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ROCZNIKI PAŃSTWOWEGO ZAKŁADU HIGIENY

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Editorial Introduction	91
Intrauterine growth restriction outcomes at the age of 2 in resource – limited settings: a systematic review <i>Najat Ababsi, Halima Ibrahimi, Ilham Elouardighi, Nihal Abitiu, Amina Essamett, Latifa Mochhoury, Milouda Chebabe</i>	93
Boundaries of the therapeutic relationship in nursing – between empathy and emotional burden <i>Dominika Szynal, Tomasz Olszowski</i>	101
Lead poisoning among children in Nigeria: A review of evidence, gaps, and interventions <i>Idris Muhammad Yakubu, Kefas Gurama Jibir, Abdullahi Adobanyi Musa, Rabi Muhammad Dansabo, Muhammad-Hadi Folarin Oyerinde</i>	113
Association between Expanded Disability Status Scale Score and Mediterranean diet adherence according to disease duration in patients with multiple sclerosis <i>Mária Kijovská, Martina Gažarová, Petra Lenártová</i>	127
Analysis of energy and macronutrients intake in patients with type 1 and type 2 diabetes mellitus: A pilot study <i>Lucia Šubová, Petra Lenártová, Marta Habánová, Martina Gažarová</i>	137
Radiocaesium activity in Polish <i>Imleria badia</i> mushrooms: Contamination levels and trends over the last three decades <i>Jerzy Falandysz, Alwyn R. Fernandes, Adam J. Daragó, Michał Saniewski</i>	145
Enhancing nursing students' learning of nutrition through podcasting: An active approach for Generation Z students in Morocco <i>Said Boucheфра</i>	161
Instruction for Authors	171

EDITORIAL INTRODUCTION

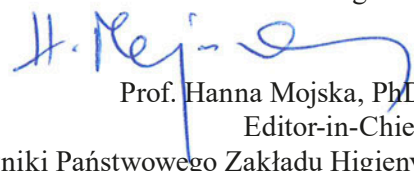
Ladies and Gentlemen,

The first 1,000 days of a child's life have a fundamental impact on health, not only during childhood but also throughout later life. It is estimated that intrauterine growth restriction (IUGR) affects between 3% and 10% of pregnancies worldwide, carrying with it the risk of impaired development in the child. The article by N. Ababsi et al., which opens Issue No. 2 of 2026 of the journal *Roczniki Państwowego Zakładu Higieny*, addresses this important problem and presents the results of a systematic review of publications concerning the developmental aspects of 2-year-old children born with intrauterine growth restriction (IUGR). In this issue, we also present a review article by D. Szynal and T. Olszowski addressing the issue of professional burnout among nurses in the context of patient relationships, a topic initiated in the first issue of 2026, an article that garnered significant interest among our readers. The following article by I.M. Yakubu et al. provides a review of research results from a period of over 20 years regarding lead exposure, based, among other things, on clinical studies of blood lead levels in children in Nigeria. The authors also identified sources of lead exposure in this country, the associated health consequences, and intervention measures, including treatment and prevention programmes. The topic of nutrition in the context of various disease was presented by authors from the Slovak University of Agriculture in Nitra. In the first study, M. Kijovská et al. assessed the association between adherence to the Mediterranean diet and the progression of multiple sclerosis, taking disease duration into account, among patients from three countries: Slovakia, Italy, and the United Kingdom. In turn, L. Šubová et al., in a pilot study, assessed the energy and macronutrient intake among 40 individuals diagnosed with type 1 and type 2 diabetes, based on a three-day dietary record. The significance of differences in blood biochemical markers between patients with type 1 and type 2 diabetes was also assessed. Food safety was discussed in an article by J. Falandysz et al. The authors presented the results of 30 years of research on radiocaesium contamination in *Imleria badia* (Bay Bolete). In this issue, I would also like to draw your attention to an article by S. Bouchefra presenting the results of using multimedia to support active nutrition education among students in Morocco.

I invite you to read the latest publications in *Roczniki Państwowego Zakładu Higieny* and consider submitting your original and review articles to this journal.



Kind regards,


Prof. Hanna Mojska, PhD
Editor-in-Chief
Roczniki Państwowego Zakładu Higieny

INTRAUTERINE GROWTH RESTRICTION OUTCOMES AT THE AGE OF 2 IN RESOURCE – LIMITED SETTINGS: A SYSTEMATIC REVIEW

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ABSTRACT

Despite significant advances in neonatal and child health, morbidity related to intrauterine growth restriction (IUGR) remains concerning, particularly in developing countries where resources are limited and geographical and socioeconomic disparities persist. This study aims to describe the clinical, nutritional, and developmental outcomes of children born with IUGR at 2 years of age, as reported in previous studies. It identifies the main findings from the selected literature and proposes ways to improve monitoring. A bibliographic search was conducted using PubMed, Science Direct, and Google Scholar. A total of 15 studies were included. The systematic review was performed in accordance with the PRISMA checklist. Most studies have shown abnormalities related to the health of children born with IUGR at the age of 2 years, including height and weight retardation; cognitive, mental, language, visual, respiratory, neurological, and metabolic impairments; developmental delay in general; and affected social skills. However, two studies showed no significant differences in height and weight or in developmental and behavioral outcomes at 2 years of age. This systematic review highlights several strong and consistent trends, despite differences in methodology, health contexts, and populations studied.

Keywords: *intrauterine growth restriction (IUGR), intrauterine growth retardation, consequences of IUGR, outcome at 2 years, IUGR morbidity*

INTRODUCTION

Intrauterine growth restriction (IUGR), defined as the failure of a fetus to achieve its genetically determined growth potential, affects approximately 5-10% of all pregnancies worldwide [1, 2]. It is most commonly caused by placental insufficiency, maternal malnutrition, hypertension, or smoking, and is associated with increased risks of perinatal morbidity, mortality, and longterm developmental impairments [3, 4]. Despite significant advances in neonatal and child health, morbidity related to IUGR remains concerning, particularly in developing countries

where resources are limited and geographical and socioeconomic disparities persist [5].

Infants with IUGR often present with low birth weight (< 10th percentile for gestational age), but the condition is distinct from being simply small for gestational age (SGA) because IUGR implies an active process of growth restriction with potential alterations in organ structure and function [6, 7]. While some children demonstrate spontaneous catchup growth during the first two years of life [8], others remain with persistent growth deficits, neurodevelopmental delays, and metabolic disturbances [9, 10].

The first two years of life represent a critical window for brain development, synaptogenesis,

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and motor skill acquisition. Adverse intrauterine conditions can disrupt these processes, leading to longterm consequences in cognition, language, fine motor skills, and social behavior [11, 12]. Several studies have reported that by 2 years of age, IUGR children may exhibit significant neurodevelopmental delay, including mental retardation and impaired psychomotor development [13-15]. Language delay and motor coordination impairment have also been documented at 24 months [16].

However, the literature shows notable heterogeneity in outcomes. Some cohorts show persistent delay in growth and weight gain with head circumference below -2 standard deviations (< -2 SD) [17], whereas others report no difference in body mass index (BMI) growth rate by age [8]. Metabolic abnormalities such as hyperinsulinemia and low adiponectin – have been detected as early as 2 years [8]. but not all studies have replicated these findings. Additionally, two studies have shown no significant differences in height and weight or in developmental and behavioral outcomes at 2 years of age [18, 19]. These discrepancies may arise from differences in IUGR severity, gestational age at birth, postnatal nutrition, assessment tools, and sample characteristics [20].

Given the persistent gaps in knowledge and the lack of a recent synthesis focusing specifically on 2-year outcomes, this systematic review aims to describe the clinical, nutritional, and developmental outcomes of children born with IUGR at 2 years of age, as reported in previous studies. It identifies the main findings from the selected literature and proposes ways to improve monitoring and early intervention.

MATERIALS AND METHODS

Study design and PRISMA guidelines

This systematic review was conducted in accordance with the 2020 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) statement (<https://www.prisma-statement.org/>) to ensure a transparent, reproducible, and unbiased selection of articles addressing our research question.

Search strategy

A literature search was conducted using three online databases: PubMed, ScienceDirect, and Google Scholar. The search strategy included the following keywords and concepts: “intrauterine growth restriction”, “intrauterine growth retardation”, “consequences of intrauterine growth restriction”, “complications of intrauterine growth restriction”, and “outcomes at 2 years”. The search was limited to articles published in English or French between 2010 and 2025.

Eligibility criteria

Studies that met the following criteria were included: (1) included the predefined keywords; and (2) assessed the health status of children born with intrauterine growth restriction (IUGR) at 24 months of age; (3) the articles must be original research (observational studies, cohort studies, systematic reviews, or meta-analyses) and (4) they must provide sufficient data on clinical, nutritional, or developmental outcomes.

Exclusion criteria: Duplicate publications, studies without full-text publications, articles that did not meet the inclusion criteria, and those lacking the information necessary for our research objective (e.g. incomplete data, poor study quality, or an inappropriate article type). Fifteen articles were selected for inclusion in this systematic review.

Data extraction and collection

The selected articles underwent a normative analysis of their content structure and classification. For each study, information was extracted on study design, sample size, definition of intrauterine growth restriction, follow-up age (24 months), and reported outcomes (growth, neurodevelopment, language, motor skills, metabolism, etc.). Data collection involved organizing and structuring the extracted information to identify converging ideas, comparing divergent viewpoints, and drawing evidence-based conclusions.

RESULTS

A total of 15 studies met the inclusion criteria and were included in this systematic review. The studies were published between 2010 and 2025 and originated from 10 countries: Spain ($n = 4$), France ($n = 3$), the Netherlands ($n = 2$), Italy ($n = 1$), Germany ($n = 1$), the United States ($n = 1$), the United Kingdom ($n = 1$), Austria ($n = 1$), Iran ($n = 1$), and Portugal ($n = 1$). Study designs included retrospective cohorts ($n = 7$), prospective cohorts ($n = 3$), observational studies ($n = 2$), one metaanalysis, one systematic review, and one randomized trial (DIGITAT). Sample sizes ranged from 42 to over 52,000 children. Followup assessment at 2 years (corrected age where specified) was available for all studies (Table 1).

Persistent delay in growth and weight gain was reported in several studies [7, 13, 14, 17]. Malnutrition and head circumference below < -2 SD were also noted [17]. In contrast, Crume et al. [8] found no difference in BMI growth rate at 2 years, although metabolic abnormalities were present. Gascoin & Flamant [3] reported no failure to fall in weight by 2 years.

Neurodevelopmental delay was the most frequent finding, appearing in 11 studies. Sacchi et al. [1] documented cognitive delay in a large

Table 1. Summary of the results of the identified studies

First author, country, year	Study design and sample size	Age of followup	Outcomes at 2 years
González García, Spain, 2022 [31]	Retrospective/observational (513 infants < 1500 g)	2 years (corrected)	Persistent delay in growth and weight gain; malnutrition; head circumference < -2 SD
Sacchi et al., Italy, 2020 [1]	Metaanalysis (89 samples, 52,822 children)	Up to 12 years (including 2 years)	Cognitive delay
Ferguson et al., Netherlands, 2021 [11]	Prospective cohort (5,487 mother-child dyads)	Up to 6 years	High poor prognosis; language delay
Hartkopf et al., Germany, 2018 [14]	Prospective cohort (73 newborns)	24 months	Persistent delay in growth and weight gain; visual disturbances; mental retardation; neurodevelopmental delay; Psychomotor Development Index (PDI) not affected
Bellido-González et al., Spain, 2017 [20]	Retrospective cohort (5,702 infants; 64 term IUGR)	School age (6-8 years)	Cognitive and academic deficits (especially working memory)
El Ayoubi, France, 2016 [13]	Retrospective singlecenter (463 infants)	2 years	Persistent delay in growth and weight gain; psychomotor delay (fine motor); social skills affected
Crume et al., United States, 2013 [8]	Retrospective longitudinal cohort (42 IUGR, 464 unexposed)	2 years (and preadolescence)	No difference in BMI growth rate at 2 years; metabolic problems (higher insulin, lower adiponectin)
Gascoin & Flamant, France, 2013 [3]	Systematic review	Children and adults	Poor mental development; no failure to fall in weight; respiratory problems
Torrance et al., United Kingdom, 2010 [17]	Cohort (180 fetuses)	2 years	Neurological problems
von Beckerath et al., Austria, 2013 [7]	Retrospective cohort (219 IUGR vs. 299 SGA)	Longterm including 2 years	Neurodevelopmental delay; growth retardation
Ventura et al., Spain, 2022 [16]	Observational (91 cases)	3, 9, 12, 18, 24 months	Language delay; motor coordination impairment
Mohammad Jafari et al., Iran, 2024 [21]	Retrospective cohort (80 infants)	6-12 and 24 months	Growth disorders; respiratory and orthopedic problems; neurological and motor delay
Cortez Ferreira et al., Portugal, 2023 [22]	Retrospective cohort (132 newborns)	24 months (corrected)	Developmental delay; social skills affected; language and communication delay
van Wyk et al., Netherlands, 2012 [18]	DIGITAT trial (term IUGR; 650 ASQ)	Longterm including 2 years	Mental retardation; no significant differences in developmental/behavioral outcomes at 2 years; IUGR predictor of neurodevelopmental delay
Jarry et al., France, 2025 [23]	Retrospective-prospective cohort (57 children)	2 years	Fine motor impairment (3%); psychomotor delay; social skills affected

metaanalysis. Hartkopf et al. [14] reported mental retardation and neurodevelopmental delay but noted that the Psychomotor Development Index (PDI) was not affected. El Ayoubi [13] described psychomotor delay (fine motor) and impaired social skills. Study of Levine et al. [24] found fine motor impairment in 3% of children. Cortez Ferreira et al. [22] reported developmental delay, social skill impairment, and language/communication delay. Von Beckerath et al. [7] confirmed neurodevelopmental delay alongside growth retardation. Torrance et al. [17] identified neurological problems.

Language delay was highlighted by Ventura et al. [16], Torrance et al. [17], and Jarry et al. [23]. Motor coordination impairment was reported by Ventura et al. [16]. Fine motor impairment was specifically noted by El Ayoubi et al. [13] and Levine et al. [24]. Metabolic problems (higher insulin, lower adiponectin) were reported by Crume et al. [8]. Respiratory problems were noted by Gascoin & Flamant [3] and Mohammad Jafari et al. [21]. The latter also described orthopedic problems and neurological/motor delay. Visual disturbances were reported by Hartkopf et al. [14]. Two studies reported no significant differences in certain outcomes at 2 years found no difference in BMI growth rate, and van Wyk et al. [18] found no significant differences in developmental or behavioral outcomes, although IUGR was identified as a predictor of neurodevelopmental delay [19].

DISCUSSION

This systematic review of 15 studies examining outcomes of intrauterine growth restriction (IUGR) at 2 years of age reveals several important findings. First, delay in growth and weight gain persists at 2 years in many IUGR infants, although some studies suggest catchup growth may occur by that age [8, 17]. Second, neurodevelopmental, language, and motor impairments are consistently reported across diverse populations and study designs [1, 13, 14]. Third, metabolic abnormalities (e.g., hyperinsulinemia, low adiponectin) can appear as early as age 2, even in the absence of overt growth failure [8].

Comparison with other studies

Our findings are broadly consistent with those of Murray et al. [25], who conducted a systematic review of early childhood neurodevelopment after IUGR and concluded that affected children are at increased risk for cognitive and motor delays by the age of 2. Similarly, study of Longo et al. [26] reported differential effects of IUGR on neurodevelopment, with language and attention being particularly vulnerable domains

finding echoed in our review by Ferguson et al. [11] and Ventura et al. [16].

However, our review also highlights important discrepancies. For example, study of Figueras & Gratacos [19] found no significant differences in developmental or behavioral outcomes at 2 years, which contrasts with the majority of studies. Another study by Eixarch et al. [27] (not included in our 15) examined term IUGR infants at 2 years and also reported no significant cognitive deficits, suggesting that gestational age at birth and severity of growth restriction may modify outcomes. In contrast, study of Gutbrod et al. [28] found that IUGR fetuses with cerebral blood flow redistribution had significantly lower neurodevelopmental scores at 2 years, supporting the hypothesis that placental insufficiency severity is a key determinant.

Regarding growth, our finding that some IUGR infants achieve catchup weight but not height by age 2 is supported by Rapaport et al. [29], who reported that catchup growth is more common in weight than in stature. Another study by Jaddoe et al. [30] followed SGA infants to adulthood and noted that height catchup often occurs after 2 years, suggesting that our 2-year time point may be too early to detect full growth recovery.

Metabolic outcomes in our review were reported only by Crume et al. [8]. However, study of Barker [9] has extensively documented that IUGR programs later metabolic syndrome, with insulin resistance detectable as early as 2-3 years. A study by González García et al. [31] found that first trimester fetal growth restriction predicts higher blood pressure and adverse lipid profiles at age 6, reinforcing that metabolic monitoring should begin early.

Persistent growth delay

Approximately half of the included studies von Beckerath et al. [7], El Ayoubi et al. [13], Hartkopf et al. [14], and Torrance et al. [17] documented persistent growth delay at 2 years. This aligns with the concept that IUGR often leads to a reduced growth trajectory that may not fully normalize by the second year of life [2, 10]. However, Crume et al. [8] and Gascoin & Flamant [3] found no difference in BMI growth rate or weight failure at 2 years, suggesting that some IUGR infants achieve catchup growth in weight while remaining at risk for metabolic disturbances. The heterogeneity in findings may be explained by differences in IUGR severity, gestational age at birth, postnatal nutrition, and study definitions of growth delay [19]. Preterm IUGR infants may have poorer growth outcomes than term IUGR infants [32].

Neurodevelopmental and cognitive impairment

Neurodevelopmental delay was the most frequently reported adverse outcome, appearing in 11 of the 15 studies. The large metaanalysis by Sacchi et al. [1] provides highcertainty evidence that IUGR increases the risk of cognitive delay that persists beyond infancy. Hartkopf et al. [14] noted mental retardation and neurodevelopmental delay but found that the Psychomotor Development Index (PDI) was not affected, suggesting that motor development may be relatively preserved compared to cognitive and language domains. This dissociation merits further investigation and may reflect differential vulnerability of cortical regions [15, 32, 33].

Another study by Geva et al. [34] followed IUGR children to age 9 and found persistent deficits in attention and executive function, which were already detectable at 2 years. Similarly, Leitner et al. [35] reported that 10yearold IUGR children had lower IQ scores and more behavioral problems, emphasizing that early delays do not resolve spontaneously.

Language and motor impairment

Language delay was prominent in study of Ferguson et al. [11], Ventura et al. [16], and Cortez Ferreira et al. [22], aligning with evidence that IUGR preferentially affects cortical regions involved in language processing [36, 37]. Fine motor impairment was specifically reported by El Ayoubi [13] and Levine et al. [24] with the latter finding only 3% of children affected at 2 years a relatively low prevalence that may reflect milder IUGR or effective early intervention.

A study by Foster-Cohen et al. [38] examined language outcomes in very preterm IUGR infants at 2 years and found that receptive language was more affected than expressive language, a nuance not captured in our included studies. Future research should differentiate between language subdomains.

Metabolic and other systemic effects

Even at the age of 2, metabolic changes are detectable. Crume et al. [8] reported higher insulin and lower adiponectin levels in IUGR children compared to controls. This supports the fetal programming hypothesis, whereby undernutrition in utero leads to permanent changes in insulin sensitivity and adipose tissue function. Another study by Jensen et al. [39] found that IUGR was associated with a 2-fold increased risk of intellectual disability, independent of gestational age, suggesting that metabolic and cognitive programming share common pathways.

Respiratory problems noted by Gascoin & Flamant [3] and Cortez Ferreira et al. [22] may be related to impaired lung development or increased susceptibility to infections in growthrestricted

infants [40]. Visual disturbances reported by Hartkopf et al. [14] are consistent with findings from Hellström et al. [41], who documented retinopathy of prematurity and visual impairment in IUGR preterm infants.

Divergent findings and heterogeneity

Two studies reported no significant differences in certain outcomes at 2 years: study by von Beckerath et al. [7] found no difference in BMI growth rate, and study of van Wyk [18] found no significant differences in developmental or behavioral outcomes. The latter is particularly notable because it comes from a randomized trial (DIGITAT). A possible explanation is that the DIGITAT trial included only term IUGR infants (≥ 36 weeks), whereas many other studies included preterm infants. Another study by Boers et al. [42] (same trial group) confirmed that term IUGR infants have better outcomes than preterm IUGR infants, highlighting the protective effect of gestational maturity.

