SYSTEMATIC REVIEW

Discrepancies in Nicotine Content of E-Cigarette Liquids: A Systematic Review of High Performance Liquid Chromatography-Based Analyses

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ABSTRACT

Introduction: E-cigarettes have emerged as a popular alternative to traditional tobacco products, largely driven by perceptions of reduced harm and customizable nicotine delivery. Accurately determining nicotine concentrations using high performance liquid chromatography is crucial for guiding public health policies and ensuring consumer safety. This assessment method is preferred due to its high sensitivity, precision and ability to reliably quantify nicotine in complex matrices especially the liquid in e-cigarettes. **Methods**: A systematic search using electronic databases was performed using PubMed, Science Direct, and Google Scholar with specific keywords to identify relevant studies to determine the findings. The articles that met the inclusion criteria were retrieved following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). **Results**: The findings of this systematic review revealed that the nicotine concentration in e-liquid samples varies across multiple studies. The deviation of nicotine content in e-liquid samples found to be high as +451% and as low as −90.6%. The analyzed e-liquid samples with concentrations ranging from 0 to 50 mg/ml indicated that nicotine levels were more than 20% and at least 10% below the labelled concentrations in packaging. The analysis also exposed the existence of nicotine in e-liquid samples labelled as nicotine-free. **Conclusion**: This systematic review employing high performance liquid chromatography as primary analytical method to uncover inconsistencies between measured nicotine content of e-liquids and their labelled values. These findings underscore the urgent need for stricter regulatory oversight and standardized quality control measures for consumer safety and compliance with regulatory standards.
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INTRODUCTION

Electronic cigarettes or also known as e-cigarettes have rapidly gained popularity as an alternative to traditional tobacco smoking, particularly among individuals seeking to reduce or quit their tobacco use (1). The appeal of e-cigarettes lies in the belief that they offer a less harmful way to consume nicotine, with users able to regulate nicotine intake by choosing different e-liquid strengths (2). However, concerns about the safety, quality, and regulatory standards of e-cigarette products have emerged (3). A major issue is the accuracy of nicotine labelling in e-liquids leading to unintended health risks, particularly for individuals using these products for smoking cessation purposes (4). As the demand for e-cigarettes continues to rise, ensuring the accuracy of nicotine labelling is crucial to protect consumer health and support public health initiatives (5).

Moreover, nicotine is a highly addictive substance that can negatively impact cardiovascular function, elevate blood pressure, impair respiratory health, and affect brain development, particularly in adolescents and young adults (6). E-cigarettes first appeared in the early 2000s as an innovative alternative to traditional combustible

tobacco products. Early research suggests that user demographics, motivations, and satisfaction levels, revealing a slowly growing adoption mainly among current smokers seeking harm reduction options (7). Around 2010, significant technological advancements, including improved battery life and refillable e-liquid cartridges, combined with aggressive marketing, fuelled a rapid increase in e-cigarette popularity worldwide (8). The surge in e-cigarette use coincided with evolving perceptions of safety, as many users viewed them as less harmful compared to conventional cigarettes (9).

Nicotine content in e-liquids is a key factor affecting their efficacy in smoking cessation and their overall safety profile for instance, users may rely on the labelled nicotine concentration to gradually reduce their intake, a method central to many smoking cessation strategies (10). However, studies have shown that the actual nicotine concentration in e-liquids often deviates significantly from what is labelled on the packaging (11,12,13). These deviations can range from lower concentrations than labelled, posing risks of insufficient nicotine delivery, to higher concentrations, which may lead to nicotine poisoning or dependence (14). The discrepancies in nicotine levels were common across several e-liquid samples, with some labelled as nicotine-free containing significant amounts of nicotine, highlighting the potential dangers of mislabelling (15,16).

