric endocrine disorders. (25)Available evidence indicates a potential for endocrine disruption from essential oil exposure that warrants further investigation through well-designed epidemiological studies.

CONCLUSION

Case reports describe an association between topical exposure to lavender and tea tree oil–containing products and prepubertal gynecomastia, with symptoms often regressing after discontinuation. In vitro studies demonstrate that certain constituents—linalool, linalyl acetate, and terpinen-4-ol—can interact with estrogen and androgen receptors under experimental conditions, providing biological plausibility. However, epidemiological evidence remains inconsistent, and a causal relationship in humans has not been established. Further well-designed clinical, epidemiological, and exposure-based studies are required before definitive risk-based conclusions can be drawn.

Declaration by Authors

Ethical Approval: Not applicable

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