Clinical implications

The high prevalence of neurodevelopmental and language delay at 2 years supports the need for routine developmental surveillance of all IUGR infants beyond the first year of life [25]. Early referral to early intervention programs (physical, occupational, and speech therapy) is warranted, even if growth appears to be normalizing [40]. Additionally, metabolic monitoring (e.g., fasting glucose, insulin, adiponectin) starting at age 2 may help identify children at risk for later metabolic syndrome, although evidence-based guidelines are lacking [9]. In low and middle income countries, where the burden of IUGR is highest [5], resources for followup are often scarce, making targeted interventions even more critical.

Limitations

Several limitations should be acknowledged. First, the included studies varied considerably in design, sample size, definition of IUGR, and outcome measurement tools, precluding a metaanalysis. Second, many studies lacked a control group of appropriate for gestational age (AGA) infants. Third, publication bias may exist, as studies reporting negative outcomes are less likely to be published. Fourth, most studies were conducted in high income European countries, limiting generalizability. Fifth, the followup period of 2 years is relatively short; long-term outcomes are needed.

Moreover, the limitation of this review is its restriction to publications in English and French between 2010 and 2025, which may have excluded relevant studies in other languages. However, adherence to PRISMA guidelines ensured methodological rigor.

CONCLUSION

This systematic review of fifteen studies demonstrates that intrauterine growth restriction (IUGR) is associated with significant and persistent adverse outcomes in children at age two. Most studies have shown abnormalities in multiple areas, including developmental delays (short stature, low weight, malnutrition, and small head circumference), neurodevelopmental disorders (cognitive delay, intellectual disability, psychomotor developmental delay, and impaired social skills), language and motor disorders (language delay, poor motor coordination, and fine motor skills difficulties), and metabolic and other disorders (hyperinsulinemia, low adenosine levels, respiratory problems, and visual impairments). However, our review reported inconsistent results: one study found no difference in the rate of growth of body mass index at age two, while another reported no statistically significant differences in developmental or behavioral outcomes, although IUGR remained a predictor of neurodevelopmental delay. The discrepancies may indicate the influence of factors such as the severity of IUGR, gestational age at birth and the quality of postnatal care. Low birth weight remains the leading indicator of adverse outcomes.

Future outlook: Further research is needed to understand the developmental trajectory of children with intrauterine growth restriction (IUGR) after age two, particularly during the first few years of life when rapid growth and development occur in all areas (height, weight, cognition, etc.). Long-term, multidisciplinary follow-up (pediatrics, nutrition, and neurodevelopmental) is essential for the early detection of disorders and improved overall prognosis. Surveys and research should evaluate the impact of current interventions and care protocols. Finally, the development of targeted guidelines including maternal awareness programs and nutritional education during the first 1,000 days of a child's life can help reduce IUGR-related illnesses.

Conflict of interest:

The authors declare no conflict of interest.

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BOUNDARIES OF THE THERAPEUTIC RELATIONSHIP IN NURSING – BETWEEN EMPATHY AND EMOTIONAL BURDEN

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ABSTRACT

The therapeutic relationship is one of the fundamental components of professional nursing practice and has a significant impact on the quality of care and the effectiveness of the therapeutic process. The aim of this paper was to analyze the importance of the therapeutic relationship in nursing, with particular emphasis on the role of empathy, professional boundaries, and the problem of emotional burden among nursing staff. The article discusses the essence of the therapeutic relationship, models of its development, barriers to effective communication, and the ethical and legal aspects of maintaining professional boundaries. It also examines the consequences of excessive emotional involvement, including compassion fatigue, secondary traumatic stress, and professional burnout. Furthermore, the paper highlights the importance of preventive strategies such as developing emotional intelligence, psychological resilience, communication skills, clinical supervision, and organizational support. Maintaining compassionate engagement while preserving appropriate professional boundaries is essential for ensuring high-quality nursing care and protecting nurses' psychological well-being.

Keywords: *therapeutic relationship, nursing, empathy, professional boundaries, burnout*

INTRODUCTION

The therapeutic relationship is one of the fundamental components of professional nursing practice. Its essence lies in the conscious and purposeful establishment of contact with the patient to support the treatment process, improve the patient's well-being, and meet their health-related and psychosocial needs. Contemporary nursing encompasses not only the performance of medical procedures but also the development of a relationship based on trust, respect, and partnership. The quality of this relationship influences patient satisfaction, treatment effectiveness, and adherence to medical recommendations [1].

Effective interpersonal communication constitutes the foundation of the therapeutic relationship, enabling nurses to identify patients' needs, provide relevant information, and offer emotional support. As a member of the therapeutic team who maintains the closest contact with the patient, the nurse plays a crucial role in fostering a sense of trust and security, thereby encouraging the patient's active participation in the treatment process.

Empathy is of particular importance in the therapeutic relationship and is understood as the ability to recognize and understand another person's emotions and experiences while maintaining one's own emotional boundaries. An empathic attitude enables nurses to identify patients' needs more effectively, reduce anxiety, and strengthen their sense of dignity and security, thereby improving the quality of care and enhancing trust in the therapeutic relationship [2, 3].

At the same time, prolonged emotional involvement in caring for individuals experiencing illness and suffering may lead to psychological strain among healthcare professionals. Continuous exposure to pain, chronic illness, and patients' deaths increases the risk of compassion fatigue, emotional exhaustion, and professional burnout. Numerous studies indicate that nurses are among the occupational groups most vulnerable to these phenomena due to the nature of their work and the intensity of their relationships with patients [1, 2, 4].

In the context of increasing nursing workforce shortages and growing professional demands, maintaining a balance between an empathic approach to patient care and preserving professional

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boundaries has become one of the major challenges of contemporary nursing practice. Clearly defined therapeutic boundaries not only protect nurses' mental well-being but also contribute to maintaining a high standard of patient care [1, 4].

Despite the growing body of literature addressing individual aspects of therapeutic relationships in nursing, including empathy, professional boundaries, compassion fatigue, secondary traumatic stress, and burnout, these issues are frequently examined separately. Existing studies and reviews have predominantly focused on specific components of this complex phenomenon, such as empathy, burnout, compassion fatigue, or professional boundaries, often without considering the interrelationships between emotional involvement in patient care, the maintenance of therapeutic boundaries, and nurses' emotional well-being.

Consequently, there remains a need for an integrative perspective that brings together the relational and emotional dimensions of nursing practice. In particular, the literature provides limited synthesis of how empathy may simultaneously support the development of therapeutic relationships and, when combined with prolonged emotional involvement and difficulties in maintaining appropriate professional boundaries, contribute to emotional burden. A broader integration of these interconnected issues may therefore help to better understand the balance between therapeutic engagement and professional self-protection.

The present narrative review addresses this gap by integrating evidence on therapeutic relationships, empathy, professional boundaries, emotional burden, compassion fatigue, secondary traumatic stress, and burnout into a coherent integrative perspective. In addition, the review considers these issues across different areas of nursing practice and discusses their ethical, legal, clinical, and organizational implications. This integrative perspective may contribute to a more comprehensive understanding of the factors necessary to maintain therapeutic engagement while protecting nurses' emotional well-being and professional functioning.

The aim of this study was therefore to analyze the boundaries of the therapeutic relationship in nursing, discuss the role of empathy in establishing and maintaining therapeutic relationships with patients, and examine the problem of emotional burden among nurses together with strategies for maintaining a balance between emotional involvement and professional conduct.

METHODOLOGY OF THE NARRATIVE REVIEW

This study was conducted as a narrative literature review. The literature search was performed using the online databases PubMed and Google Scholar. In addition, the reference lists of the retrieved publications were manually screened (hand-searching) to identify further relevant sources. Current legal acts, professional organizations' documents, and classical nursing theory publications were also included. The review included scientific publications in both English and Polish addressing therapeutic relationships, therapeutic communication, person-centred care, empathy, professional boundaries, compassion fatigue, secondary traumatic stress (STS), psychological resilience, and professional burnout among nurses. Preference was given to studies published within the last decade; however, older publications were also included when they represented seminal works underpinning contemporary nursing theory or constituted current legal and professional regulations. The review primarily included systematic reviews, meta-analyses, concept analyses, original research articles, and publications presenting recommendations issued by scientific and professional organizations. Publications unrelated to the study topic, articles without full-text availability, and sources considered to have insufficient scientific quality or relevance were excluded. The main strength of the adopted search strategy was the inclusion of a wide range of scientific evidence, enabling a comprehensive analysis of the topic from clinical, ethical, and organizational perspectives. However, this study has several limitations. As a narrative review, it did not include a formal methodological quality assessment of all included studies or a quantitative synthesis of findings, both of which are characteristic features of systematic reviews.

The database selection represents a limitation of the present review. The search was limited to PubMed and Google Scholar and did not include specialized databases such as CINAHL or PsycINFO, nor multidisciplinary databases such as Scopus or Web of Science. Therefore, some relevant nursing or psychological literature may have been omitted. In addition, as a narrative review, this study did not include a formal methodological quality assessment of all included studies or a quantitative synthesis of findings. Consequently, the findings should be interpreted as a narrative and integrative overview of the available literature rather than as the results of a systematic review.

THERAPEUTIC RELATIONSHIP IN NURSING

The therapeutic relationship is one of the fundamental components of professional nursing practice. It is a deliberately established, trust-based relationship between the nurse and the patient, aimed at supporting the treatment process, improving the patient's well-being, and providing care tailored to individual needs [5]. Contemporary nursing, based on the principles of person-centered care, recognizes the therapeutic relationship as one of the most important factors influencing the quality of care and achieving positive health outcomes [6, 7].

Establishing a therapeutic relationship requires not only clinical competence but also well-developed interpersonal skills. Among the most important are effective communication, empathy, active listening, respect for the patient, and recognition of the patient's autonomy [7, 8]. These competencies enable nurses to create an atmosphere of trust and safety, encouraging patients to express their needs, concerns, and expectations regarding the treatment process. Research indicates that the therapeutic relationship develops gradually through mutual acquaintance and the development of trust; however, responsibility for maintaining its professional nature rests primarily with the nurse [9].

The therapeutic relationship differs from personal relationships in both its purpose and scope of responsibility. It is exclusively focused on the patient's well-being and the achievement of therapeutic goals, whereas personal relationships are intended to satisfy the emotional needs of both parties. Therefore, nurses are required to maintain professional boundaries that protect patients from breaches of trust while safeguarding healthcare professionals against loss of objectivity and excessive emotional involvement [10]. Professional boundaries include respecting patient confidentiality, autonomy, and dignity, avoiding personal relationships with patients, and limiting contact to that required for the therapeutic process. These principles also apply to electronic communication and social media, where nurses are expected to adhere to the same ethical standards as in face-to-face interactions [6, 10].

Mutual trust is the cornerstone of an effective therapeutic relationship and develops through the nurse's consistent, ethical, and professional conduct [7]. Patients who trust healthcare professionals are more willing to share information about their health status, actively participate in treatment, and adhere to therapeutic recommendations [7, 11]. Therapeutic communication also plays a pivotal role and is understood as a conscious, two-way process of information exchange tailored to the patient's needs,

age, and health condition. Active listening is an essential component of this process, facilitating a better understanding of the patient's concerns and promoting a relationship based on mutual respect [8, 11].

Empathy holds a particularly important place within the therapeutic relationship and is defined as the ability to understand the patient's emotions and experiences while maintaining appropriate professional emotional boundaries. An empathic attitude helps reduce patients' anxiety, enhances their sense of safety, and increases satisfaction with the care they receive [7, 12]. At the same time, maintaining a balance between empathic engagement and professional conduct is essential, as excessive emotional identification with patients' problems may contribute to emotional burden and psychological strain among nursing staff.

The therapeutic relationship plays a crucial role in ensuring high-quality nursing care. Evidence indicates that it enhances patient engagement in the treatment process, improves adherence to therapeutic recommendations, increases patient satisfaction, and strengthens the patient's sense of security [6, 7, 11]. Open communication and mutual trust also facilitate the early identification of health-related problems and reduce the risk of errors resulting from misunderstandings. Therefore, a well-developed therapeutic relationship constitutes not only the foundation of professional nursing practice but also one of the key determinants of the quality and safety of patient care.

MODELS AND STAGES OF THE THERAPEUTIC RELATIONSHIP AND BARRIERS TO ITS DEVELOPMENT

One of the most widely recognized models of the therapeutic relationship in nursing is Hildegard E. Peplau's Theory of Interpersonal Relations. Peplau regarded the nurse-patient relationship as the primary therapeutic tool, emphasizing that the effectiveness of nursing care depends not only on the clinical competence of healthcare professionals but also on the quality of their interpersonal interactions. According to Peplau [13], the nurse assumes multiple roles, including those of teacher, counselor, caregiver, and patient advocate, adapting these roles to the patient's changing health and psychosocial needs.

Peplau's model describes the therapeutic relationship as a dynamic process consisting of four stages: orientation, identification, exploitation, and resolution. The orientation stage begins with the initial encounter between the nurse and the patient and involves identifying the patient's problems, needs, and expectations. During the identification stage, mutual trust develops, and the patient gradually becomes actively engaged in the therapeutic process. The exploitation stage is characterized by the patient's

active collaboration with healthcare professionals and the effective use of available healthcare resources and support. The final stage, resolution, occurs when the established therapeutic goals have been achieved or the treatment process has been completed. Successful progression through all four stages promotes a collaborative partnership and enhances the effectiveness of the therapeutic process [6, 13].

The development of a therapeutic relationship may be hindered by numerous barriers related to the patient, healthcare professionals, and the organization of care. The most frequently reported obstacles include time constraints, excessive workload, staff shortages, and high levels of occupational stress among healthcare personnel. In addition, ineffective communication, inadequate active listening, the use of medical terminology that is difficult for patients to understand, and insufficient attention to patients' emotional needs may negatively affect the quality of the therapeutic relationship [5, 6].

Patient-related factors also constitute important barriers to establishing an effective therapeutic relationship. These include severe anxiety, pain, cognitive impairment, communication difficulties, and cultural or language differences. Contemporary person-centered care models emphasize the need to adapt communication strategies to the patient's individual abilities and circumstances while fostering a relationship based on mutual respect and partnership [5]. Reducing communication barriers and strengthening nurses' interpersonal competencies contribute to increased patient trust, improved therapeutic collaboration, and better treatment outcomes [5, 6, 10].

THE ROLE OF EMPATHY IN PATIENT CARE

Empathy is one of the fundamental interpersonal competencies of nurses and represents a cornerstone of professional patient care. It is defined as the ability to understand another person's emotions, needs, and experiences and to respond to them appropriately. The literature distinguishes between cognitive empathy, which involves understanding the patient's perspective, and affective (emotional) empathy, which refers to sharing or resonating with the patient's emotional experiences. In nursing practice, maintaining an appropriate balance between these dimensions is essential, as it enables nurses to provide effective support while preserving professional emotional boundaries [14, 15].

It is important to distinguish empathy from other forms of emotional involvement that may have different implications for nurses' occupational well-being. Empathy involves understanding another person's

emotional experience while maintaining an appropriate distinction between oneself and the other person [2, 3]. In contrast, excessive affective involvement or over-identification with a patient may be associated with difficulties in maintaining appropriate emotional and professional boundaries [9]. Such processes should not be equated with empathy itself, as emotional burden may be more closely related to excessive emotional involvement and prolonged exposure to patients' suffering than to empathy per se [1, 2, 4]. These factors may contribute to compassion fatigue and other adverse consequences for nurses' occupational well-being, particularly when appropriate emotional and professional boundaries are difficult to maintain [1, 4, 9].

Empathy should not be confusing with compassion. Whereas compassion involves an emotional response to another person's suffering, empathy primarily enables healthcare professionals to understand the patient's situation from the patient's perspective and to adapt communication and supportive interventions accordingly [14]. This allows nurses to identify patients' needs more effectively, foster an atmosphere of trust and security, and encourage patients' active participation in the therapeutic process.

Research has demonstrated that higher levels of empathy among nursing staff are associated with improved interpersonal communication, greater patient trust, and higher perceived quality of nursing care [16]. An empathic approach also helps alleviate anxiety, feelings of helplessness, and uncertainty commonly experienced during hospitalization and chronic illness. Empathy is particularly important in the care of patients with cancer, terminal illnesses, or chronic conditions, where communication often involves difficult issues such as poor prognosis, severe pain, or approaching end of life [17, 18].

Effective empathic communication requires active listening, acceptance of patients' emotions, and the adaptation of information to their individual needs and abilities. Behaviors such as interrupting patients, making judgments, or minimizing their concerns hinder the development of a therapeutic relationship and may weaken patients' trust in healthcare professionals [17].

Empathy is therefore not only an essential interpersonal competency but also a key determinant of high-quality nursing care. It facilitates the establishment of therapeutic relationships, enhances communication with patients, and strengthens patients' sense of safety and satisfaction with the care they receive. At the same time, empathic practice should be accompanied by adequate emotional regulation and the maintenance of professional boundaries, which help prevent excessive affective involvement, emotional over-identification, and other forms of maladaptive emotional responding that may contribute to psychological burden.

PROFESSIONAL BOUNDARIES: BOUNDARY CROSSINGS AND BOUNDARY VIOLATIONS

Professional boundaries define the framework of the therapeutic relationship between nurses and patients, helping to protect patients, nurses, and the integrity of professional practice. Maintaining appropriate professional boundaries does not require emotional detachment from the patient. Rather, contemporary person-centered nursing emphasizes compassionate engagement combined with role clarity, self-awareness, emotional regulation, and awareness of appropriate professional limits. However, not every departure from usual professional boundaries should be considered a boundary violation. A distinction may be made between boundary crossings and boundary violations. A boundary crossing refers to a departure from usual professional practice or relational limits that should be evaluated within its specific clinical and therapeutic context. Its significance may depend on its purpose, the patient's needs and vulnerability, the professional relationship, and the potential risks involved.

In contrast, a boundary violation involves conduct that exceeds appropriate professional limits and may create a risk of harm, exploitation, or the misuse of the inherent power imbalance within the therapeutic relationship. Boundary violations may include exploiting a patient's dependency to satisfy the nurse's own emotional, personal, financial, or other needs, engaging in emotionally or romantically intimate relationships, accepting inappropriate financial benefits, or other conduct that compromises the professional purpose of the relationship [9, 19].

Although some boundary violations may develop gradually as the distinction between therapeutic and personal relationships are becoming blurred, boundary crossings should not automatically be equated with boundary violations. The assessment of a boundary crossing should take into account its therapeutic purpose, the clinical context, the patient's vulnerability, and whether there is a potential risk of exploitation or harm [9, 10, 19].

Crossing professional boundaries has significant ethical implications. The primary concern is the loss of professional objectivity and a diminished ability to make decisions solely in the patient's best interest. Such violations may lead to a loss of patient trust, feelings of exploitation or unequal treatment, and breaches of the fundamental ethical principles of nursing, including respect for autonomy, dignity, beneficence, and justice [9, 20].

Violations of therapeutic boundaries may also result in legal and professional consequences. Nurses are required to comply with regulations governing professional practice, maintain patient confidentiality,

and respect patients' rights. Failure to fulfill these obligations may result in disciplinary proceedings before professional regulatory bodies, civil liability, or, in certain circumstances, criminal responsibility. Maintaining professional boundaries is therefore not only an ethical obligation but also a legal requirement established by applicable laws and professional regulations [20, 21].

The rapid development of social media and electronic communication has introduced additional challenges for nursing professionals. Social networking platforms, instant messaging applications, and private online communication create new opportunities for interaction with patients while simultaneously increasing the risk of blurred professional boundaries. Behaviors considered unprofessional include establishing personal relationships with patients through social media, sharing information that could identify a patient, or providing professional consultations through private online accounts. Professional organizations emphasize that the ethical standards governing face-to-face interactions must be applied equally in digital environments [10, 19].