To address these concerns, High-Performance Liquid Chromatography (HPLC) has become one of the most widely employed techniques for determining the nicotine content in e-liquids. HPLC offers a high degree of precision and sensitivity, making it an ideal tool for the accurate quantification of nicotine in complex liquid matrices (17). The global market for electronic cigarettes (e-cigarettes) has expanded dramatically in recent years, resulting in an increasingly diverse range of e-liquids available to consumers. These e-liquids, which are the primary substance used in e-cigarette devices to produce vapor, come in various formulations, including a wide array of nicotine concentrations, ranging from nicotine-free options to high-concentration products exceeding 50 mg/mL (18). The nicotine content in e-liquids varies significantly not only between brands but also within the same brand, which raises concerns about the accuracy of labelling and potential health risks. Such discrepancies are particularly critical for users who rely on e-cigarettes for smoking cessation, as variations in nicotine levels can affect the efficacy of these products in helping individuals reduce their nicotine intake (19).

The availability of e-liquids with varying nicotine concentrations provides smokers with the opportunity to gradually decrease their nicotine intake, a method central to many smoking cessation strategies (20). However, studies have shown that the nicotine content in e-liquids often deviates from what is indicated on the packaging. This mislabelling can lead to unintended health risks, such as insufficient nicotine delivery or excessive nicotine exposure, which could contribute to dependence or nicotine poisoning (21,22,23). Additionally, the regulatory standards surrounding e-liquid labelling and quality control remain inconsistent across countries, further exacerbating concerns regarding consumer safety (24).

Despite these challenges, e-cigarettes are increasingly promoted as a harm-reduction tool for smokers seeking to quit traditional tobacco products (21). As the market for e-cigarettes grows, it becomes increasingly important to ensure that the nicotine concentrations in e-liquids are accurately labelled and consistent across products (25). This would help safeguard consumers' health, provide more reliable smoking cessation options, and support public health initiatives (26). Recent research showed that e-cigarette usage is associated with socio-demographics factors like living in urban, having poor lifestyle behaviours such as alcohol consumption and drug abuse, lack of knowledge awareness of health effects vaping e-cigarettes and most importantly poor education initiatives in school (27). Therefore, the objective of this systematic review is to evaluate the accuracy of nicotine labelling in commercially available e-liquids by comparing the labelled concentrations with the actual measured values using HPLC. In addition, it aims to identify inconsistencies across e-liquid samples and detect the presence of nicotine in products labelled as nicotine-free.

METHODOLOGY

A systematic review was conducted in accordance with the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) guidelines (28). The review adhered to the criteria for identifying and screening the collected scientific papers, as illustrated in the PRISMA flowchart of the systematic review's study selection process (Fig 1).

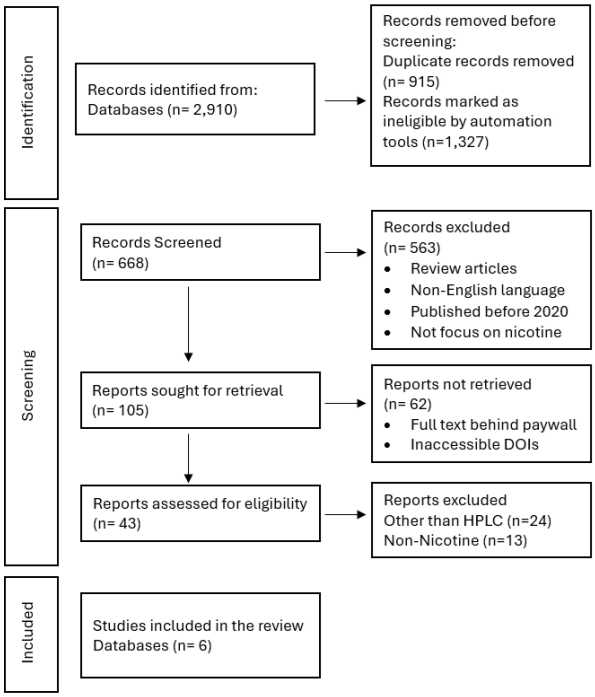

Fig. 1: PRISMA 2009 Flow Diagram. A flowchart illustrating the selection process of eligible articles included in the review.

Search Strategy

A comprehensive data search, collection, and extraction was performed using multiple databases, including PubMed, Science Direct, and Google Scholar. The search was conducted in January 2025, covering literature published between 2020 and 2024. A combination of relevant keywords was used to identify appropriate studies. The keywords included: (i) determination OR quantification, combined with (ii) e-liquid AND (iii) e-cigarettes OR vaping AND (iv) nicotine content AND (v) High Performance Liquid Chromatography. This search strategy was applied uniformly across all three databases.