The acceptance of gifts from patients also raises important ethical concerns. Small tokens of appreciation with symbolic value are generally not considered unethical when they simply express gratitude for the care provided. However, accepting expensive gifts, money, or other material benefits may create conflicts of interest, undermine public trust in healthcare professionals, and give the impression of preferential treatment. In such situations, nurses should follow applicable legislation, professional codes of ethics, and the internal policies of their healthcare institutions [20].

Similar concerns apply to maintaining relationships with patients after the formal therapeutic relationship has ended. Although such relationships may appear harmless in certain circumstances, the literature emphasizes that transitioning from a professional to a personal relationship requires careful consideration and a thorough assessment of the potential risk of compromising professional boundaries. Maintaining clear professional boundaries and role clarity helps protect both the patient and the nurse while contributing to patient safety and the integrity of the professional relationship [9, 10].

CONSEQUENCES OF EXCESSIVE EMOTIONAL INVOLVEMENT

Nursing is a profession characterized by continuous exposure to patients' suffering, pain, disability, and death. Emotional involvement, an inherent component of the therapeutic relationship, may gradually deplete healthcare professionals' psychological resources.

The literature emphasizes that prolonged exposure to occupational stressors increases the risk of developing chronic stress, compassion fatigue, secondary traumatic stress (STS), and professional burnout [1, 4].

Occupational stress is a natural response to the demands associated with professional responsibilities. In nursing, its primary sources include the high level of responsibility for patients' health and lives, the need to make rapid decisions under time pressure, staff shortages, and frequent exposure to suffering and death. While short-term stress may enhance performance and motivation, persistent stress often progresses into chronic stress, negatively affecting both the psychological and physical well-being of healthcare professionals [4, 22].

Chronic stress commonly manifests as fatigue, sleep disturbances, irritability, impaired concentration, low mood, and reduced physical and mental performance. Persistent emotional overload may subsequently contribute to the development of compassion fatigue and professional burnout [1].

For the purposes of this review, burnout, compassion fatigue, and secondary traumatic stress are treated as conceptually related but distinct phenomena. However, the boundaries between compassion fatigue and secondary traumatic stress are not always clearly defined in literature, and these terms may partially overlap or be used differently across studies [1]. In the present review, burnout is understood primarily as an occupational phenomenon associated with chronic workplace stress, whereas compassion fatigue and secondary traumatic stress are discussed in relation to the emotional consequences of prolonged exposure to patients' suffering and traumatic experiences [1, 21]. This distinction is intended to provide conceptual clarity while acknowledging the overlap and ongoing debate surrounding these constructs.

Compassion fatigue, often described in literature as the "cost of caring," is a specific form of psychological and physical exhaustion resulting from continuous empathic engagement with individuals experiencing suffering. Its development is closely associated with deep empathic involvement and indirect emotional exposure to patients' traumatic experiences. Although secondary traumatic stress is commonly associated with indirect exposure to traumatic experiences, its conceptual boundaries with compassion fatigue are not always clearly defined. In some studies, these constructs partially overlap or are discussed using closely related terminology. In this review, secondary traumatic stress is used primarily to describe trauma-related symptoms resulting from indirect exposure to another person's traumatic experiences, while compassion fatigue is discussed as a broader form of emotional and psychological burden associated with prolonged exposure to patients' suffering

[1, 23]. Clinical manifestations include cognitive exhaustion, emotional desensitization to patients' suffering, feelings of helplessness and isolation, impaired decision-making, and reduced professional satisfaction. Evidence indicates that nurses constitute one of the occupational groups at greatest risk of compassion fatigue, particularly those working in emergency departments, oncology, palliative care, and mental health services, where regular exposure to patients' distress is an integral part of daily clinical practice [1, 2].

Secondary traumatic stress (STS) refers to a constellation of symptoms resulting from indirect exposure to traumatic events experienced by others. Nurses who regularly witness patients' traumatic experiences, severe illness, or sudden loss may develop symptoms resembling post-traumatic stress disorder (PTSD). These symptoms include intrusive thoughts or memories, persistent hyperarousal, and avoidance of reminders associated with the traumatic event [24]. Unlike compassion fatigue, which develops primarily through prolonged empathic engagement, secondary traumatic stress is more directly associated with exposure to patients' traumatic experiences and the emotional intensity of those events.

Professional burnout is a syndrome resulting from chronic workplace stress that has not been successfully managed. According to the World Health Organization (ICD-11), burnout is characterized by three core dimensions: emotional exhaustion, depersonalization or increased mental distance from work, and a reduced sense of professional accomplishment [22]. In contrast to compassion fatigue, burnout develops gradually and is primarily associated with organizational factors such as excessive workload, inadequate managerial support, limited professional autonomy, and persistent staff shortages.

The manifestations of burnout include persistent fatigue, loss of motivation, cynicism toward patients, reduced work performance, and deterioration in the quality of healthcare services. Studies have demonstrated that burnout significantly increases the risk of sickness absence, staff turnover, and compromised patient safety [1, 22].

The factors associated with emotional burden and adverse occupational outcomes among nurses are multifactorial. Available evidence indicates that occupational factors such as prolonged exposure to patients' suffering and death, excessive workload, staff shortages, shift work, insufficient organizational support, and limited opportunities for psychological recovery may contribute to chronic occupational stress and emotional burden. Individual factors, including low psychological resilience, excessive affective involvement, emotional contagion, empathic distress, over-identification with patients, and

difficulties in maintaining appropriate professional boundaries, may also be associated with increased vulnerability. However, the relative contribution of these factors may vary across clinical settings and individual circumstances [4, 23]. Individual factors that may further increase vulnerability to emotional exhaustion include perfectionism, low psychological resilience, excessive affective involvement, emotional contagion, empathic distress, over-identification with patients, and difficulties in maintaining appropriate professional boundaries [4, 23]. These factors should be distinguished from empathy itself, which, when combined with adequate emotional regulation and clear professional boundaries, constitutes an important component of effective and patient-centered nursing care.

The consequences of excessive emotional involvement extend beyond psychological well-being and affect both physical health and professional functioning. Common outcomes include chronic fatigue, sleep disturbances, anxiety, depressive symptoms, somatic complaints, and reduced job satisfaction. Prolonged emotional burden has been associated with adverse psychological and occupational outcomes, including chronic fatigue, sleep disturbances, anxiety and depressive symptoms, reduced job satisfaction, sickness absence, and impaired professional functioning. However, the available evidence is heterogeneous, and the relative contribution of emotional burden to these outcomes may be influenced by occupational, organizational, and individual factors. Emotional burden may also be associated with difficulties in maintaining concentration, decision-making, and empathic, patient-centered care, although the nature and magnitude of these effects may vary across clinical and organizational contexts. Consequently, the prevention and early recognition of emotional burden may represent important components of efforts to protect nurses' mental well-being and support the delivery of safe, high-quality patient care.

PROTECTING THERAPEUTIC BOUNDARIES

Maintaining professional boundaries within the therapeutic relationship requires not only adherence to ethical principles but also the continuous development of nurses' personal competencies and the provision of appropriate organizational support. Preventive strategies aimed at reducing emotional burden among nurses can be broadly divided into individual-level and organizational-level interventions. However, the strength and consistency of the available evidence supporting these approaches are not uniform. While some interventions, particularly structured

organizational and educational approaches, have been evaluated in systematic reviews and meta-analyses, the evidence supporting other strategies remains limited or heterogeneous. Therefore, the potential benefits of individual and organizational interventions should be interpreted with consideration of the quality and consistency of the available evidence [1, 2].

Individual-level strategies

At the individual level, emotional intelligence, self-awareness, psychological resilience, mindfulness, and effective coping strategies may support nurses in managing emotional demands and maintaining appropriate professional boundaries.

Emotional intelligence may represent an important factor supporting the management of emotional involvement in nursing practice. It can be understood as the ability to recognize, understand, regulate, and appropriately express one's own emotions while effectively responding to the emotions of others. Higher emotional intelligence may support nurses in maintaining professional distance, making sound clinical decisions, and establishing empathic relationships without compromising objectivity [3, 6].

Closely related to emotional intelligence is self-awareness, which may enable nurses to recognize their own emotional responses, personal limitations, and early signs of psychological overload. Regular self-reflection may facilitate the early identification of stress and emotional burden, allowing preventive measures to be considered before more serious consequences develop [2, 25].

In recent years, increasing attention has been paid to the role of psychological resilience as a potential protective factor against the adverse effects of chronic occupational stress. Resilience refers to the ability to adapt effectively to challenging situations and recover from adversity. Higher levels of psychological resilience have been associated with lower levels of occupational distress, burnout, and compassion fatigue, as well as greater job satisfaction and psychological well-being among nurses. However, the available evidence should be interpreted cautiously, as the strength and design of studies vary and causal conclusions cannot always be drawn [26, 27]. Strategies aimed at strengthening resilience may include the development of effective coping skills, promoting social support networks, and enhancing self-efficacy.

Mindfulness-based interventions have also received growing attention as a potentially supportive approach to improving healthcare professionals' well-being. Regular mindfulness practice has been associated with reduced stress levels, improved emotional regulation, and enhanced psychological well-being among healthcare workers. However, the magnitude and consistency of these effects may vary depending

on the type, duration, and intensity of the intervention, as well as the characteristics of the study population [28]. Mindfulness should therefore be considered a potentially supportive component of prevention rather than a universally effective intervention.

Preventive strategies at the individual level may also include maintaining a healthy work-life balance, encompassing adequate rest, regular physical activity, supportive social relationships, and attention to personal well-being. The ability to maintain an appropriate separation between professional and personal life may support psychological recovery and reduce prolonged exposure to occupational stressors [26, 28]. However, individual-level strategies should not be regarded as sufficient measures when adverse working conditions remain unaddressed.

Organizational-level strategies

Organizational-level interventions are essential because many factors contributing to emotional burden and burnout, including excessive workload, staff shortages, limited professional autonomy, and insufficient managerial support, cannot be adequately addressed through individual coping strategies alone.

Workplace-based support interventions such as clinical supervision and structured debriefing may provide nurses with opportunities to reflect on emotionally challenging clinical situations and receive professional and psychological support. Clinical supervision provides opportunities to reflect on challenging clinical experiences under the guidance of an experienced supervisor and may support professional development and the management of emotional burden [29]. Its effectiveness, however, may depend on factors such as the structure, frequency, accessibility, and quality of supervision, as well as the broader organizational context in which it is implemented.

Similarly, in the present review, structured debriefing refers to a facilitated, team-based reflective discussion conducted after emotionally challenging or critical clinical events, such as an unexpected patient death. Its purpose is to provide an opportunity for members of the healthcare team to reflect on the event, share experiences, discuss immediate emotional reactions, and promote communication and mutual support. Such an approach may provide support following challenging clinical events; however, its potential benefits may depend on the specific format, timing, facilitation, and intended purpose of the intervention. Structured reflective debriefing should therefore not be considered equivalent to all forms of post-event psychological intervention, and its effectiveness should not be assumed to be uniform across different types of debriefing [30].

The work environment itself has a significant influence on nurses' psychological well-being and their ability to maintain appropriate therapeutic boundaries. Positive teamwork, opportunities for professional reflection, and peer support may help reduce occupational stress and promote psychological resilience [2]. Leadership also plays an important role. Nurse managers may contribute to the prevention of emotional burden by monitoring workload, supporting professional development, and fostering an organizational culture that encourages open communication and allows staff to discuss emotional challenges without fear of stigma or negative consequences [26].

Educational interventions represent another potentially beneficial approach to strengthening nurses' professional competencies. Training programmes focusing on therapeutic communication, stress management, emotional intelligence, and professional boundary setting may improve interpersonal skills and professional confidence. However, the long-term effects of such interventions on emotional burden, compassion fatigue, secondary traumatic stress, and burnout may vary depending on the content and duration of the intervention and the characteristics of the study population [5, 6].

Organizational support should also include measures aimed at addressing structural sources of occupational stress. Appropriate staffing levels, workload management, supportive leadership, access to psychological support, opportunities for professional development, and the promotion of a supportive workplace culture may help reduce factors contributing to chronic occupational stress. Importantly, individual-level interventions should not be considered substitutes for organizational measures aimed at improving working conditions.

Overall, protecting therapeutic boundaries and preventing emotional burden in nursing is likely to require a comprehensive and multilevel approach integrating individual competency development with appropriate organizational support. Individual strategies, including the development of emotional intelligence, self-awareness, psychological resilience, mindfulness, and effective coping skills, may support nurses in managing emotional demands. At the same time, organizational measures are necessary to address workplace conditions that contribute to chronic occupational stress. Although the available evidence suggests potential benefits of several preventive approaches, the strength and consistency of this evidence vary across interventions and study populations. Preventive recommendations should therefore be formulated cautiously, implemented in accordance with the available evidence, and tailored to the specific organizational and clinical context.

THE IMPORTANCE OF THE THERAPEUTIC RELATIONSHIP ACROSS DIFFERENT NURSING SPECIALTIES

The therapeutic relationship is a fundamental component of professional nursing practice and an important determinant of the quality of healthcare services. Although its core elements, including trust, empathy, effective communication, and appropriate professional boundaries, are relevant across all areas of nursing, the nature of the therapeutic relationship differs depending on the clinical setting. These differences are particularly evident in the intensity and duration of contact, the clinical context, and the specific emotional challenges associated with patient care.

In psychiatric nursing, the therapeutic relationship often constitutes an integral part of the treatment process and may be characterized by substantial emotional intensity and prolonged interpersonal contact. Patients may experience anxiety, social isolation, and difficulties in establishing interpersonal relationships; therefore, trust, acceptance, and effective communication are particularly important [31]. At the same time, the emotional intensity of these relationships may increase the importance of role clarity, self-awareness, emotional regulation, and appropriate professional boundaries [32, 33].

In palliative care, the therapeutic relationship is shaped by prolonged exposure to advanced illness, suffering, and the end-of-life period. Nurses frequently provide support not only to patients but also to their families, which may further increase the emotional complexity of care [34, 35]. In this context, the main challenge is not only the intensity of individual interactions but also the cumulative emotional impact of repeated exposure to suffering, loss, and death, which may contribute to compassion fatigue and emotional exhaustion [34-36].

Nursing oncology is also frequently characterized by long-term and repeated contact, although the therapeutic relationship develops within the context of ongoing treatment, uncertainty regarding prognosis, and changing patient needs. Nurses often combine caregiving, educational, and emotional support roles, assisting patients and their families throughout different stages of the disease and treatment [37, 38]. Compared with palliative care, the emotional burden may be associated not only with suffering and loss but also with prolonged uncertainty and repeated exposure to the consequences of serious illness and treatment [35, 37].

In geriatric nursing, the therapeutic relationship is particularly influenced by the long-term nature of care and the complex needs associated with multimorbidity, functional decline, loneliness, and loss of independence.

Repeated and prolonged interactions may promote the development of strong interpersonal bonds, while also requiring sustained attention to professional role clarity and the regulation of emotional involvement [31-33]. The challenge in this setting therefore relates primarily to maintaining an individualized and supportive relationship over an extended period without allowing professional and personal boundaries to become blurred.

By contrast, critical care and intensive care nursing are characterized by high clinical intensity but often more limited opportunities for the gradual development of long-term therapeutic relationships. Life-threatening conditions, rapidly changing clinical situations, and the need for immediate decision-making may place considerable emotional and professional demands on nurses [32, 33]. In this setting, emotional burden may arise less from the duration of individual relationships and more from the acute nature of clinical events, high levels of responsibility, and frequent exposure to death and critical incidents.

A comparative perspective therefore indicates that the challenges associated with therapeutic relationships are not uniform across nursing specialties. Psychiatric and geriatric nursing may involve particularly sustained interpersonal contact and greater potential for the development of close relational bonds. Palliative and oncology nursing are characterized by prolonged exposure to serious illness, suffering, uncertainty, and, in many cases, death. In contrast, critical care nursing is distinguished by the acute intensity of clinical situations, even when the duration of individual therapeutic interactions is relatively limited. Thus, while empathy and compassionate engagement are important across all nursing specialties, the factors contributing to emotional burden and the challenges associated with maintaining appropriate professional boundaries vary according to the intensity, duration, context, and emotional demands of the therapeutic relationship.

Understanding these differences is important when considering strategies to support nurses' professional functioning and psychological well-being. Preventive approaches should therefore take into account the specific characteristics of different clinical settings rather than assuming that the same strategies are equally applicable across all areas of nursing practice.

CONCLUSIONS

1. The therapeutic relationship, founded on trust, effective communication, and respect for the patient's dignity and autonomy, is widely recognized as an important component of professional nursing practice. The literature reviewed suggests that the quality of this relationship may be associated with

patient engagement, perceived safety, and selected aspects of the care process.

2. Empathy appears to be an important competency in nursing and may facilitate the recognition of patients' needs and the development of trust within the therapeutic relationship. However, empathy should be distinguished from excessive affective resonance, emotional contagion, empathic distress, and over-identification with patients. Maintaining appropriate professional boundaries and emotional self-awareness may help nurses engage compassionately with patients while reducing the risk of excessive emotional involvement.
3. The literature reviewed suggests that appropriate professional boundaries may contribute to the protection of both patients and nurses within the therapeutic relationship. Boundary crossings should be interpreted in relation to their therapeutic purpose, clinical context, patient vulnerability, and potential risks, whereas boundary violations may be associated with ethical, legal, and professional consequences and may undermine the quality and integrity of care.
4. Prolonged exposure to patients' suffering, multimorbidity, and death has been associated with emotional and occupational burden among nurses, including compassion fatigue, secondary traumatic stress, and burnout. However, the reviewed literature indicates that these outcomes are multifactorial and may also be influenced by organizational conditions, workload, available support, individual characteristics, and the specific clinical context. Their potential consequences for nurses' well-being and professional functioning may therefore vary across settings.
5. The available literature suggests that both individual- and organizational-level interventions may support the prevention or reduction of emotional burden among nurses. Strategies aimed at strengthening self-awareness, emotional regulation, and psychological resilience may be beneficial for some nurses, while organizational measures such as supportive working conditions, access to clinical supervision, and structured opportunities for reflection may also play an important role. However, the strength and consistency of the available evidence vary across intervention types, and no single strategy can be considered universally effective.
6. Overall, the literature reviewed supports the importance of balancing compassionate, patient-centered engagement with role clarity, self-awareness, emotional regulation, and appropriate professional boundaries. Such a balance may support nurses' psychological well-being and professional functioning while contributing to the

provision of safe, ethical, and patient-centered care. Given the narrative nature of the present review and the heterogeneity of the available evidence, these conclusions should be interpreted cautiously. Further high-quality research is needed to clarify the relationships between empathy, emotional involvement, professional boundaries, and occupational outcomes, as well as the effectiveness of preventive interventions across different areas of nursing practice.

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LEAD POISONING AMONG CHILDREN IN NIGERIA: A REVIEW OF EVIDENCE, GAPS, AND INTERVENTIONS

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ABSTRACT

Lead poisoning is a public health problem with a long-term impact on children globally. Nigerian children, in particular, are exposed to elevated blood lead levels (BLLs) from artisanal mining, unofficial battery recycling, occupational take-home contamination, leaded paint, legacy leaded gasoline pollution, and many other sources of pollution, despite decades of progress worldwide. This review provides information on the epidemiology, causes, health consequences, and prevention of pediatric lead poisoning in Nigeria, including children under five years of age, who are most impacted by lead neurotoxic effects.

We then synthesized the relevant studies narratively. Exposure context was a significant determinant of reported BLLs. Urban communities without point sources had geometric means of around 4-16 µg/dL, with a few above 10 µg/dL; artisanal-mining groups had means of 35-119 µg/dL, with a typical level of 45 µg/dL. The risks of uncontrolled exposure were highlighted by the 2010-2013 Zamfara mining disaster, which resulted in about 400 child deaths and a median BLL of 119 µg/dL in the most affected area.

Children of workers are also at risk of contamination from Nigeria's vast informal industry, which includes battery recycling, painting and metalworking. Neurodevelopmental damage, anemia, growth retardation, renal failure and, at high exposures, mortality are among the health effects. Systematic prevention is hampered by inadequate infrastructure, poverty, and lax regulation despite chelation therapy, environmental remediation, workplace safety measures, and community education.