Study Selection

The research selection principles including inclusion and exclusion criteria were established to screen and choose the data for this systematic review. The PRISMA flowchart was used to filter and select the collected journal articles. The identified papers were aligned with the study objectives including the determination and quantification of nicotine content or concentration in e-liquids of e-cigarettes using HPLC. All selected studies were original articles published in English between 2020 and 2024, focusing on optimal sources or current literature (Table I). The articles were selected based on clearly defined inclusion and exclusion criteria. The inclusion criteria were: (1) studies that utilized High-Performance Liquid Chromatography (HPLC) as the analytical method, (2) studies focused on commercially available e-liquids from various brands, (3) studies examining the quantification and accuracy of nicotine content in e-liquids, and (4) studies providing data on both labelled and measured nicotine concentrations to assess discrepancies. After initial selection, exclusion criteria were applied to further refine eligible articles. These included: (1) non-original research articles such as reviews or editorials, (2) articles not written in English, (3) studies published before 2020, and (4) studies focusing solely on compounds or alkaloids other than nicotine, which did not align with the objective of this systematic review. A MeaSurement Tool to Assess systematic Reviews (AMSTAR 2) is used to assess the quality of the systematic review on the accuracy of nicotine labelling in e-liquids, several strengths and limitations emerge. The review demonstrates strengths in having a clearly defined objective and a comprehensive search strategy, utilizing multiple databases with relevant keywords from 2020 to 2024. The inclusion and exclusion criteria were well-defined, focusing on studies using High-Performance Liquid Chromatography (HPLC) to quantify nicotine in e-liquids. Additionally, the synthesis of findings appears appropriate, providing valuable insights into the discrepancies in nicotine concentrations across various e-liquid samples. However, notable limitations include the lack of a formal risk of bias assessment for the included studies, which could undermine the credibility of the findings. Furthermore, the review does not discuss the funding sources of the studies, which are crucial for evaluating potential conflicts of interest. The quality of the evidence was not graded using a recognized system like Grading of Recommendations Assessment, Development and Evaluation (GRADE) and there was no overall risk of bias assessment for the systematic review process itself. These gaps in methodological rigor suggest that the credibility of the review's conclusions could be compromised. Therefore, despite the strengths of the review, the absence of these critical quality appraisal components should be acknowledged as a limitation that may impact the confidence in the review's conclusions (29).

Table I: Summary of findings from six studies evaluating the accuracy of labelled nicotine concentrations in e-cigarette e-liquids.