Keywords: *lead poisoning, children, Nigeria, blood lead level, artisanal mining, environmental health*

INTRODUCTION

Childhood lead poisoning is a preventable environmental health challenge of the twenty-first century [1]. Lead, a cumulative toxicant, has no known safe exposure limits. Levels as low as 3.5 µg/dL have been linked to impaired learning, cognitive, and behavioral problems in children [1, 2]. Children absorb 40 to 50% of ingested lead compared to 10% in adults, making them vulnerable to acute and lifelong poisoning [3]. Global-burden-of-disease models show that low- and middle-income countries (LMICs), especially Nigeria, bear most of the burden [2].

In Nigeria, millions earn a living in fast-growing informal lead-related jobs (painting, battery recycling,

artisanal mining, smelting, auto repair, etc.), frequently without safety regulations or protective equipment [4]. The 2010-2013 Zamfara crisis, the deadliest documented artisanal pediatric lead poisoning, brought Nigeria's lead problem to global attention and exposed critical failures in environmental health surveillance and emergency response [5, 6].

Growing evidence indicates sources other than mining. In one cluster survey in Jos, Nigeria, 70% of young children exceeded the 10 µg/dL action threshold [7, 8]. Children of lead-exposed workers have high blood lead levels (BLLs), suggesting exposure at home [9]. Higher-than-safe BLLs have been found in household dust, soil, water, and food through environmental sampling. Paint assessments show

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that most decorative paints exceed the WHO/UNEP 90 ppm guidelines, with solvent-based home-use paints exceeding by 74% [10].

Childhood lead exposure has multi-organ and multi-system clinical implications. Neurodevelopmental effects at 5 µg/dL include lower IQ, executive function, attention, and behavior [3, 11]. Hundreds of children developed acute encephalopathy, coma, and seizures at Zamfara's extreme exposures [5, 12]. Other effects include anemia due to lower haem production, nutritional impairment, and renal and cardiovascular complications.

Despite these complications, there is a lack of coordination on prevention: there is no monitoring and very few children at risk are being tested, regulatory frameworks are underfunded and poorly implemented, and intervention research is very limited. Low awareness of lead risks is widespread among the general public and health professionals. Because most vulnerable children are aged 5 years and younger, we present evidence to inform policy, practice, and research to address this problem. Our goals are to: (1) identify exposure prevalence and sources; (2) summarize health effects; (3) evaluate the effectiveness of interventions; (4) identify gaps; and (5) provide a framework for this preventable tragedy.

METHODS

Search strategy

We searched PubMed, Google Scholar, Web of Science, African Journals Online, and the WHO Global Health Library for studies on lead poisoning in Nigerian children from January 2004 to February 2025. Exposure and outcome concepts were combined (lead poisoning, lead exposure, blood lead, lead toxicity) with particular contexts (artisanal mining, battery recycling, occupational exposure, environmental contamination, leaded paint, leaded petrol) and geographical and age focus (Nigeria; children, pediatric, under-five, infants). Reference lists were manually searched, and WHO regional office reports, international NGO publications, and Nigerian government health ministry websites were used to search for gray literature.

Eligibility criteria

Studies that: (1) included Nigerian children under 18; (2) measured BLLs or assessed exposure through environmental sampling; (3) looked at health outcomes related to lead; (4) described interventions or policies; or (5) provided relevant contextual information on sources and pathways were included. Studies limited to adults, conducted outside Nigeria, lacking original data, or not available in English were excluded.

Study selection and data extraction

Two reviewers independently screened titles and abstracts, and then assessed the full texts. They resolved disputes by discussion and summarized the data flow in Figure 1. We extracted study characteristics, the sample age range, the BLL measurement method and its values, exposure sources, health outcomes, and interventions using a standardized form completed independently by two reviewers.

Synthesis and quality assessment

We grouped studies by exposure source, region, health outcome, and intervention type using narrative synthesis and not meta-analysis because of the diverse study designs, populations, and settings. Using criteria modified from the Newcastle-Ottawa Scale and the Cochrane Risk-of-Bias tool, we considered representativeness, exposure and outcome assessment, adjustment for confounding, and analysis to judge the quality of evidence. Higher-quality evidence was given more weight, and limitations were emphasized.

EPIDEMIOLOGY OF CHILDHOOD LEAD EXPOSURE IN NIGERIA

Figure 2 is a schematic presentation of the distribution of lead poisoning in Nigeria. Symbols distinguish artisanal-mining areas with documented outbreaks or high exposure (e.g., Zamfara and Niger states), occupational-exposure studies (e.g., Lagos, Ibadan, and Kano), urban environmental studies without specific point sources, and intervention sites. The map illustrates the geographic concentration of research in south-western Nigeria and Zamfara State, with large areas of the country unstudied.

Overview of blood lead levels

Major studies are presented in Table 1. Study results vary widely across sources, contexts, and populations. Typically, geometric means are 4-16 µg/dL in urban populations without high-intensity sources, and most are much higher [8, 13] than in high-income countries (i.e., less than 2 µg/dL), indicating that background exposure is still high even without point sources. The levels are even higher where there are sources: children in mining villages have an average of 35-119 µg/dL, some have much higher values than that, and many are in need of urgent chelation [5, 6]; children of occupationally exposed parents have an average of several-fold higher means [9], and there is a difference between the 18-35 µg/dL recorded from informal battery recycling or smelting [14]. Only a few years of longitudinal data are available, and there is no reliable way to know time-series trends. Nigeria's leaded-gasoline phase-out in 2008 probably reduced exposure from that source, but mining, informal

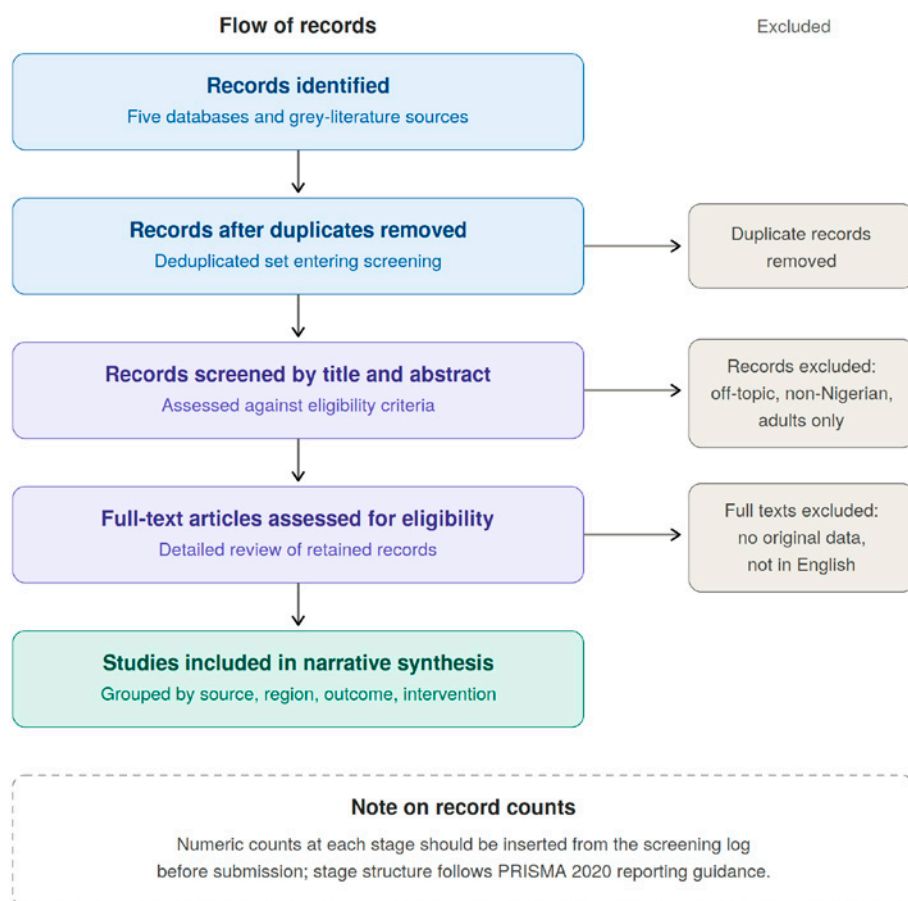


Figure 1. Flow of records through the review (PRISMA-style diagram)

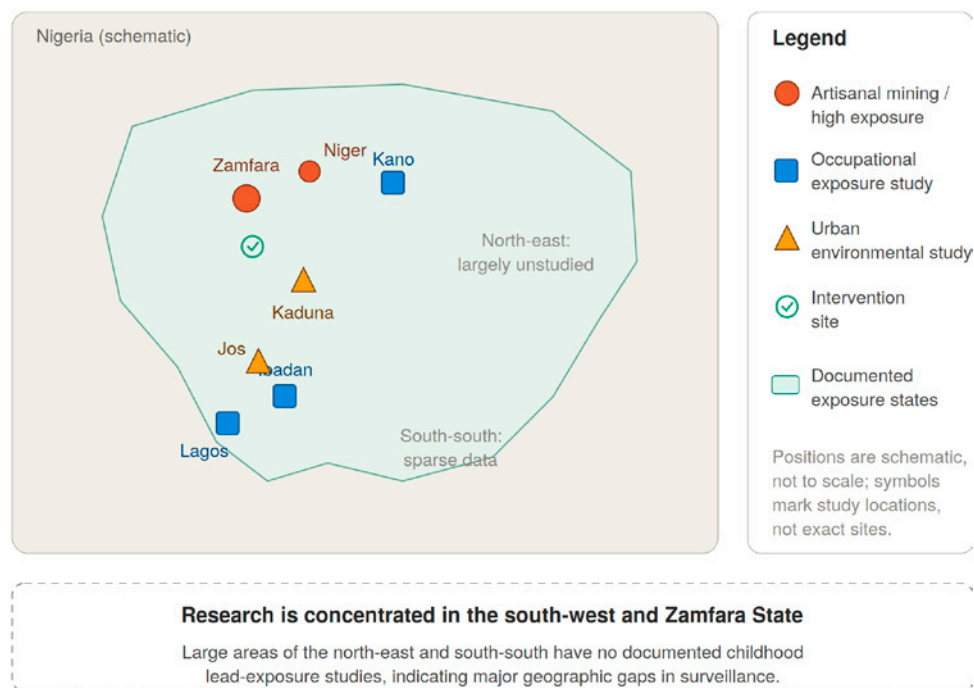


Figure 2. Geographic distribution of documented childhood lead-exposure studies in Nigeria, 2004-2025

Sources: Most Nigerian studies included in this review (1997-2025), especially [5-13, 15-18, 20, 21] (see references). Symbols distinguish artisanal-mining sites with documented outbreaks (triangles), occupational exposure studies (circles), urban environmental studies (squares), and intervention site (marked). Geographic locations are approximate; the map is a schematic representation only and does not reflect official administrative boundaries.

Table 1. Summary of blood lead studies in Nigerian children

Study	Location	Year	N	Age range (yr)	Design/exposure	GM or median BLL (µg/dL)	% ≥ 10 µg/dL	Key findings
Dooyema et al. [5]	Zamfara State	2010	204	0-5	Cross-sectional; artisanal gold mining	Median 119	~100%	Outbreak investigation; > 400 deaths
Tirima et al. [6]	Zamfara (Bagega)	2011-2013	535	0-10	Longitudinal; artisanal gold mining	71 (pre-remediation)	91.4%	~74% BLL reduction after remediation
Greig et al. [12]	Zamfara State	2010-2011	972	≤ 5	Retrospective; artisanal gold mining	All ≥ 45 (inclusion)	100%	Neurological features linked to higher BLL
Wright et al. [7]	Jos	2003-2004	275	0.5-3	Cross-sectional, urban environmental	Mean 8.7 ± 5.7 µg/dL	~70%	Car ownership/tarred-road residence key risks
Adebamowo et al. [8]	Lagos/Ibadan	2005	40	1-5	Cross-sectional, urban environmental	NR (a qualitative study)	NR	Knowledge, attitudes, and exposure risk factors
Nriagu et al. [9]	Kaduna	1995	87	1-6	Cross-sectional; urban/traffic	Mean 10.6	NR, but 2% > 30 µg/dL	Highest in 5-year-olds

NR – not reported; BLL – blood lead level; GM – geometric mean. Dashes indicate values not reported. The Zamfara median of 119 µg/dL refers to Bagega at outbreak; the Tirima et al. [6] figure is a pre-remediation cohort value.

recycling, occupational exposure, and leaded paint are still present and could appear to be increasing or getting worse; therefore, if we do not get enough information, we cannot predict trends clearly.

Zamfara mining disaster

The most severe recorded childhood lead poisoning event occurred in Zamfara State from 2010 to 2013. Artisanal gold ore, rich in lead sulfide, was crushed in or next to homes, contaminating soil, dust, water, and food [6]. Investigations by the Nigerian government and MSF revealed lead poisoning; the first deaths were reported in March 2010, and over 400 child deaths were eventually recorded [5].

The median BLL in Bagega was 119 $\mu\text{g/dL}$ (range 10–320 $\mu\text{g/dL}$), and most children were at least 45 $\mu\text{g/dL}$ at the chelation level [5]. Soil lead levels exceeded 150,000 ppm in compounds and were far above the US EPA residential soil guideline of 400 ppm, which is used here as an internationally recognized benchmark, with no enforced Nigerian standard [5, 6].

Seizures, altered awareness, acute encephalopathy, and severe anemia were some of the symptoms of the disease in 972 children with venous BLLs $\geq 45 \mu\text{g/dL}$, and neurological disorders were also in high correlation with higher concentrations [12]. Case-fatality among under-fives reached around 25% in the poorest areas before emergency care, and most were severely neurodevelopmentally damaged [5].

Mass screening, chelation of BLLs $\geq 45 \mu\text{g/dL}$, environmental remediation, relocation of ore processing, and health education were part of the response, carried out by the Federal Ministry of Health, MSF, US CDC, WHO, and partners. While levels remained above safe criteria and re-contamination occurred when mining resumed [15], the Bagega median had dropped by about three-quarters from 119 to about 30 $\mu\text{g/dL}$ [6]. The long-term effects of BLLs in survivors are still being investigated. Zamfara revealed systemic flaws in Nigeria's informal sector, including poor rural health facilities, lack of surveillance, lengthy response times, inadequate mining regulation, and low public awareness.

Occupational exposure and take-home contamination

Millions of people in Nigeria's informal sector work in lead-exposed jobs outside mining, putting their children at risk of exposure at home (Table 2). With several operations in Nigeria, informal lead-acid battery recycling is one of the biggest global sources of exposure; workers disassemble batteries in residential areas without protection, and children in the neighbourhood have high BLLs and elevated household dust lead levels [4, 14].

Take-home contamination from spray painters in African towns has been linked to increased child BLLs; artisan painters who use lead-pigmented spray paints and industrial paints carry lead home on their skin, hair, and clothing and store equipment close to dwelling areas [9]. BLLs are raised in children by workers who handle lead alloys and solders through informal metalworking, welding, and smelting.

Other understudied methods include garbage collection, lead-glazed ceramics, traditional medicine preparation, and recycling electronic waste. The pathway is facilitated by children's hand-to-mouth conduct and intimate parental touch, as well as dust on unmodified clothing, contaminated skin, hair, cars, and shared laundry. Longer, more intense exposure and the lack of washing facilities or protective clothing increase risk; workplace-home separation, changing and washing before returning home, and a clean home provide protection.

Environmental lead sources

According to Olawoyin et al. [16], the use of lead petrol up until 2008 resulted in decades of soil contamination along highways and in cities, which persisted through direct contact and resuspended dust. Urban soil lead levels are higher in areas with heavy traffic. Decorative paints often go beyond safety regulations: 74% of solvent-based home-use samples (40 of 54) exceeded 90 ppm, with some exceeding tens of thousands of ppm [10]. Children are exposed to paint dust, chips, and hand-to-mouth contact.

The Standards Organization of Nigeria set a 90 ppm limit, although it is not strictly enforced (section 'Regulatory and policy interventions') [17]. Lead enters drinking water from contaminated sources, lead-soldered connections, and corroding pipes; this is especially dangerous for neonates fed formula. There are few studies, but traditional medicines, holding containers and cans, and crop absorption can all contaminate food. Consumer products such as imported toys, kohl cosmetics, lead-glazed pottery, some vinyls, costume jewelry, and traditional treatments have modifiable, regulation-friendly channels.

There are regional differences in lead levels. In northwest mining regions (Zamfara, Niger, Katsina), there are the highest elevations; metropolitan areas (Lagos, Ibadan, Kano, Port Harcourt) have moderate elevations from a variety of sources; rural regions, apart from industry and mining, tend to have lower elevations; but very few rural surveys exist [8]. The relationship seems to be U-shaped because of socioeconomic patterns [8]. Wealthier families are also at risk from imported goods, renovations, high-lead paints, poor living conditions with paint deterioration, informal industry, and hazardous work (mothers are

Table 2. Sources of childhood lead exposure in Nigeria

Exposure source	Extent	Typical BLL range (µg/dL)	Primary pathway	Population at risk	Intervention priority
Artisanal mining	Localized (Zamfara, Niger, Katsina)	35-119	Environmental contamination: food and water	Children in mining villages	High – remediation, mining regulation [5, 6]
Occupational take-home	Widespread, urban/peri-urban	12-35	Contaminated clothing, skin, and household dust	Children of lead-exposed workers	High – occupational safety, hygiene [4, 9]
Lead-based paints	Nationwide	5-15 (contribution)	Hand-to-mouth contact; paint dust/chips	Children in painted environments	High – paint regulation and enforcement [17]
Leaded-gasoline legacy	Urban areas nationwide	3-12 (contribution)	Contaminated soil; suspended dust	Urban children, especially near roads	Medium – soil remediation in hotspots [16]
Battery recycling	Urban/peri-urban clusters	18-32	Environmental contamination; dust	Children near recycling sites	High – relocation, regulation, remediation [4, 14]
Contaminated water	Variable by location	2-8 (contribution)	Drinking-water consumption	Children with contaminated supplies	Medium – water system improvement [16]
Contaminated food	Nationwide, variable	2-6 (contribution)	Food consumption	All children, higher with local produce	Low-medium – food-safety monitoring [19]
Consumer products	Nationwide, sporadic	Variable	Product use: hand-to-mouth	Children using contaminated products	Medium – product regulation and testing [18]

BLL – blood lead level. “Contribution” indicates the source adds to the total body burden rather than acting as a dominant point source. BLL ranges represent approximate values reported in Nigerian studies and may vary by exposure intensity and population.

more likely to work), as well as nutrition (iron and calcium deficiency) [18]. BLLs are typically lower in infants unless they are exposed through formula, water, or breast milk; levels drop after 3 to 4 years, even with continued cumulative exposure [19]. Sex differences are negligible, and slightly higher levels are reported in boys [20]. There is little research on seasonal variation; dust exposure may increase during dry seasons, and water pollution may increase during wet seasons [21].

HEALTH IMPACTS OF CHILDHOOD LEAD EXPOSURE

Health effects of lead exposure in Nigerian children are described in Tab 3.

Neurodevelopmental effects

Neurotoxicity is one of the most serious impacts of lead in childhood, and its long-term effects are profound. Lead alters neurotransmitter systems

(dopamine, glutamate, GABA), synaptic plasticity, neuronal migration and neuronal differentiation, calcium signaling, oxidative stress and gene expression, and is associated with increased stress and impaired gene expression.

Limited neuropsychological evaluations on Nigerian children show some effects consistent with international studies. Evidence from Zamfara and elsewhere indicates high blood lead levels are linked to intellectual, behavioral, and motor deficits. Zamfara survivors experienced intellectual disability, motor issues, seizures, behavioral disorders, and acute encephalopathy at a median of 119 µg/dL, with long-term epilepsy, motor impairment, and severe intellectual disability.

At 10-40 µg/dL of blood lead, subtle but significant effects occur: each 10 µg/dL increase links to a 3-5 point IQ drop below 5 µg/dL [3, 11]. These include impacts on verbal ability, attention, executive function, memory, visuospatial skills, behavior (aggression,

Table 3. Health effects of lead exposure in Nigerian children: summary of evidence

Health effect	Evidence strength	Key findings from Nigerian studies	Typical BLL range for effect	Clinical significance
Neurodevelopmental impairment	Strong	Zamfara survivors: intellectual disability, motor dysfunction, seizures; developmental delay at moderate exposure [3, 11, 12]	Effects < 5 µg/dL; severe > 45 µg/dL	High – irreversible, lifelong
Anaemia	Strong	High prevalence in high-exposure groups; dose-response with hemoglobin [5]	Effects > 10 µg/dL; severe > 45 µg/dL	High – compound malnutrition burden
Growth impairment	Moderate	Mixed findings; associations with stunting in some studies [22]	Associations > 10 µg/dL	Moderate – hard to isolate from malnutrition
Renal dysfunction	Moderate	Documented at extreme BLL in Zamfara; subclinical effects possible at moderate BLL [12]	Clinical effects > 45 µg/dL	Moderate – long-term concerns uncertain
Acute encephalopathy	Strong	Seizures, coma, cerebral edema in severe Zamfara cases [12]	Occurs > 70-100 µg/dL	Very high – life-threatening emergency
Mortality	Strong	> 400 deaths in Zamfara; ~25% case-fatality in worst-affected villages [5]	Deaths > 70 µg/dL	Very high – preventable deaths

BLL – blood lead level.

hyperactivity, impulsivity, anxiety), movement, hearing, and social and academic problems.

Chelation reduces blood lead and might slow progression but doesn't restore lost function; effects are permanent. Lead damage lowers human capital and productivity. In low- and middle-income countries, economic models show substantial impact, but Nigeria's specific impact is not well assessed and needs further study [2].

Hematological effects

Lead buildup increases protoporphyrin, lowers hemoglobin, and causes anemia by inhibiting enzymes like ferrochelatase and δ -aminolaevulinic acid dehydratase. Studies in Nigeria show anemia worsens at high Zamfara blood lead levels and shows a dose-response with moderate exposure [5]. Lead-induced anemia raises iron shortages, malaria, parasites, and hemoglobinopathies, increasing mortality alongside malaria, pneumonia, and diarrhea. It also causes exhaustion, weakened immunity,

delayed growth, and impaired cognition. Iron-deficient children absorb more lead due to upregulated DMT-1, which transports iron and lead, possibly creating a loop where iron supplements offer dual benefits.

Growth and nutritional effects

Lead may hinder growth by disrupting hormone signaling, bone health, and appetite, and indirectly by causing chronic illness and anemia [22]. Data in Nigeria is mixed: some studies show little correlation after adjusting for confounders, while others link elevated blood lead to stunting. Although lead's small effect is hard to detect amid high stunting rates, Nigeria's large pediatric population means many children are affected even by minor effects [22].

Renal effects

Lead causes impaired kidney function, hypertension, and tubular dysfunction, with effects known in adults but less studied in children [12]. In Nigeria, low-level exposure rarely causes renal

disease, but subclinical effects can develop. High Zamfara blood lead levels are linked to renal issues like increased creatinine, proteinuria, and electrolyte abnormalities, with uncertain long-term impacts [12].

Cardiovascular effects

Lead's cardiovascular effects are well known in adults but less so in children [1]. Long-term blood pressure rise links to blood lead levels, with adults more affected, associated with stroke, cardiovascular disease, and hypertension [1].

Other health effects

Other effects include gastrointestinal issues (abdominal pain, constipation, vomiting) at higher blood lead levels; immunological effects increasing infection risk; endocrine disruption affecting thyroid and puberty; dental effects like delayed eruption and more caries [1].

Mortality

At extreme Zamfara blood lead levels, lead poisoning caused over 400 child deaths from encephalopathy, cerebral edema, convulsions, and brainstem dysfunction [5]. Lead-induced anemia and immune suppression may raise mortality, warranting studies on lead's interaction with malaria, pneumonia, and diarrhea. Lower lead levels may also indirectly worsen anemia, immune issues, and health.

INTERVENTIONS AND THEIR EFFECTIVENESS

Chelation therapy

In Nigeria, agents such as CaNa_2EDTA , dimercaptosuccinic acid (DMSA), and dimercaprol (BAL) are used to bind lead for urinary excretion. Chelation is the main pharmacological treatment for high BLLs. The most important pediatric chelation experience in Africa was the Zamfara response: the median Bagega dropped from 119 to about 30 $\mu\text{g}/\text{dL}$, with symptoms resolved after MSF; the Federal Ministry of Health and partners screened and treated children with BLLs greater than 45 $\mu\text{g}/\text{dL}$, using CaNa_2EDTA at each follow-up (Figure 3) [6].

Limitations include rebound when children return to contaminated homes, requiring simultaneous remediation. Adverse effects are minor and manageable with monitoring. Remote delivery is challenging, and chelation does not reverse established damage. Results are sparse outside Zamfara, with limited agents and services and high care costs. Recommended chelation for ≥ 45 $\mu\text{g}/\text{dL}$, consideration at 20–44 $\mu\text{g}/\text{dL}$ if symptomatic or environmental control fails, and environmental priority below 20 $\mu\text{g}/\text{dL}$ [6].

Environmental remediation

Contaminated materials, dust, and soil must be removed or contained to prevent rebound and new cases.

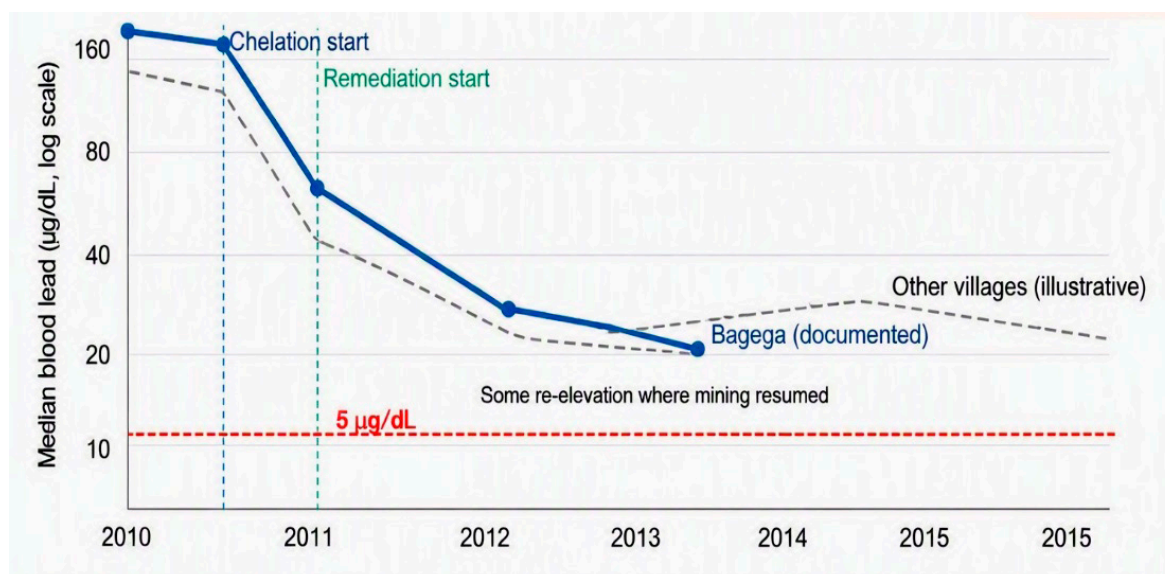


Figure 3. Temporal trends in median blood lead levels among children in Zamfara State mining villages, 2010–2015

Reading the figure: The Bagega trajectory (solid blue) reflects reported values, with a median of 119 $\mu\text{g}/\text{dL}$ at the outbreak, falling below 30 $\mu\text{g}/\text{dL}$ after remediation. The other-village line (dashed grey) illustrates the general pattern, not the reported point estimates. The y-axis is on a log scale; levels remained above the 5 $\mu\text{g}/\text{dL}$ reference line throughout the follow-up. Separate lines for individual villages, with vertical markers indicating the timing of chelation therapy initiation and environmental remediation start. Median levels declined by roughly 70–75% from peak values following intervention but remained above the 5 $\mu\text{g}/\text{dL}$ reference line, with some re-elevation where mining resumed. Data from Tirima et al., 2018 [6], and Nigerian Federal Ministry of Health surveillance reports.

Zamfara's efforts included removing contaminants, replacing soil, decontaminating buildings, changing ore processes, and educating locals, which lowered soil lead levels and reduced rebound in remediated areas [6, 15]. Challenges included vast contamination, safe soil management, community acceptance, temporary relocation, and recontamination risks. Elsewhere, remediation is limited, and pollution from legacy petrol remains unaddressed due to a lack of legal, technical, and financial resources.

Occupational safety interventions

Reducing occupational exposure and contamination is logical but limited in the informal sector. Components include protective gear, workplace hygiene, training, engineering controls, work-home separation, and worker BLL monitoring. Pilot programs with equipment and washing facilities for battery recyclers seem feasible and could reduce exposure, but adherence suffers from heat, cost, and behavioral issues; rigorous evaluations are needed. The main challenge is lack of enforcement and economic constraints, requiring innovations like subsidies, community monitoring, artisan engagement, consumer pressure, and formalization.

Regulatory and policy interventions

While Nigeria's source-directed regulation has authority, enforcement is weak. The Standards Organization set a 90 ppm paint limit [17], but most samples exceed it, hindered by limited testing, weak inspections, manufacturers' interests, low consumer awareness, and non-compliant imports [10]. International success shows compliance improves with clear standards, mandated testing, surveillance, sanctions, public awareness, and reformulation support. Lead industry regulations are covered by Nigeria's Factories Act, mainly for the official sector, but rarely enforced. Its informal extension may need voluntary certification, community monitoring, and incentives. Environmental laws exist but lack monitoring, requiring investments in labs, staff, and infrastructure.

Screening and surveillance

Although systematic screening and surveillance are essential, they are mainly used in research and emergencies in Nigeria due to the lack of a national program. Barriers include costly testing, insufficient trained personnel, poor follow-up, and low awareness. Strategies for expansion involve integrating testing into routine child health services in high-risk areas, using point-of-care devices, targeting high-risk populations (like mining and recycling communities), establishing low-cost laboratories, and implementing national surveillance to track levels and detect clusters. Donor

and NGO efforts support context-specific screening, but sustainable domestic capacity remains limited. Less invasive methods should be promoted, and extended screening should include schools, clinics for under-5s, outpatient centers, immunization sites, and displaced camps.

Community education and mobilization

Without addressing structural barriers, education that raises knowledge of risks and prevention is crucial but insufficient. Effective programs use community meetings, skilled community health workers, information in the local language, safer practice demonstrations, leader engagement, and connections to tangible resources. Zamfara's extensive education was important to the acceptance of remediation and behavior change. Education must be combined with institutional interventions that support protective behaviors, since families frequently know protective measures but cannot afford them; for example, a painter may know to shower and change clothes but lack the facilities.

Nutritional interventions

Given lead-nutrition interactions, nutritional measures offer supplementary benefits: iron supplementation reduces absorption and treats anemia; calcium may reduce absorption and bone mobilization; and adequate intake of iron, calcium, zinc, and vitamin C is associated with lower BLLs. In Nigeria, where malnutrition and micronutrient deficiencies are common, these align with broader child health goals but should complement, not replace, source elimination.

Minimizing lead exposure in pregnancy

Lead exposure during pregnancy poses severe risks to child health, potentially causing adverse birth outcomes, because lead crosses the placenta [23-25]. Prenatal exposure can compromise fetal development, increasing the risk of structural abnormalities like neural tube defects and undermining a child's future neurological and physiological potential [26]. Addressing these risks requires clinical management and public health interventions to identify and eliminate sources of exposure [27]. Additionally, targeted nutritional interventions during pregnancy, such as calcium, iron, zinc, magnesium, Vitamin C, and Vitamin E, may serve as a supportive strategy, as certain nutrients have been evaluated for their potential to help lower maternal blood lead levels [28].

KNOWLEDGE GAPS AND RESEARCH PRIORITIES

Epidemiological gaps

Gaps include lack of nationally representative BLL data; lack of quantification of paint, water, food, and products contributions; poor temporal trends; lack of prenatal and infant data; and non-assessed geographic variation [29].

Priority: nationally representative biomonitoring, longitudinal cohorts, source apportionment (isotopic analysis and modeling), prenatal and early-life studies using cord and infant blood, and increased surveillance in neglected areas. Addressing these epidemiological gaps is a core objective of Pillar 2 ('Surveillance and screening systems').

Health-effects research gaps

Gaps include limited standardized neurodevelopmental assessment, inadequate longitudinal follow-up, little investigation below 10 µg/dL, inadequate assessment of lead interactions with malaria, malnutrition and infection, and little economic analysis [18].

Priority: longitudinal neurodevelopmental studies using validated instruments (e.g., Bayley, Wechsler), low-BLL effect studies, interaction studies, economic-burden studies and long-term follow-up of Zamfara survivors. The research priorities identified here inform Pillar 3 ('Clinical services and treatment') and provide the evidence base for Pillar 1 ('Regulatory strengthening and enforcement').

Intervention research gaps

Gaps include limited evaluation of effectiveness in Nigerian contexts, lack of comparative effectiveness research, poorly understood implementation barriers, limited economic assessment and insufficient acceptability and sustainability.

Priorities: randomized or quasi-experimental studies of household cleaning, occupational safety and education, comparative effectiveness and implementation science research; cost-effectiveness analyses and community-based design of contextually appropriate interventions. These gaps map directly to Pillar 4 ('Environmental remediation and source control') and Pillar 5 ('Occupational safety and informal sector').

Policy and systems gaps

Gaps include lack of knowledge of regulatory barriers, under-investigation of economic and political capacity, insufficient assessment of health system capacity, and lack of stakeholder representation [30]. Policy analysis of regulatory frameworks; political economy analysis of paint and occupational safety

enforcement; health systems research on screening, treatment, and prevention capacity; and stakeholder engagement research to inform policy. Closing these systemic gaps is the principal aim of Pillar 1 ('Regulatory strengthening and enforcement') and the cross-cutting governance mechanisms described in section 'Cross-cutting elements'.

A STRUCTURED FRAMEWORK FOR ACTION

Reducing childhood lead exposure in Nigeria requires a multi-faceted response that integrates prevention, early detection, treatment, environmental restoration, and policy development (Figure 4). Based on evidence on the ground, we developed six complementary strategic pillars supported by cross-cutting governance mechanisms (Figure 5).

Pillar 1: Regulatory strengthening and enforcement

Aim: Control lead exposure at source. The focus of primary prevention still needs to be strengthening and enforcing regulations regarding lead-containing products. The priority is to establish a national paint lead limit of ≤ 90 ppm, to make workers' lives safer and the environment safer, to regulate lead in the products we use (toys, cosmetics, ceramics) and to make laboratory technology more efficient for product testing, inspection, and regulatory enforcement [31]. Appropriate penalties for non-compliance and incentives to produce and use safer products should be present in implementation.

Pillar 2: Surveillance and screening systems

The objective is to detect exposure early and take action in public health. A national surveillance system is necessary to identify the real burden of childhood lead exposure and identify high-risk groups [29]. This will include representative biomonitoring, targeted screening of children in high-risk populations, reliable laboratory services, electronic reporting systems, and routine environmental monitoring. Standardized follow-up protocols would support early intervention and timely response to emerging exposure clusters.

Pillar 3: Clinical services and treatment

Objective: Improve access to timely diagnosis and evidence-based care. Health systems must be better equipped to identify, diagnose, and respond to childhood lead poisoning with a common set of clinical guidelines, trained healthcare workers to manage it, and better access to diagnostic services, chelation therapy and treatment, and specialist referral pathways [32]. Long-term follow-up should be done to address not only lead toxicity but also associated

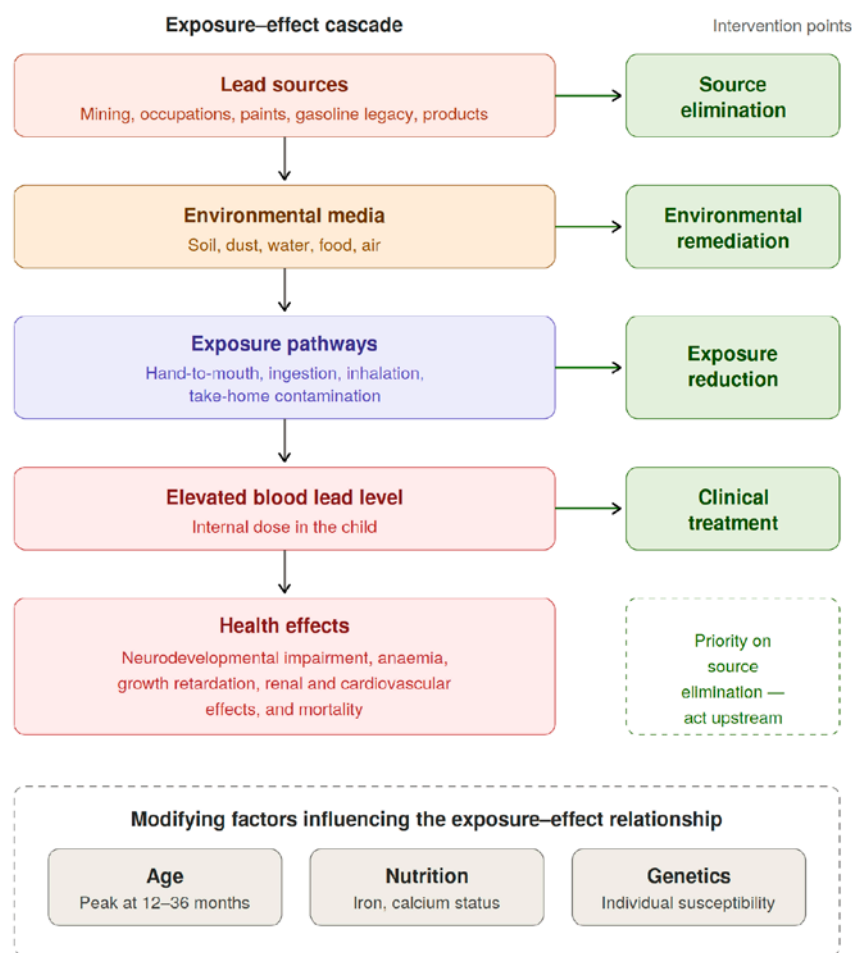


Figure 4. Conceptual framework of exposure pathways and intervention points

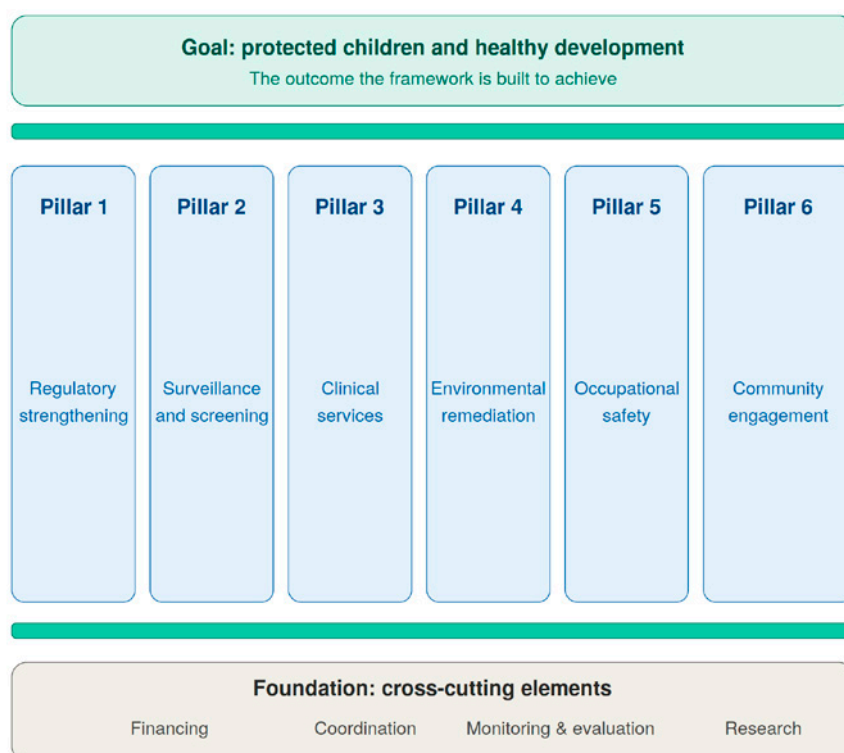


Figure 5. The six-pillar framework for addressing childhood lead poisoning in Nigeria

diseases (anemia, nutritional deficiencies, and neurodevelopmental dysfunction).