Study Title	Author & Year	Total E-liquid Sample Tested	Concentration of nicotine stated in label	Main Findings
Investigating the efficiency of mechanical agitation on the quantification of nicotine in e-cigarettes, using a novel method	Althakfi et al (2024) (30)	7	0–50 mg/ml	E-liquid sample 1 (30mg/ml) contains nicotine deviation − 86.9%. E-liquid sample 2 (3mg/ml) contains nicotine deviation + 451%. E-liquid sample 3 (35mg/ml) contains nicotine deviation – 71.3%. E-liquid sample 4 (50mg/ml) contains nicotine deviation – 87.3%. E-liquid sample 5 (50mg/ml) contains nicotine deviation – 90.6%. E-liquid sample 6 (50mg/ml) contains nicotine deviation – 52.0%. E-liquid sample 7 (0mg/ml) no traces of nicotine found.
Method Development and Validation of an Aerosol Sampling Technique for the Analysis of Nicotine in Electronic Cigarette Aerosols	Dill et al (2024) (17)	15	3–20mg/ml	5 e-liquid samples contain 10% less nicotine compared to the label. Meanwhile, other e-liquid samples recorded high nicotine concentration deviation with average −8.11% and ± 30 limit values.
Nicotine in electronic cigarettes	Althakfi et al (2024) (37)	94	0–25mg/ml	11 of e-liquid samples with 0–25mg/ml contains nicotine deviation ranging from − 63.1% to + 3.24 %. 12 of e-liquid samples with 0–18mg/ml contains nicotine deviation ranging from + 12% to + 17.9%. 12 of e-liquid samples with 3–6mg/ml contains nicotine deviation ranging from – 37.34% to + 12.34%. 27 of e-liquid samples with 6–22mg/ml contains nicotine deviation ranging from - 55% to + 39%. 32 of e-liquid samples with 3–24mg/ml contains nicotine deviation ranging from −100% to + 3.3%.
Simple HPLC method for rapid quantification of nicotine content in e-cigarettes liquids	Alhusban et al (2021) (38)	11	0–25mg/ml	E-liquid sample 1 (25mg/ml) contains nicotine deviation – 23.6%. E-liquid sample 2 (20mg/ml) contains nicotine deviation – 29.1%. E-liquid sample 3 (10mg/ml) contains nicotine deviation – 36.2%. E-liquid sample 4 (20mg/ml) contains nicotine deviation – 15.7%. E-liquid sample 5 (25mg/ml) contains nicotine deviation – 26.9%. E-liquid sample 6 (25mg/ml) contains nicotine deviation – 9.7%. E-liquid sample 7 (25mg/ml) contains nicotine deviation +3.24%. E-liquid sample 8 (25mg/ml) contains nicotine deviation – 10.3%. E-liquid sample 9 (3mg/ml) contains nicotine deviation – 63.1%. E-liquid sample 10 (3mg/ml) contains nicotine deviation – 41.6%. E-liquid sample 11 (0mg/ml) is nicotine-free.
E□cigarette quality control: Impurity and nicotine level analysis in electronic cigarette refill liquids.	Bennani et al (2020) (39)	32	3–24mg/ml	The average deviation of nicotine concentration ranged between □100% to 3.3%. 10 e-liquid samples have similar nicotine content as in label. 18 e-liquid samples contain 20% more nicotine compared to the label. In 2 non-nicotine labelled e-liquid samples, the traces of nicotine were found. 2 e-liquid samples labelled as non-nicotine were found to contain no nicotine after testing.
Labelling accuracy in low nicotine e-cigarette liquids from a sampling of US manufacturers.	Jackson et al (2020) (4)	12	3mg/ml	E-liquid sample 1 contains nicotine deviation 21.3%. E-liquid sample 2 contains nicotine deviation 35.6%. E-liquid sample 3 contains nicotine deviation 25.4%. E-liquid sample 4 (3mg/ml) contains nicotine deviation 37.4%. E-liquid sample 5 contains nicotine deviation 8.77%. E-liquid sample 6 contains nicotine deviation 13.9%. E-liquid sample 7 contains nicotine deviation 13.4%. E-liquid sample 8 contains nicotine deviation 22.5%. E-liquid sample 9 contains nicotine deviation 24.2%. E-liquid sample 10 contains nicotine deviation 14.7%. E-liquid sample 11 contains nicotine deviation 3.15%. E-liquid sample 12 contains nicotine deviation 12.4%.

Notes: (-) = negative; (+) = Positive; (mg/ml) = the information in the parenthesis is the content listed on the label.

Data extraction and management

The literature review process was conducted in three phases, following the PRISMA guidelines. In the first phase, studies that did not meet the inclusion criteria were excluded based on their titles. In the second phase, the abstracts of the remaining studies were evaluated and any studies that did not meet the inclusion criteria were further excluded. In the final phase, the full-text articles of the selected studies were retrieved and carefully reviewed to ensure they adhered to the inclusion criteria. Furthermore, duplicate articles were identified and removed during each of these phases. The eligibility of articles was assessed by a minimum of two reviewers to ensure reliability and accuracy. The titles and abstracts were reviewed and in case of any disagreement, a third reviewer will be appointed to assess and make the final decision. To ensure consistency of data collection, the data was independently extracted using a standardized data collection form. The following data was extracted from each selected study: (1) article title, (2) name of author and year of publication, (3) total sample tested, (4) concentration of nicotine stated in label, and (5) findings of the study.