Pillar 4: Environmental remediation and source control

Goal: Eliminate environmental contamination and prevent repeat exposure. To prevent pollution for sustainable prevention, we need to remedy the environment (i.e., in mining communities, informal battery recycling sites, and urban areas). Environmental interventions should be complemented by engineering controls, safer industrial practices, and the removal of lead-containing materials in the future in order to reduce the risk of environmental exposure [33].

Pillar 5: Occupational safety and informal sector

Objective: Reduce occupational exposure and prevent take-home contamination. Occupational exposure is a major source of childhood lead poisoning via contamination into the home [6]. Preventive measures must include better workplace hygiene, access to appropriate personal protective equipment, education for workers in the informal sector and artisan associations to work safely, and regular monitoring of workplace exposure, if possible.

Pillar 6: Community engagement and education

Goal: Increase public awareness and prevention. Community involvement is critical for prevention to be sustainable [34]. Public education should focus on common sources of lead exposure, associated health risks, and practical preventive measures. Community health workers, schools, traditional and religious leaders, and local organizations can also play a key role in risk communication, behavior change, and early health-seeking behavior in the affected families.

Cross-cutting elements

Implementing these pillars needs ongoing political support, sufficient domestic funding, multisectoral cooperation, and robust monitoring. Partnerships among government, academia, professional groups, civil society, and development partners are vital for program success. Research should fill knowledge gaps, assess interventions in Nigeria, and generate evidence for policy and resource decisions.

Feasibility/prioritization of pillars under resource constraints

Given the resource constraints endemic to Nigeria's health system, simultaneous implementation of all six pillars is neither realistic nor necessary as a first step. A tiered approach is recommended: Pillars 1 (regulatory strengthening), 2 (surveillance and screening), and 6 (community engagement) offer comparatively high impact at lower initial cost and

should be treated as priority entry points. Pillars 3 (clinical services) and 4 (environmental remediation) require sustained financing and external partnership, and should be developed progressively; Pillar 5 (occupational safety) can advance in parallel through existing labour-inspection frameworks at minimal additional cost.

CONCLUSIONS

Childhood lead poisoning in Nigeria remains a severe yet preventable public health crisis. Children face dangerously high blood lead levels from artisanal mining, leaded products, and legacy contamination, leading to cognitive impairment, anemia, stunted growth, and death. While acute disasters like Zamfara highlight the risks, chronic low-to-moderate exposure is widespread and equally damaging. This burden reflects broader environmental health threats driven by rapid urbanization, weak regulation, poverty, and unsafe housing.

Evidence shows interventions work: chelation and remediation saved lives in Zamfara, occupational safety and education pilots proved effective, and global paint regulation demonstrates prevention is possible. A coordinated six-pillar approach (strengthening regulation, expanding surveillance, improving occupational and environmental controls, and integrating prevention into child health services) can shift Nigeria from isolated projects to systematic protection.

The stakes are high: each year's exposure erodes lifelong cognition and costs more than prevention. Although research gaps exist, evidence is sufficient. Political will, resources, and proven strategies are needed to protect Nigeria's children.

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Conflicts of interest

The authors declare no conflicts of interest.

AI tools

AI tools were carefully used to refine outlines, schematic diagrams and figures, and English language grammar. The authors are responsible for the manuscript.

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ASSOCIATION BETWEEN EXPANDED DISABILITY STATUS SCALE SCORE AND MEDITERRANEAN DIET ADHERENCE ACCORDING TO DISEASE DURATION IN PATIENTS WITH MULTIPLE SCLEROSIS

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ABSTRACT

Background. Multiple sclerosis (MS) is a long-term condition in which the immune system attacks the brain and spinal cord, affecting approximately 2.9 million people worldwide. Among the dietary patterns studied in MS, the Mediterranean diet has attracted the most research attention for its potential to reduce inflammation and slow the progression of disability.

Objective. This study used a survey-based approach to collect data from one hundred MS patients across three countries – Slovakia, Italy, and the United Kingdom/international cohort to explore the association between disability levels, Mediterranean diet adherence, and disease duration. The main aim was to examine how Expanded Disability Status Scale (EDSS) scores and length of time living with MS were associated with how closely patients followed the Mediterranean diet. Secondary aims included looking at how often patients consumed specific food groups, whether they were taking vitamin D or omega-3 supplements, whether their eating habits had changed since their MS diagnosis, and how many patients had received formal nutrition advice from their healthcare team, with results broken down by country and level of disability.

Material and Methods. This cross-sectional study explored the relationship between disability level, Mediterranean diet adherence measured using the validated 14-item Mediterranean Diet Adherence Screener (MEDAS), and disease duration in 100 MS patients from Slovakia (n = 47), Italy (n = 36), and a UK/international cohort (n = 17).

Results. The overall mean MEDAS score was 3.96 ± 2.26 , reflecting predominantly poor dietary adherence across the entire sample: 77% of patients fell into the low-adherence range (score 0-5), 22% into the moderate range (6-9), and only one patient (1%) reached high adherence (10-14). MEDAS scores were highest in patients with the lowest disability (mean 4.73 at EDSS 0-2) and declined across higher EDSS groups, with the proportion of low-adherence patients rising from 63.6% at EDSS 0-2 to 90.0% at EDSS 6-8. Vegetable consumption, the most important food component of the Mediterranean diet, declined modestly from 4.64 to 4.33 times per week across the disability spectrum. Regarding disease duration, the lowest mean MEDAS scores were observed in patients diagnosed for 1-5 years (3.75) and those living with MS for 20 or more years (3.69), the latter group also showing the highest rate of low adherence (85.7%). Italian patients had the highest mean MEDAS score (4.56), compared with 4.12 in the UK/international group and 3.45 in Slovakia. A notable discrepancy was found between the 24% of patients who self-identified as following the Mediterranean diet and the objective MEDAS results, in which only one patient achieved high adherence. Only 26% of patients had received formal dietary advice from their doctor, despite 47% having changed their eating habits independently after diagnosis.

Conclusions. These findings show that higher disability and longer disease duration are both linked to poorer Mediterranean diet adherence when assessed with a validated tool and highlight the need to include structured nutritional support as a regular part of MS care.

Keywords: multiple sclerosis, Expanded Disability Status Scale, Mediterranean diet, disability progression, dietary adherence

INTRODUCTION

Multiple sclerosis (MS) is a long-term condition in which the immune system attacks the brain and spinal cord, gradually damaging nerve fibres and leading to worsening neurological symptoms over time. According to Walton et al. [1], the condition

affects more than 2.9 million people globally, though its prevalence differs considerably from one region to another, with higher rates observed in countries further from the equator. The condition works by causing the immune system to mistakenly attack and destroy the cells responsible for protecting nerve fibres, which gradually leads to worsening neurological problems

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over time. Although modern treatments have greatly improved the lives of people with the relapsing form of MS, managing the progression of disability in the later stages of the disease remains difficult and there is still no fully effective solution [2].

The Expanded Disability Status Scale Score (EDSS) is a widely used scale developed by Kurtzke [3] to measure disability in MS patients (the scoring criteria are described in detail in the Methods). Because it is so commonly used in research and clinical settings, the EDSS serves as the main tool for measuring how various factors, including lifestyle choices, affect the disease. This has led to growing interest in understanding how things like physical activity, body weight, and diet may influence how disability develops over time. Over the last ten years, researchers have become increasingly interested in the connection between the gut, the brain, and the immune system as a possible way through which diet may affect inflammation in MS. What we eat plays an important role in shaping the types of bacteria living in our gut and the substances they produce. For example, fibre-rich foods encourage the growth of certain beneficial bacteria that produce compounds known as short-chain fatty acids, including butyrate, propionate, and acetate. These compounds interact with immune cells in ways that help reduce inflammation and may help keep the immune system better balanced [4, 5].

Diet is one of the lifestyle factors that researchers have been paying increasing attention to when looking at how disability and quality of life develop in MS, with the Mediterranean diet receiving the most focus. This eating pattern is mainly built around foods such as vegetables, legumes, whole grains, olive oil, and fish, while limiting red meat, processed meats, and refined carbohydrates. Over recent years, several studies have found meaningful links between following the Mediterranean diet and better disability outcomes in MS. For example, Sand et al. [6] found in a real-world study that people who followed the Mediterranean diet more closely tended to have lower disability scores. A large Italian study involving 435 patients similarly found that greater adherence to the Mediterranean diet was linked to lower levels of both disability and disease severity [7]. Tryfonos et al. [8] found that patients who followed the Mediterranean diet less closely were approximately twice as likely to reach more advanced stages of disability. More recently, a review and analysis of multiple studies by Kong et al. [9] confirmed that closer adherence to the Mediterranean diet was associated with less fatigue and a healthier body weight in people with MS.

There is now a reasonable body of evidence supporting the idea that diet can influence disability in MS. The Mediterranean diet is rich in fibre, natural plant compounds, and healthy fats, all of which help

support a healthy and diverse gut environment. This in turn encourages the growth of beneficial gut bacteria that produce compounds helping to calm the immune system and reduce the kind of inflammation that contributes to nerve damage in MS [4, 5]. On the other hand, diets that are low in plant-based foods and high in heavily processed foods can disrupt the balance of gut bacteria, weaken the gut lining, and increase inflammation throughout the body, which may worsen nerve damage and lead to greater disability over time [10]. It is also important to recognise that this relationship works in both directions – as disability worsens, it becomes harder for people to maintain a healthy diet due to physical limitations and other practical challenges, and in turn, a poorer diet may further fuel inflammation and accelerate disease progression.

Although a growing number of studies have looked at the Mediterranean diet and MS, most of this research has been carried out in Southern and Western European countries. There is still a lack of large studies that look at how closely people with MS follow the Mediterranean diet across different levels of disability and disease duration, particularly in Central European countries where eating habits tend to differ quite a lot from those in Mediterranean regions.

This study aims to fill that gap by looking at data from one hundred MS patients across three countries – Slovakia, Italy, and the UK. The main goal was to explore the relationship between disability levels, Mediterranean diet adherence, and how long patients had been living with MS. Additional goals included looking at what specific foods patients were eating, how dietary habits differed between countries, what supplements patients were taking, and how many patients had received any nutrition advice as part of their regular MS care.

MATERIALS AND METHODS

Study design and participants

A cross-sectional online survey was administered to adults with a confirmed neurologist-diagnosed MS across three national cohorts: Slovakia ($n = 47$), Italy ($n = 36$), and UK/international respondents ($n = 17$), yielding a total sample of 100 participants. Participation was voluntary and anonymous; the survey was distributed through neurological patient organisations and MS community platforms during 2023–2024. All participants provided electronic informed consent. The study adhered to the principles of the Declaration of Helsinki as revised in 2024 [11]. Inclusion criteria were age ≥ 18 years, a self-reported neurologist-confirmed diagnosis of MS, and completion of the MEDAS and EDSS survey items; responses with incomplete data on these items were excluded from

analysis. The sample was predominantly female (92%; Slovakia 91.5%, Italy 94.4%, UK/international 88.2%) with a median age band of 40-50 years across the whole sample (Slovakia skewed older, with 66.0% of participants aged ≥ 50 years, versus 27.8% in Italy and 52.9% in the UK/international group). Educational attainment was not collected as part of this survey and could therefore not be reported or adjusted for; independent confirmation of MS diagnosis (e.g., from medical records) was likewise not collected. These represent limitations of the study and are addressed further in the Discussion.

Disability assessment

Neurological disability was quantified using the EDSS [3], self-reported with reference to the most recent clinical evaluation. The EDSS ranges from 0 (no disability) to 10 (death due to MS) and is based on functional-system scores and ambulatory ability; a score of 4.0 or above indicates that walking ability in daily life is noticeably impaired, and a score above 6.0 indicates that the person requires a walking aid. Because EDSS values were self-reported rather than verified against clinical records, and because participants were not asked to specify individual symptoms, some misclassification cannot be excluded; this limitation is discussed further below. Responses were grouped into five functional bands: 0-2 (no or minimal disability), 2-4 (mild to moderate), 4-6 (moderate; ambulatory with aid), 6-8 (severe; requiring assistance), and > 8 (very severe).

Disease duration assessment

Disease duration was assessed by a direct survey question asking participants to indicate how long they had been living with a confirmed MS diagnosis. Responses were captured in six ordinal intervals: less than 1 year, 1-5 years, 5-10 years, 10-15 years, 15-20 years, and 20 or more years. Unlike previous studies that relied exclusively on EDSS as a proxy for disease duration, the present study incorporates self-reported duration as a primary variable, enabling direct examination of its relationship with both disability severity and dietary adherence.

Dietary assessment

Mediterranean diet adherence was measured using the Mediterranean Diet Adherence Screener (MEDAS), a validated 14-item questionnaire developed by Martínez-González et al. [12]. Each item is worth one point, giving a total score ranging from 0 to 14. Scores between 0 and 5 indicate low adherence, scores between 6 and 9 reflect moderate adherence, and scores between 10 and 14 represent high adherence to the Mediterranean diet. The 14 items

cover a range of dietary behaviours, including the use of olive oil as the main cooking fat, daily consumption of vegetables (≥ 2 portions) and fruit (≥ 3 portions), limited intake of red meat (< 1 portion/week), butter, and sugary drinks, as well as regular consumption of fish (≥ 3 portions/week), legumes (≥ 3 portions/week), nuts (≥ 3 times/week), and wine (≥ 7 glasses/week). It also considers preferences for leaner meats such as chicken or turkey over red or processed meats, and the use of sofrito, a sauce made from tomatoes, onions, and olive oil, at least twice per week in cooking. In addition to MEDAS scoring, self-reported dietary pattern (including self-identification with the Mediterranean diet), food group consumption frequencies, supplementation use, and receipt of dietary advice from a physician were recorded. The MEDAS was self-administered online, as part of the electronic survey, in the respondent's local language; participants were not required to have prior familiarity with the Mediterranean diet, as the instrument itself defines the relevant food groups and portion sizes for each item. Although MEDAS was originally validated in a Mediterranean population, it was selected for use across all three national samples because it is a short, freely available, and widely used screening tool that permits direct comparison with the substantial existing body of MEDAS-based MS literature; its cross-cultural applicability to non-Mediterranean dietary contexts is nonetheless a limitation of the present approach and is discussed further below. Information on whether following the Mediterranean diet had been specifically recommended by a physician was not collected.

Statistical analysis

Microsoft Office Forms and Excel were used to process input data. Quantitative data (including MEDAS scores and food-group consumption frequencies) are presented descriptively as means and standard deviations, and qualitative data as frequencies and percentages, calculated separately by country, EDSS band, and disease-duration category. Given the exploratory, hypothesis-generating nature of this pilot survey and the small and unevenly distributed size of several subgroups (e.g., $n = 3$ for EDSS > 8), formal between-group inferential statistics (e.g., ANOVA and post-hoc comparisons) are not reported in detail here; the analysis is therefore presented as descriptive rather than confirmatory, and the patterns described in the Results should be interpreted as observations warranting confirmation in adequately powered future studies rather than as evidence of statistically significant differences.

RESULTS

Sample characteristics and EDSS distribution

The study enrolled 100 patients with MS: 47 from Slovakia (mean EDSS 4.91), 36 from Italy (mean EDSS 3.33), and 17 from the UK/international cohort (mean EDSS 3.24), yielding an overall mean EDSS of 4.06. Slovak patients exhibited substantially higher mean disability, with the largest proportions in the EDSS 4-6 (38.3%) and 6-8 (27.7%) bands. Italian and UK/international participants were predominantly distributed across EDSS 0-2 and 2-4 (Table 1).

Disease duration distribution

Disease duration was reported directly by all 100 participants. The largest group (35.0%, $n = 35$) had been living with MS for 20 or more years, followed by those with 10-15 years (17.0%, $n = 17$) and 5-10 years (16.0%, $n = 16$). A further 16 patients (16.0%) had been diagnosed within 1-5 years, 10 patients (10.0%) within 15-20 years, and 6 patients (6.0%) within less than one year. Longer disease duration was associated with higher EDSS: among patients with ≥ 20 years' disease duration, 40.0% ($n = 14$) were in the EDSS 4-6 band and 25.7% ($n = 9$) in EDSS 6-8, compared with 50.0% ($n = 8$) in EDSS 0-2 among those with 1-5 years of disease (Table 2).

MEDAS score and Mediterranean diet adherence by EDSS group

The overall mean MEDAS score across the full cohort was 3.96 ± 2.26 , placing the sample firmly within the low-adherence range. The great majority of patients (77 of 100, 77.0%) scored 5 or below, 22 patients (22.0%) scored in the moderate range (6-9), and only one patient (1.0%) achieved high adherence (score of 10). No patient scored above 10.

MEDAS scores showed a general declining trend across increasing EDSS groups, with the highest mean score at EDSS 0-2 (4.73) and progressively lower values at EDSS 2-4 (3.55) and EDSS 4-6 (3.73). The proportion of patients in the low-adherence category rose from 63.6% at EDSS 0-2 to 75.9% at EDSS 2-4, 80.8% at EDSS 4-6, and 90.0% at EDSS 6-8, indicating a substantially higher burden of poor dietary adherence as disability advances. The very severe group (EDSS > 8) had a mean of 5.00, though this is based on only three patients and should be interpreted with caution.

Vegetable intake, the most central food component of the MedDiet, showed a modest declining pattern, from 4.64 times/week at EDSS 0-2 to 4.33 times/week at EDSS > 8 . Fish intake showed a modest upward trend across groups (1.05 to 1.67 times/week), while

Table 1. EDSS distribution by country ($n = 100$)

EDSS Group	Slovakia ($n = 47$)	%	Italy ($n = 36$)	%	UK/Intl ($n = 17$)	%	Total ($n = 100$)	%
0-2	2	4.3	14	38.9	6	35.3	22	22.0
2-4	13	27.7	11	30.6	5	29.4	29	29.0
4-6	18	38.3	4	11.1	4	23.5	26	26.0
6-8	13	27.7	5	13.9	2	11.8	20	20.0
> 8	1	2.1	2	5.6	0	0.0	3	3.0
Mean EDSS	4.91	—	3.33	—	3.24	—	4.06	—

EDSS – Expanded Disability Status Scale; UK/Intl – United Kingdom and international respondents.

Table 2. EDSS distribution by disease duration ($n = 100$)

Disease duration	n	EDSS 0-2 n (%)	EDSS 2-4 n (%)	EDSS 4-6 n (%)	EDSS 6-8 n (%)	EDSS > 8 n (%)	Self-reported MedDiet n (%)
< 1 year	6	2 (33.3)	4 (66.7)	0 (0.0)	0 (0.0)	0 (0.0)	3 (50.0)
1-5 years	16	8 (50.0)	5 (31.2)	2 (12.5)	1 (6.2)	0 (0.0)	6 (37.5)
5-10 years	16	5 (31.2)	4 (25.0)	3 (18.8)	3 (18.8)	1 (6.2)	4 (25.0)
10-15 years	17	2 (11.8)	7 (41.2)	4 (23.5)	3 (17.6)	1 (5.9)	2 (11.8)
15-20 years	10	2 (20.0)	1 (10.0)	3 (30.0)	4 (40.0)	0 (0.0)	2 (20.0)
≥ 20 years	35	3 (8.6)	8 (22.9)	14 (40.0)	9 (25.7)	1 (2.9)	7 (20.0)

Self-reported MedDiet – proportion of patients in each duration group who identified as following the Mediterranean diet; EDSS – Expanded Disability Status Scale.

Table 3. MEDAS score, adherence categories, and key food frequency indicators by EDSS group (n = 100)

Indicator	EDSS 0-2 (n = 22)	EDSS 2-4 (n = 29)	EDSS 4-6 (n = 26)	EDSS 6-8 (n = 20)	EDSS > 8 (n = 3)
Mean MEDAS score	4.73	3.55	3.73	3.85	5.00
Low adherence (0-5), n (%)	14 (63.6)	22 (75.9)	21 (80.8)	18 (90.0)	2 (66.7)
Moderate adherence (6-9), n (%)	8 (36.4)	7 (24.1)	4 (15.4)	2 (10.0)	1 (33.3)
High adherence (10-14), n (%)	0 (0.0)	0 (0.0)	1 (3.8)	0 (0.0)	0 (0.0)
Vegetable intake (×/week)	4.64	4.97	4.63	4.75	4.33
Fruit intake (×/week)	4.88	4.04	4.53	5.35	7.00
Fish intake (×/week)	1.05	0.98	1.20	1.21	1.67
Legume intake (×/week)	1.31	1.36	1.16	1.42	0.83
Whole grain intake (×/week)	1.08	1.62	1.84	1.80	0.17
Red meat intake (×/week)	1.14	1.12	1.14	1.08	2.17
Fast food intake (×/week)	0.50	0.37	0.56	0.25	0.33

MEDAS – Mediterranean Diet Adherence Screener; values for food frequency represent mean times/week; adherence categories: low – 0-5, moderate – 6-9, high – 10-14.

whole grain intake was lowest in the highest disability groups. Fast food intake was generally low across all groups (Table 3).