RESULTS

Search Result

A total of 2,910 publications were initially identified during the literature search as potentially relevant to the study. Comparing with other search engines, 915 publications found to be duplicated and removed from the selection. Meanwhile, a total number of 1,890 publications were excluded after reviewing the titles and abstracts and did not meet the inclusion criteria. The examples of rejected articles were focusing on determination of arsenic content in aerosol of e-cigarettes, determination of propylene glycol (PG), vegetable glycerol (VG) content, cannabinoids, natural plant compounds and flavours, and using Fourier-transform infrared spectroscopy (FTIR), high-resolution mass spectrometry fragmentation experiments (HRMS/MS) and The Next Generation Impactor and Dekati Low Pressure Impactor as tool for analyzing. The remaining 43 articles were then subjected to further evaluation and data extraction. Eventually, only 6 articles that met all the inclusion criteria were selected for the final analysis. The results presented from the studies reviewed highlight significant discrepancies between the nicotine concentrations labelled on e-liquid products and the actual nicotine content found in those products.

Variability in Nicotine Concentrations

One of the most striking patterns across the studies is the considerable variability in nicotine concentrations, with many e-liquid samples showing substantial deviations from their labelled concentrations. Table 2 mentioned the e-liquid samples with percentage of nicotine deviation. E-liquid samples labelled as containing 50mg/ml nicotine demonstrated deviations of up to −90.6%, with some samples containing no detectable nicotine despite being labelled as nicotine-containing. Similarly, deviations in nicotine concentrations ranged from −100% to +3.3%, with some samples labelled as non-nicotine containing traces of nicotine, raising concerns regarding the accuracy and reliability of labelling practices in the market. These discrepancies could have serious consequences for consumers, especially those relying on the nicotine content to manage their nicotine consumption or to quit smoking. The findings also support the notion that nicotine content can be less than expected, with an average deviation of −8.11% from the labelled concentration (30).

Table II: E-liquid sample with percentage of nicotine deviation between labelled and measured nicotine concentrations in seven e-liquid samples.

Sample No.	Nicotine on Label (mg/mL)	Measured Nicotine (mg/mL)	Deviation (%)
1	30	3.96	-86.9
2	3	16.53	+451
3	35	10.10	-71.3
4	50	6.35	-87.3
5	50	4.7	-90.6
6	50	24	-52
7	0	0	0

Methods for Quantification of Nicotine

In terms of methods for nicotine quantification, analytical techniques such as high-performance liquid chromatography (HPLC) and mechanical agitation methods have been utilized to assess nicotine concentrations. These approaches have proven to be effective in capturing nicotine content but also reveal variability in accuracy, especially when comparing the concentrations in commercial products with their labelled values (31). In some instances, the deviations were so extreme such as up to 451% higher than the labelled value that it raises significant concerns about the standards of testing and the potential inaccuracies in current nicotine measurement methods (32). The use of novel methods may provide an opportunity to refine and improve the accuracy of nicotine quantification in e-liquids and aerosol samples, ultimately supporting better regulation (33).

Public Health Implications

The findings from these studies have significant implications for public health. As e-cigarettes are increasingly used as smoking cessation tools, the reliability of their nicotine content becomes a key factor in their effectiveness and safety. Inconsistent nicotine concentrations could lead to under- or overdosing, which may undermine the ability of e-cigarettes to effectively assist with smoking cessation or even contribute to new health risks. For example, individuals using e-liquids labelled with higher nicotine concentrations may