MEDAS score and Mediterranean diet adherence by disease duration

When disease duration was examined as an independent variable, MEDAS scores demonstrated a generally declining trajectory with longer disease duration. The highest mean MEDAS score was observed in the 15-20 years group (4.70), followed by the 5-10 years group (4.44) and the less-than-one-year group (4.00). The nadir was observed in patients diagnosed for 1-5 years (3.75) and those with the longest disease history of ≥ 20 years (3.69), who also recorded the highest proportion of low adherence (85.7%).

The self-reported Mediterranean diet adoption rate declined from 50.0% in patients within the first

year of diagnosis to 11.8% in the 10-15 years group, before recovering partially to 20.0% in the 15-20 and ≥ 20 years groups. Notably, the ≥ 20 -year group was the largest in the cohort and was heavily concentrated in higher EDSS bands: 65.7% of this group fell in EDSS 4-6 or above, reinforcing the interdependence of disease duration and disability severity in shaping dietary behaviour (Table 4).

MEDAS adherence by EDSS as disease stage proxy

Table 5 presents MEDAS adherence stratified by EDSS group. As already reported above (see MEDAS score and Mediterranean diet adherence by EDSS group), the proportion of patients with low MEDAS adherence rose from 63.6% at EDSS 0-2 to 90.0% at EDSS 6-8, while the proportion maintaining at least moderate adherence fell correspondingly, from 36.4% to 10.0%; these figures are not repeated in full elsewhere in this section to avoid duplication and

Table 4. MEDAS score and Mediterranean diet adherence by disease duration (n = 100)

Disease Duration	n	Mean MEDAS	Low (0-5) n (%)	Moderate (6-9) n (%)	High (10-14) n (%)	Self-reported MedDiet n (%)	Predominant EDSS band
< 1 year	6	4.00	4 (66.7)	2 (33.3)	0 (0.0)	3 (50.0)	EDSS 2-4 (66.7%)
1-5 years	16	3.75	13 (81.2)	3 (18.8)	0 (0.0)	6 (37.5)	EDSS 0-2 (50.0%)
5-10 years	16	4.44	11 (68.8)	5 (31.2)	0 (0.0)	4 (25.0)	EDSS 0-2 (31.2%)
10-15 years	17	3.82	13 (76.5)	4 (23.5)	0 (0.0)	2 (11.8)	EDSS 2-4 (41.2%)
15-20 years	10	4.70	6 (60.0)	4 (40.0)	0 (0.0)	2 (20.0)	EDSS 6-8 (40.0%)
≥ 20 years	35	3.69	30 (85.7)	4 (11.4)	1 (2.9)	7 (20.0)	EDSS 4-6 (40.0%)

MEDAS – Mediterranean Diet Adherence Screener; predominant EDSS band indicates the most frequent EDSS group within each duration category.

should instead be discussed and interpreted in the discussion.

MEDAS adherence, supplementation, and dietary guidance by country

Country-level analysis revealed substantial heterogeneity in both MEDAS scores and self-reported dietary patterns. Italian patients had the highest mean MEDAS score (4.56), followed by UK/international patients (4.12) and Slovak patients (3.45). No patient in Italy or Slovakia achieved high MEDAS adherence; the single patient with high adherence was in the UK/international group. Slovak patients had the highest proportion of low MEDAS adherence (85.1%) and the highest proportion following no specific dietary pattern (57.4%).

Vitamin D supplementation was near-universal in Slovakia (95.7%) and highly prevalent in the UK/international cohort (88.2%), with

a lower but still substantial rate in Italy (69.4%). Omega-3 supplementation was most common in UK/international patients (41.2%). Despite 47% of the total sample reporting dietary change after MS diagnosis, with the highest rate in the UK/international group (82.4%), only 26% of patients overall received formal dietary guidance from a treating physician (Table 6).

DISCUSSION

This study, which brought together data from three European countries, found that Mediterranean diet adherence, measured using the validated MEDAS questionnaire, was generally poor across the whole MS sample and tended to decline as disability increased and as patients had been living with the disease for longer. The overall mean MEDAS score of 3.96 ± 2.26 , with 77% of patients falling into the

Table 5. MEDAS adherence by EDSS group as proxy for disease stage (n = 100)

EDSS group (disease stage proxy)	Mean MEDAS score	Low adherence (0-5) n (%)	Moderate adherence (6-9) n (%)	Mean vegetable intake (×/week)
EDSS 0-2 early/mild (n = 22)	4.73	14 (63.6)	8 (36.4)	4.64
EDSS 2-4 mild-moderate (n = 29)	3.55	22 (75.9)	7 (24.1)	4.97
EDSS 4-6 moderate (n = 26)	3.73	21 (80.8)	4 (15.4)	4.63
EDSS 6-8 severe (n = 20)	3.85	18 (90.0)	2 (10.0)	4.75
EDSS > 8 very severe (n = 3)	5.00	2 (66.7)	1 (33.3)	4.33

MEDAS adherence expressed as n (%); vegetable intake in mean times/week.

Table 6. MEDAS adherence, supplementation, and dietary guidance by country (n = 100)

Indicator	Slovakia (n = 47)	Italy (n = 36)	UK/Intl (n = 17)	Total (n = 100)
Mean MEDAS score	3.45	4.56	4.12	3.96
Low MEDAS adherence, n (%)	40 (85.1)	25 (69.4)	12 (70.6)	77 (77.0)
Moderate MEDAS adherence, n (%)	7 (14.9)	11 (30.6)	4 (23.5)	22 (22.0)
High MEDAS adherence, n (%)	0 (0.0)	0 (0.0)	1 (5.9)	1 (1.0)
Self-reported MedDiet, n (%)	5 (10.6)	15 (41.7)	4 (23.5)	24 (24.0)
Anti-inflammatory diet, n (%)	2 (4.3)	2 (5.6)	1 (5.9)	5 (5.0)
Intermittent fasting, n (%)	6 (12.8)	2 (5.6)	2 (11.8)	10 (10.0)
No specific diet, n (%)	27 (57.4)	13 (36.1)	5 (29.4)	45 (45.0)
Changed diet post-diagnosis, n (%)	20 (42.6)	13 (36.1)	14 (82.4)	47 (47.0)
Vitamin D supplementation, n (%)	45 (95.7)	25 (69.4)	15 (88.2)	85 (85.0)
Omega-3 supplementation, n (%)	13 (27.7)	6 (16.7)	7 (41.2)	26 (26.0)
Received dietary advice from physician, n (%)	16 (34.0)	8 (22.2)	2 (11.8)	26 (26.0)

UK/Intl – United Kingdom and international respondents combined; MEDAS – Mediterranean Diet Adherence Screener.

low-adherence category, tells a more detailed and accurate story than simply asking patients whether they follow the Mediterranean diet. While 24% of patients said they did, very few of them scored high enough on the MEDAS to confirm this, pointing to a significant gap between what patients believe they eat and what they eat.

The pattern of declining MEDAS scores with rising disability – from a mean of 4.73 at EDSS 0-2 dropping to 3.55 at EDSS 2-4, while the proportion of poorly adherent patients climbed from 63.6% to 90.0% between the lowest and most severe disability groups – is in line with what other European studies have found. Felicetti et al. [7] found inverse links between Mediterranean diet adherence and both disability and disease severity scores in a large Italian sample. Tryfonos et al. [8] showed that patients with lower adherence were around twice as likely to reach more advanced disability thresholds. Sand et al. [6] confirmed that following the Mediterranean diet was independently linked to lower objective disability in a real-world setting. What the present study adds is the use of an objective, validated screening tool rather than relying on self-report, showing that the link between diet and disability is still visible even when dietary habits are measured more rigorously.

The disease duration results add another useful layer to understanding how diet and disability interact. MEDAS scores were lowest in patients who had been diagnosed for 1-5 years (3.75) and in those living with MS for 20 years or more (3.69), suggesting that both the early period after diagnosis and the longer-term chronic phase are associated with poor dietary habits. The slight improvement seen in the 15-20 age group (mean 4.70) might reflect a survivor effect – patients who have had the disease for a long time but whose condition has remained relatively stable and who have found ways to manage their lifestyle more effectively – though it may also simply reflect differences in who is included in that group. The fact that 65.7% of patients in the longest-duration group were in the moderate-to-severe disability bands is consistent with the interpretation that disease duration and disability level are closely associated and may, together, make it harder to maintain a healthy diet; however, as this is a cross-sectional, single-timepoint study rather than a longitudinal one, this association cannot be taken to demonstrate a causal or temporal influence of disease duration.

There is a growing body of research explaining why diet might influence disability in MS. The Mediterranean diet is rich in fibre, healthy fats, and natural plant compounds that support a healthy and varied gut bacterial environment, which in turn produces anti-inflammatory substances that help regulate the immune system and reduce the nerve

damage that drives disability in MS [4, 5]. The gradual decline in vegetable consumption seen across disability groups, from 4.64 times per week at EDSS 0-2 to 4.33 times per week at EDSS > 8, means that patients are consuming less and less of the foods that feed these beneficial gut bacteria, reducing their body's ability to control inflammation over the course of the disease [10, 13]. A cycle in which poorer diet contributes to more inflammation, which in turn may drive faster disability progression, is biologically plausible based on this existing mechanistic literature [4, 5, 10, 13]; however, as this study did not measure inflammatory biomarkers directly and its cross-sectional design precludes causal inference, this interpretation remains hypothetical and should be tested in future studies incorporating objective markers of inflammation.

Differences between countries in MEDAS scores are also worth noting. The highest scores were seen in Italian patients (mean 4.56), which is consistent with the Mediterranean diet's cultural origins in Southern Europe and has been documented in prior Italian research [7]. Slovak patients scored considerably lower (mean 3.45), which reflects the Central European dietary tradition of higher consumption of refined carbohydrates, dairy products, and red meat, alongside lower intake of fish, vegetables, and legumes. The combination of the lowest dietary quality scores and the highest mean disability level (EDSS 4.91) in the Slovak cohort fits with the broader hypothesis that diet and disability are connected, though it is important to acknowledge that differences in disease type, access to treatment, and socioeconomic conditions between countries are also likely to play a role.

It should be emphasised that this was an observational, cross-sectional survey rather than a dietary intervention study; the variable “formal dietary advice” reflects only whether a patient recalled having received such advice from a physician, not the content, nature, or duration of any advice actually given, which was not captured by the survey instrument.

The high prevalence of vitamin D supplementation observed across all three countries is broadly consistent with widely used clinical guidance in MS, reflecting evidence linking vitamin D status to relapse risk and disease activity, with recent meta-analyses of randomised controlled trials showing statistically significant, if clinically modest, reductions in EDSS scores and relapse rates with long-term (> 12 months) high-dose supplementation [14], while the lower and more variable prevalence of omega-3 supplementation likely reflects its less consistently established role; a systematic review of omega-3/fish oil supplementation in MS reported beneficial effects on relapse rate, inflammatory markers, and quality of life, supporting its more selective use [15].

However, the present survey did not record whether these supplements were clinician-recommended or self-initiated, nor did it capture use of other vitamins or minerals; consequently, the clinical appropriateness or adequacy of the supplementation patterns observed cannot be determined from these data, and this should be addressed directly in future studies.

One of the most practically important findings of this study is the gap between patient motivation and professional support around diet. Only 26% of patients had received any formal dietary advice from their doctor, even though 47% had changed their eating habits after being diagnosed. Most strikingly, the UK/international group, where 82.4% had changed their diet independently, had the lowest rate of physician dietary guidance (11.8%). Patients are clearly motivated to make dietary changes but are largely doing so without guidance, which risks poor nutritional choices. Including registered dietitians as a standard part of multidisciplinary MS care, with particular attention to patients who have higher disability or have been living with the disease for many years, is supported by the evidence and should be a clinical priority [16-19].

Limitations of the study

This study has several important limitations that should be considered when interpreting the findings. First, its cross-sectional, single-timepoint design means that only associations, not causal or longitudinal relationships, can be inferred; in particular, the reported patterns by disease duration reflect differences between patients diagnosed at different times, not change within individuals over time, and the study is best regarded as a pilot investigation rather than a definitive test of these associations. Second, the sample was recruited through patient organisations and online community platforms using a convenience-sampling approach, and subgroup sizes were modest and unevenly distributed across countries, EDSS bands, and disease-duration categories (e.g., $n = 3$ in the EDSS > 8 group); this raises the possibility of selection bias and limits the precision and generalisability of subgroup comparisons. Third, EDSS scores, MS diagnosis, and disease duration were all self-reported rather than verified against clinical records, and educational attainment was not collected, preventing adjustment for this potential confounder (age and sex, which were collected, are reported in the Study design and participants section, though their distribution differed somewhat between the three national samples). Fourth, dietary intake and Mediterranean diet adherence were assessed using a self-administered, self-reported questionnaire (MEDAS), which is subject to recall and social desirability bias, and which was originally validated

in a Mediterranean population; its performance in Central European and non-Mediterranean populations has not been independently established. Fifth, no biological markers of inflammation or nutritional status were measured, so the proposed mechanistic pathway linking diet, gut microbiota, inflammation, and disability could not be tested directly. Finally, information on participants' dietary habits prior to MS diagnosis, and on whether dietary changes were made on physician recommendation or on patients' own initiative, was not collected, which limits interpretation of the reported changes in eating habits after diagnosis. An alternative analytic approach – for example, directly contrasting MEDAS-defined adherent versus non-adherent patients across EDSS and disease-duration categories – could complement the descriptive analysis presented here and is recommended for future re-analysis of these data.

Given the cross-sectional design, modest and unevenly distributed subgroups, and the other methodological limitations discussed above, these findings should be interpreted as preliminary and hypothesis-generating rather than as evidence of a causal, longitudinal, or dose-dependent influence of disability or disease duration on diet; on this basis, the present study is best regarded as a pilot investigation.

CONCLUSIONS

This cross-sectional survey suggests that Mediterranean diet adherence, assessed using the validated MEDAS tool, is predominantly poor among people with MS across all three countries studied, and that self-reported adherence to the Mediterranean diet substantially overestimates adherence as measured objectively. Lower MEDAS-assessed adherence was observed in association with higher self-reported disability and, less consistently, with longer disease duration.

Nonetheless, the gap between the proportion of patients who changed their diet independently after diagnosis and the much smaller proportion who recalled receiving formal dietary advice from a physician point to an unmet need for structured, professionally guided nutritional support in MS care. Incorporating evidence-based nutritional guidance on the Mediterranean diet, assessed through validated tools such as the MEDAS, into multidisciplinary MS care warrants consideration, with confirmatory research particularly needed for patients with greater disability or longer disease duration.

Future research should build on these findings by using study designs that follow patients over time, confirm disability and diagnosis through clinical assessment and medical records rather than self-report, recruit larger and more balanced samples across EDSS

and disease-duration strata, and include objective measures of dietary quality, nutritional status, and inflammation, such as validated biomarkers and gut microbiome analysis.

Conflict of interest

There were no conflicts of interest.

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ANALYSIS OF ENERGY AND MACRONUTRIENTS INTAKE IN PATIENTS WITH TYPE 1 AND TYPE 2 DIABETES MELLITUS: A PILOT STUDY

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ABSTRACT

Background. Diabetes mellitus (DM) is a metabolic disease characterized by impaired glycaemic control. We are familiar with the various types of DM and the different treatment options available. Nutrition is important for each type of DM.

Objective. The objective of this study was to calculate daily energy and macronutrient intake in people with DM using three-day dietary records.

Materials and Methods. A total of 40 people with type 1 (45%) or type 2 (55%) DM completed a three-day dietary record. Daily energy and macronutrient intake were assessed using the Planeat nutritional application. Statistical analyses were performed using the two-sample t-test assuming unequal variances and one-way analysis of variance (ANOVA), with statistical significance set at $p < 0.05$.

Results. The participants had a mean age of 48.33 ± 21.71 years, with an average body weight of 73.60 ± 22.07 kg and height of 168.43 ± 12.80 cm. Compared with the reference values, fasting plasma glucose, HbA1c and triacylglycerol concentrations differed significantly ($p < 0.001$), whereas no significant difference was observed for total cholesterol ($p > 0.05$). Dietary analysis showed lower intakes of carbohydrates (155.04 ± 50.49 g) and fats (59.94 ± 30.44 g), while protein intake remained within the recommended range (78.35 ± 31.94 g). Carbohydrates accounted for a lower proportion of total daily energy intake ($43.03 \pm 8.75\%$), whereas the contributions of fats ($34.61 \pm 9.39\%$) and proteins ($22.36 \pm 6.61\%$) were higher. However, none of these differences between the measured and recommended macronutrient intakes reached statistical significance ($p > 0.05$).

Conclusions. Medical nutrition therapy remains a key component of DM management. These findings emphasize the importance of individualized dietary counselling aimed at improving macronutrient balance, dietary quality, and patient education to support glycaemic control and reduce the risk of diabetes-related complications.

Keywords: diabetes mellitus, treatment, nutrition, macronutrient intake, energy intake

INTRODUCTION

Diabetes mellitus (DM) is a long-term disease that occurs when the body is unable to process and regulate blood glucose levels, either due to excessive insulin secretion from the pancreas or due to insulin being unable to regulate blood glucose levels [1]. DM is a chronic metabolic condition characterised by persistent hyperglycaemia caused by deficiencies in insulin synthesis or action [2]. The first and most common symptoms of DM are increased thirst (polydipsia), hunger, frequent urination, headache, blurred vision, fatigue, weight loss, skin infections and slow wound healing. These are all symptoms of long-term hyperglycaemia [3]. Diagnostic criteria for diabetes mellitus are the random plasma glucose ≥ 200 mg/dL (≥ 11.1 mmol/L) or the fasting plasma glucose ≥ 126 mg/dL

(≥ 7.0 mmol/L) or the 2-hour oral glucose tolerance test (OGTT) value in venous plasma ≥ 200 mg/dL (≥ 11.1 mmol/L) or glycated hemoglobin (HbA1c) $\geq 6.5\%$ (≥ 48 mmol/mol Hb) [4]. DM is classified into several clinical categories, although these are being reevaluated based on genetic, metabolomic and other characteristics and pathophysiology: type 1 diabetes mellitus (T1DM), type 2 diabetes mellitus (T2DM), specific types of DM caused by other causes and gestational diabetes mellitus (GDM). T1DM is caused by autoimmune damage to pancreatic β cells, usually leading to absolute insulin deficiency, including latent autoimmune diabetes in adults (LADA). It accounts for 5-10% of all types of DM. T1DM most often occurs in children and young adults (< 35 years) [5].

The primary treatment option for T1DM is insulin replacement therapy. The current treatment regimen for T1DM involves combining an intensive diet with the

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lifelong administration of exogenous insulin, either via multiple daily injections or by using insulin pumps [6].

The growing number of obese people worldwide is one of the factors contributing to the increasing prevalence of T2DM [7]. T2DM is characterised by dysregulation of glucose metabolism, leading to hyperglycaemia. It is typically caused by insulin resistance and impaired insulin secretion, both of which result in impaired glucose tolerance [8]. More than 90 % of diabetes cases worldwide are T2DM. T2DM can be prevented and managed through education, lifestyle changes, necessary medication and other available treatments [7].

Medical nutrition therapy is an essential component of both diabetes management and self-management education [9]. The long-term goals of nutritional therapy for diabetics should be to achieve near-normal blood glucose levels without an excessive risk of frequent hypoglycaemia; to focus on cardiovascular health; to maintain a normal body weight; to prevent acute and chronic complications of diabetes; and to improve overall health and quality of life [10].