unknowingly consume more nicotine than intended, potentially leading to adverse effects such as nicotine poisoning (34). When the nicotine content in a product is lower than what is declared on the label, several potential hazards can arise, particularly for consumers who rely on accurate information for managing their nicotine intake. One of the main risks is ineffective nicotine delivery, which can undermine the product's intended purpose, especially for users trying to manage nicotine addiction. For example, if an e-cigarette or nicotine replacement therapy contains less nicotine than expected, users may not experience the desired reduction in cravings or withdrawal symptoms, leading them to consume more of the product to compensate. This may increase their overall nicotine intake and exacerbate health risks, such as cardiovascular issues or nicotine poisoning (35). Furthermore, if the product is marketed as effective for helping individuals quit smoking, lower nicotine content may reduce its efficacy, possibly causing users to relapse and continue smoking or using alternative nicotine products that may be more harmful (31). Additionally, consumers may resort to using other nicotine sources to make up for the discrepancy, which can result in increased exposure to harmful substances, especially if those sources are not adequately regulated or tested for safety (11). This issue is particularly concerning when nicotine products are marketed to vulnerable populations, such as youth, who may unknowingly consume more to achieve the intended effects, potentially leading to addiction and long-term health complications (36). Conversely, those relying on lower nicotine concentrations for gradual reduction may not be able to achieve the desired effect due to discrepancies in actual nicotine levels. Additionally, the presence of nicotine in non-nicotine labelled e-liquids, as seen in several studies, presents an ethical concern. Consumers may purchase e-liquids assuming they are free from nicotine, only to discover the presence of nicotine later, which can pose a particular risk to vulnerable groups, including non-smokers, minors, and pregnant women. The identification of such discrepancies also draws attention to the lack of transparency and accuracy in the labelling of e-cigarette products. One of the significant findings from the studies reviewed is the variation in testing methods.

DISCUSSION

These findings are corroborated by a range of international studies, pointing to significant deviations between the labelled and actual nicotine concentrations in e-cigarettes. This is critical for public health, regulation, and consumer safety, as they underscore the challenges in ensuring the quality control of nicotine in e-cigarettes.

Variability in Nicotine Concentrations

The significant deviations observed in these studies suggest that the method of production and quality control may not be standardized or properly regulated across manufacturers. Furthermore, the prevalence of products deviating from their labelled nicotine concentrations indicates that both manufacturers and regulatory bodies must improve their oversight practices to protect consumers from potential mislabelling and its associated health risks. The studies reviewed align with findings from another global research. For instance, a study in the UK found that a substantial portion of e-cigarette products failed to meet the labelled nicotine concentrations, with deviations ranging from −20% to +30% in many samples (15). This finding parallels the deviations observed in the current studies, such as the extreme variations observed where deviations ranged from +451% to −90.6%, and deviations between −100% and +3.3%. These discrepancies in nicotine levels may arise from several factors, including manufacturing inconsistencies, poor quality control, or the use of non-standardized testing methods, all of which are prevalent in the global e-cigarette market. In similar vein, low-nicotine e-liquids (3 mg/ml) had nicotine concentration deviations ranging from +3.15% to +37.4%, highlighting the widespread nature of this issue, particularly among products with low nicotine content. These deviations are particularly concerning, as they can undermine the efficacy of e-cigarettes as smoking cessation aids, especially when the nicotine levels are higher or lower than intended, leading to either overconsumption or insufficient nicotine intake.

Public Health Implications

The use of different techniques for nicotine quantification, such as HPLC and mechanical agitation has led to varying results, with some methods yielding more accurate or consistent readings than others. This lack of standardized testing methods has been highlighted in several studies worldwide. A review emphasized that the inconsistency in testing methods across laboratories and manufacturers contributes to unreliable nicotine content measurements (37). Standardization of testing methods is therefore critical for ensuring consistency in nicotine quantification and for enhancing consumer confidence in the accuracy of product labelling. Moreover, the findings that employed mechanical agitation, point to the potential benefits of adopting newer, more refined testing techniques. This approach has shown promise in increasing the accuracy of nicotine quantification compared to traditional methods. However, more studies are required to validate such techniques and ensure their applicability across different e-liquid formulations and production processes. Other studies, including one also reported discrepancies due to the

variation in the production processes and quality control measures employed by different manufacturers (38). A more systematic approach to testing would help mitigate the inconsistencies observed in the current studies and other global investigations.

Regulatory and Quality Control Recommendations

These findings emphasize the need for stronger regulations and quality control measures in the e-cigarette industry. Government agencies, such as the FDA and other global regulatory bodies, must enforce stricter guidelines for the labelling and testing of e-liquids to ensure consumer safety. This could include mandatory third-party testing and more stringent oversight of manufacturing practices to ensure that the nicotine concentrations listed on labels match the actual nicotine content. Moreover, standardized and more accurate testing methods need to be developed and universally adopted to help improve the consistency of nicotine quantification. Manufacturers should also be incentivized to improve their quality control processes to ensure the accuracy of their products. This could involve the implementation of more robust internal testing and the adoption of cutting-edge methods for nicotine detection and quantification. Additionally, transparency in manufacturing practices should be prioritized to build trust with consumers and regulatory bodies. The discrepancies in nicotine content also have significant implications for public health. As more individuals turn to e-cigarettes as smoking cessation tools, the effectiveness of these products is closely tied to the accuracy of nicotine delivery. Deviation in nicotine concentrations can undermine their effectiveness and, in some cases, contribute to unintended nicotine toxicity. A study by found that incorrect nicotine labelling, especially in high-concentration e-liquids, can lead to adverse health outcomes such as nicotine poisoning (39). These findings are consistent with the results from the studies reviewed here, particularly the extreme deviations observed whereby some samples showed nicotine concentrations far higher than labelled (30). Furthermore, the presence of nicotine in e-liquids labelled as non-nicotine is a particularly concerning issue where e-liquids labelled as nicotine-free contained detectable levels of nicotine (40,41). This raises ethical concerns, particularly regarding vulnerable populations such as minors and non-smokers. Previous study has highlighted the potential risks posed by these mislabelled products, which can advertently expose non-smokers to nicotine and increase the risk of nicotine dependence (42). In light of these findings, it is imperative that regulatory authorities enforce stricter labelling regulations and increase oversight on the e-cigarette market.

Global Regulatory Context

Internationally, the regulatory landscape for e-cigarettes varies widely. In the United States, the FDA has made strides in regulating e-cigarettes, but the enforcement of labelling accuracy remains inconsistent. The results from studies like those underscore the need for more stringent testing and regulation of nicotine content in e-liquids (4,43). Similarly, in Europe, the European Union's Tobacco Products Directive in 2014 mandates that e-liquids contain a maximum of 20 mg/ml of nicotine and require accurate labelling (44). However, as demonstrated by studies such as those by McNeill et al. (2019), deviations from labelled concentrations continue to be a global issue. Meanwhile, study suggest that programs related to the prevention of e-cigarette use should focus on instilling deeper knowledge and understanding about e-cigarettes such as its various product forms, chemical composition and associated health risks to raise awareness (45). Hence, it is clear that there is a need for stronger, harmonized regulatory frameworks across different jurisdictions to ensure consumer safety.

Limitations and Future Research

Although the studies reviewed provide important insights, there are several limitations to be considered. First, the sample sizes in some studies were relatively small, which may limit the generalizability of the findings. Furthermore, the testing methods varied between studies, with some utilizing novel techniques and others relying on more established methods, making direct comparisons challenging. Future research should aim to standardize testing protocols to allow for more reliable comparisons between different studies. Additionally, while the studies focused primarily on nicotine content, further research is needed to investigate the presence of other potentially harmful substances in e-cigarette products, such as impurities, additives, and degradation products, which could also affect consumer health.

CONCLUSION

The inconsistency in nicotine concentrations found in e-liquid products with those stated on the label, as demonstrated by the studies discussed, highlights a significant public health concern. This review highlights substantial inconsistencies between labelled and actual nicotine concentrations in e-cigarette products, a concern consistently reflected across numerous international studies. This includes variability for both across brands and between production batches to stems from non-standardized manufacturing practices, insufficient quality control, and inconsistent analytical methodologies. These discrepancies compromise the safety and effectiveness of e-cigarettes, particularly as smoking cessation aids, and erode consumer trust and broader public health efforts. The observed deviations in nicotine content pose significant risks, including potential nicotine overexposure, underdosing, and inadvertent exposure among users of low-nicotine or nicotine-free products. Addressing these challenges requires increased regulatory scrutiny, the development and implementation of standardized, validated testing methods, and rigorous enforcement of labelling accuracy. Regulatory authorities, manufacturers, and the

scientific community must collaborate to enhance testing precision, ensure greater transparency in production processes, and uphold quality standards across the e-cigarette market. Furthermore, future research should extend beyond nicotine quantification to investigate other harmful constituents in e-liquids and assess the long-term health effects of mislabelled products. Establishing a harmonized, evidence-based regulatory framework is critical for ensuring product consistency, protecting consumer health, and maintaining public confidence in tobacco harm reduction strategies.

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