Monitoring carbohydrate intake is a key strategy for achieving normal blood glucose levels in people with T1DM and T2DM [9]. The glycemic index (GI) indicates how quickly and for how long an individual food will raise blood sugar levels in people without DM [11]. Foods are divided according to their GI: foods with a low GI raise blood sugar levels slowly (e.g. legumes, nuts, rye bread, white yogurt). Foods with a medium GI raise blood sugar level somewhat more quickly (e.g. boiled potatoes, parboiled rice, wheat bread). Foods with a high GI raise blood sugar level quickly (e.g. sweetened drinks, pastries, honey). People with DM should prefer foods with low or medium GI. High GI foods are good for hypoglycaemia [12]. For people with DM, the main goal of fat intake is to limit saturated fat and cholesterol intake [9]. People with DM should consume for fats containing monounsaturated and polyunsaturated fatty acids, including omega-3 [13]. Good sources of protein include milk and dairy products, legumes, eggs, fish, poultry, and lean meat [14].

The objective of this study was to calculate the daily energy intake, the daily intake of macronutrients and the average percentage of energy from macronutrients in diet of people with DM.

MATERIAL AND METHODS

Characteristics of the patients with DM

The study population comprised 40 individuals with DM from Slovakia. Study participants were recruited from a diabetes outpatient clinic and a diabetes association in Nitra. Nitra is a city located in the western part of Slovakia, in the Nitra

Region, approximately 90 km east of the capital city, Bratislava. It lies in the Nitra Region, in the Danubian Lowland, at the foothills of the Tribeč Mountains. Of the participants, 45% were diagnosed with type 1 DM and 55% with type 2 DM. The sample included 15 men (37.5%) and 25 women (62.5%). The study cohort consisted of 4 children and 36 adults with diabetes mellitus. No age restrictions were applied during participant recruitment, allowing for the inclusion of a diverse study population.

Participants were eligible for inclusion if they had been diagnosed with type 1 or type 2 DM, were willing to participate in the study and provided written informed consent, were able to independently complete the questionnaire and maintain a food intake record and had a stable health status at the time of data collection. Of all patients with diabetes included in our pilot study, 23 were treated with insulin therapy, 20 received oral or other pharmacological antidiabetic medications, and 15 were managed through dietary interventions. Thus, the distribution of treatment modalities reflected the diversity of therapeutic approaches within the study population.

Participants were excluded if they (women) had GDM, a serious acute or chronic disease that could significantly affect dietary intake or metabolism (e.g., oncological, renal, or hepatic diseases), followed a specific therapeutic diet unrelated to diabetes (e.g., a diet for phenylketonuria), were using antibiotics at the time of data collection, or provided incomplete dietary records or questionnaires.

Data acquisition methods

Data were collected using an anonymous online questionnaire that included a three-day dietary record. The questionnaire was created and administered through Google Forms and consisted of 42 questions, including 15 closed-ended and 27 open-ended questions, with the latter also incorporating items from the dietary protocol.

The questionnaire was divided into two sections. The first section collected demographic information, anthropometric data (body weight and height), basic information regarding diabetes, selected biochemical parameters, and lifestyle characteristics. Current values of body weight and height, as well as selected biochemical blood parameters were obtained from participants' medical records with their informed consent. Following the calculation of BMI using the appropriate formula, BMI values were assessed separately for children and adults. In children, the calculated BMI values were subsequently plotted on percentile charts according to age and sex. Based on the corresponding percentile, children were classified into the following categories: underweight – BMI < 5th percentile; normal weight – BMI from the 5th to

< 85th percentile; overweight – BMI from the 85th to < 95th percentile; and obesity – BMI $\geq$ 95th percentile. In the adult participants of our pilot study, BMI was classified as follows: underweight – < 18.5 kg/m²; normal weight – 18.5-24.9 kg/m²; overweight – 25.0-29.9 kg/m²; and obesity – $\geq$ 30.0 kg/m². The second part focused on dietary habits. Dietary intake data were collected using a three-day dietary record, in which participants documented all consumed food and beverages, including portion sizes, during the selected days. Participants were instructed to record their intake for two randomly selected weekdays and one randomly selected weekend day. The dietary records included the following meals: breakfast, morning snack, lunch, afternoon snack, dinner, and an optional second dinner.

Data collection

Data collection was performed between November 2025 and February 2026. Participants received the questionnaire either electronically via email and social media platforms or in a paper-based format during in-person contact. The questionnaire for pediatric patients with diabetes mellitus was completed by a parent. The results of the blood tests were obtained from the patients' medical records with their informed consent. Blood samples were collected at the diabetology outpatient clinic attended by the patients. Blood was collected by venipuncture with the patients in a seated position, and the procedure was performed by qualified healthcare personnel. The blood samples were subsequently sent to a certified laboratory, where individual blood parameters were analyzed according to the requirements of the diabetologist. According to the DCCT methodology, the range of HbA1c is as follows: nondiabetics usually falls within the range of 4.0-5.6%, prediabetes usually has HbA1c levels of 5.7-6.5%, people with a glycated haemoglobin level of more than 6.5% have DM. As DM is associated with multiple complications, recommendations for individuals with the condition include maintaining HbA1c levels below 7.0% (DCCT) [15].

No nutritional counseling or dietary intervention was provided to participants during or after the study period.

Ethical considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki as revised in 2024 [16]. Ethical approval from an ethics committee was not required for this study. All participants provided informed consent for participation and for the use of data obtained from the questionnaire and dietary protocol. For participants who were children, informed consent was obtained from their parents or legal guardians.

Data analysis

The data collected from the questionnaires was evaluated statistically and graphically using Microsoft Office Excel 2010 (Los Angeles, Ca, USA). Energy and macronutrient intake were assessed individually for each participant using the Planeat nutritional application (this application is used to create personalised nutritional plans and is available in three versions, depending on the professional focus: Trainer, Nutritionist and Medical). The Planeat application includes a dedicated "Medical" version designed to support nutritional management in patients with specific medical diagnoses. The application can be used in various medical fields, including diabetology, obesity medicine, dietetics, gastroenterology, cardiology, nephrology, neurology, and oncology. It enables the assessment of dietary habits, including the intake of energy, macronutrients and selected vitamins and minerals, and allows other lifestyle factors, such as fluid intake, sleep patterns, and physical activity, to be taken into account. In addition, the application facilitates the development of individualized meal plans based on the patient's nutritional requirements, health status, and individual dietary preferences. Energy and macronutrient intake were assessed individually for each participant using the Planeat nutritional application, based on data obtained from the participants' nutritional protocols. Participant characteristics, including age, gender, body weight, height, body mass index (BMI), were entered into the application. Based on these data, the application automatically calculated individualized reference values for energy and nutrient requirements. The final analysis and summary of the results were based on the individually assessed dietary intake data of each participant. The data obtained from Planet were then evaluated statistically and graphically using Microsoft Office Excel 2010 (Los Angeles, Ca, USA). The levels of statistical significance were set at $p < 0.05$, $p < 0.01$ and $p < 0.001$. We used a t-test: two-sample assuming unequal variances for the statistical evaluation of biochemical parameters. We statistically evaluated the energy and macronutrient intake of patients with DM using one-factor analysis of variance (ANOVA). Given the nature of the variables studied and the objectives of the statistical analysis, the use of parametric methods (two-sample assuming unequal variances and one-way ANOVA) was considered appropriate. However, given the relatively small sample size, verification of the results using non-parametric methods may be warranted and should be considered in future research.

RESULTS

The final analysis included data from all 40 participants enrolled in the study. This section

presents the demographic and anthropometric characteristics of the study population, with particular focus on age, gender distribution, body weight, height, and BMI values. The obtained results are summarized in Table 1. The average age of the participants was 48.33 ± 21.71 years (range: 7.00-96.00 years). The mean body weight and height were 73.60 ± 22.07 kg and 168.43 ± 12.80 cm, respectively. The average BMI was 25.65 ± 6.58 kg/m², corresponding to the threshold between the normal weight and overweight categories. Based on BMI classification, 5 participants (12.5%) were underweight, 14 (35.0%) had normal weight, 12 (30.0%) were overweight, and 9 (22.5%) were classified as obese.

Table 2 presents the biochemical parameters of participants with DM. Reference values for the monitored biochemical parameters were as follows (normal/prediabetes/diabetes): FPG < 5.6/5.6-6.9/ ≥ 7.0 mmol/L; HbA1c < 39/39-47/ ≥ 48 mmol/mol (in percentage terms 4.0-5.6/5.7-6.5/ $> 6.5\%$). Normal values for TG

and total cholesterol (for diabetes) were < 1.7 mmol/L and < 4.5 mmol/L, respectively [5, 15]. Their mean fasting glucose level was elevated (7.06 ± 1.70 mmol/L) and showed a highly statistically significant difference compared with the reference values ($p < 0.001$). The percentage distribution of fasting blood glucose values showed that 0% of diabetic patients fell below the reference range, 77.5% were within the normal range, and 22.5% were above the reference range. Similarly, triacylglycerol levels (1.08 ± 0.87 mmol/L) differed significantly from the reference values ($p < 0.001$). In the case of triacylglycerols, 27.5% of patients had values below the normal range, 65% within the normal range, and 7.5% above the normal range. A statistically significant difference was found in the HbA1c parameter ($8.23 \pm 1.34\%$) compared with the reference values ($p < 0.001$). In contrast, no statistically significant differences were observed for total cholesterol levels (4.30 ± 0.13 mmol/L) when compared with the respective reference values ($p > 0.05$). For glycated hemoglobin,

Table 1. Characteristics of DM patients

	average $\pm$ SD	min. – max.	med	mod
Age (yrs)				
All (n = 40)	48.33 ± 21.71	7.00 – 96.00	49.50	66.00
Men (n = 15)	44.73 ± 24.58	7.00 – 96.00	46.00	-
Women (n = 25)	50.48 ± 20.01	16.00 – 79.00	54.00	66.00
Body weight (kg)				
All (n = 40)	73.60 ± 22.07	23.00 – 138.00	70.00	70.00
Men (n = 15)	75.33 ± 25.47	23.00 – 112.00	77.00	-
Women (n = 25)	72.56 ± 20.25	51.00 – 138.00	68.00	70.00
Body height (cm)				
All (n = 40)	168.43 ± 12.80	115.00 – 198.00	168.00	175.00
Men (n = 15)	170.00 ± 18.40	115.00 – 190.00	175.00	175.00
Women (n = 25)	167.48 ± 8.13	155.00 – 198.00	165.00	165.00
BMI (kg/m ²)				
All (n = 40)	25.65 ± 6.58	15.00 – 47.00	25.00	23.00
Men (n = 15)	25.33 ± 6.40	15.00 – 37.00	25.00	23.00
Women (n = 25)	25.84 ± 6.81	17.00 – 47.00	25.00	25.00

Data are expressed as average $\pm$ standard deviation (SD); n – number of participants; min. – max.; med – median; mod – modus; BMI – body mass index.

Table 2. Biochemical parameters of DM patients

Biochemical parameters	DM patients (n = 40)			
	average $\pm$ SD	min. – max.	med	p-value
Fasting plasma glucose (mmol/L)	7.06 ± 1.70	4.50 – 12.00	6.80*	0.0000
HbA1c (%)	8.23 ± 1.34	4.30 – 10.50	6.85*	0.0002
Cholesterol (mmol/L)	4.30 ± 0.13	3.00 – 7.20	4.29	0.0726
TG (mmol/L)	1.08 ± 0.87	0.42 – 4.70	0.89*	0.0003

Data are expressed as average $\pm$ standard deviation (SD); n – number of participants; min. – max.; med – median; HbA1c – glycated haemoglobin; TG – triacylglycerols; these values are compared with the reference values; * statistically significant differences ($p < 0.05$).

2.5% of patients had values below the normal range, 37.5% had values within the normal range, and 60% had values above the normal range. The percentage distribution of total cholesterol values showed that 0% of diabetic patients had values below the reference range, 80% within the normal range, and 20% above the reference range.

Table 3 presents the energy intake (in kJ and kcal) and the macronutrient intake (in grams) based on three-day dietary records of participants with DM. The analysis of the three-day nutritional protocols revealed considerable variability in nutrient intake among participants with DM. Compared with the recommended values for individuals with DM, participants in this study consumed, on average, lower amounts of carbohydrates (155.04 ± 50.49 g/day) and fat (59.94 ± 30.44 g/day) than recommended. The percentage distribution of carbohydrate intake (g/day) was as follows: 85% of the patients monitored in our pilot study had an intake below the recommended level. An intake within the normal range was observed in 10% of diabetic patients, while an intake above the normal range was observed in the remaining 5%. The percentage distribution of fats intake (g/day) was as follows: 65% of the patients monitored in our pilot study had an intake below the recommended level. An intake within the normal range was observed in 15% of diabetic patients, while an intake above the normal range was observed in the remaining 20%. According to Gažarová et al. [17], the recommended daily intake of carbohydrates should range from 200 to 250 g, while fat intake should be approximately 80 g/day. The recommended protein intake is 1 g/kg/day, although

a lower intake of 0.8 g/kg/day is also considered appropriate [17]. Based on the participants' body weight, the recommended protein intake was calculated individually for each participant. The average protein intake in this study was 78.35 ± 31.94 g/day, which was within the individually calculated recommended range. No statistically significant differences were observed between the participants' intake of individual macronutrients and the corresponding recommended values ($p > 0.05$).

Compared with the recommended values for people with DM, the proportion of total daily energy intake derived from carbohydrates was lower ($43.03 \pm 8.75\%$) than the recommended range of 45-60% [18]. In contrast, the proportions of total daily energy intake derived from fats ($34.61 \pm 9.39\%$) and proteins ($22.36 \pm 6.61\%$) were higher than the recommended ranges of approximately 20-30% and 15-20%, respectively [11]. However, no statistically significant differences were observed between the observed and recommended values for any of the three macronutrients ($p > 0.05$).

Table 4 presents the percentage contribution of macronutrients to total energy intake based on three-day dietary records of participants with DM. Compared with the recommended values for individuals with DM, the percentage of total daily energy intake from carbohydrates was lower ($43.03 \pm 8.75\%$) than the recommended value. Conversely, the percentage of energy intake from fats ($34.61 \pm 9.39\%$) and proteins ($22.36 \pm 6.61\%$) was higher than recommended. No statistically significant differences were observed for any of the three macronutrients ($p > 0.05$).

Table 3. Energy and macronutrients intake from 3 days in patients with DM

Energy and macronutrients	DM patients (n = 40)			
	average $\pm$ SD	min. – max.	med	p-value
Energy (kJ; kcal)	6360.83 ± 2109.21 ; 1520.27 ± 504.11	3170.00 – 11393.33; 757.65 – 2723.07	5999.50; 1433.91	0.9981
Carbohydrates (g)	155.04 ± 50.49	55.67 – 285.33	154.00	0.4681
Fats (g)	59.94 ± 30.44	17.67 – 147.33	54.00	0.8061
Proteins (g)	78.35 ± 31.94	24.00 – 159.67	73.00	0.8610

Data are expressed as average $\pm$ standard deviation (SD); n – number of participants; min. – max.; med – median these values are compared with the reference values.

Table 4. Percentage (%) macronutrients intake from 3 days in patients with DM

Macronutrients	DM patients (n = 40)			
	average $\pm$ SD	min. – max.	med	p-value
Carbohydrates (%)	43.03 ± 8.75	23.67 – 64.33	42.33	0.1827
Fats (%)	34.61 ± 9.39	16.67 – 57.00	34.67	0.6092
Proteins (%)	22.36 ± 6.61	10.67 – 40.67	22.00	0.3780

Data are expressed as average $\pm$ standard deviation (SD); n – number of participants; min. – max.; med – median; these values are compared with the reference values.

DISCUSSION

DM is a chronic disease characterised by elevated blood glucose concentrations. It is a major risk factor for cardiovascular disease, as well as increasing the risk of mortality and morbidity [19].

Glycated haemoglobin (HbA1c) values represent average glycaemic control over the previous two to three months [20]. In our study, the mean HbA1c concentration was $8.23 \pm 1.34\%$, indicating suboptimal glycaemic control in the study population. This finding is comparable to that reported by Russo et al. [21], who observed a mean HbA1c value of 8.40%. The comparable HbA1c levels suggest that inadequate glycaemic control remains a relevant issue among people with DM, despite differences in dietary patterns and lipid parameters. In contrast to the HbA1c findings, our participants demonstrated a more favourable lipid profile than that observed by Russo et al. [21]. Mean total cholesterol and triglyceride concentrations in our cohort were 4.30 ± 0.13 mmol/L and 1.08 ± 0.87 mmol/L, respectively, compared with 4.85 mmol/L and 1.62 mmol/L, respectively, in the study by Russo et al. [21]. Although these differences may indicate better lipid control in our study population, they should be interpreted cautiously, as lipid concentrations are influenced by several factors, including pharmacological treatment, dietary intake, physical activity, body composition, and diabetes duration. Moreover, differences in patient characteristics and treatment strategies between the two studies may have contributed to the observed variation. Current recommendations emphasise that glycaemic and lipid targets should be individualised according to factors such as age, duration of diabetes, comorbidities, treatment regimen, and the risk of complications. Nevertheless, achieving adequate glycaemic and lipid control remains an important component of reducing the risk of both microvascular and macrovascular complications [17, 22].

A diabetic diet is a lifelong measure. The basis of a diabetic diet should be a varied and balanced diet to support maintaining an appropriate weight. The main food groups provide all the necessary nutrients, including carbohydrates, fats, proteins, vitamins, minerals and fibre. The recommended daily division of the diet is into six meals [12, 23]. The total daily energy intake should be sufficient to achieve and maintain the desired body weight. Most patients with type 2 DM are overweight or obese. Therefore, the main goal is to lose weight by reducing daily calorie intake [10, 13]. There is no clear evidence on the ideal amount of carbohydrates, fats and proteins that people with DM should consume. However, general recommendations for therapeutic nutrition in diabetes are as follows: the amount of carbohydrates should be

between 200–250 g per day, the amount of fat should be approximately 80 g, and the recommended dose of protein should be 1 g/kg, or a lower value of 0.8 g/kg is also recommended [22, 23].

In our study, the distribution of macronutrient intake differed from that reported by Farooqi et al. [22]. Participants in our cohort consumed lower mean amounts of carbohydrates and fat but a higher mean amount of protein. Farooqi et al. [24] reported mean daily intakes of 230.6 g of carbohydrates, 66.1 g of fat, and 68.1 g of protein. These differences may reflect variations in dietary habits, cultural patterns, energy requirements, body composition, treatment characteristics, or other population-specific factors.

The proportion of energy derived from carbohydrates in our study was $43.03 \pm 8.75\%$, which was similar to the 44% reported by Li et al. [25]. This value is within or close to the range generally reported for carbohydrate intake among adults with DM (45–60%), although the optimal proportion should not be considered universal. Contemporary nutritional recommendations emphasise that carbohydrate intake should be individualised according to dietary preferences, metabolic goals, medication, physical activity, body weight, and individual glycaemic response [18, 26]. Thus, the similarity between our findings and those of Li et al. [25] suggests a comparable relative contribution of carbohydrates to total energy intake in the two study populations. However, carbohydrate proportion alone does not reflect carbohydrate quality, including the intake of dietary fibre, whole grains, fruits and vegetables, as well as refined carbohydrates, all of which may influence metabolic outcomes.

In contrast, fat accounted for approximately $34.61 \pm 9.39\%$ of total daily energy intake in our study, which was comparable to the proportion reported by Li et al. [25] but higher than the 20–30% range recommended in some dietary guidelines [11]. This finding may suggest that dietary fat intake warrants particular attention in our study population. This negative trend in fat intake is of particular concern in people with DM, as excessive fat consumption may contribute to elevated blood lipid concentrations (hyperlipidaemia) and is associated with cardiovascular disease and stroke, which are complications of DM [27]. However, the total amount of dietary fat should not be considered independently of its quality, as the type of fat consumed, particularly the balance between saturated and unsaturated fatty acids, also plays an important role in lipid metabolism and cardiovascular risk. Therefore, nutritional interventions should focus not only on limiting excessive fat intake but also on improving dietary fat quality by favouring unsaturated over saturated fatty acids.

The recommended protein intake generally accounts for approximately 15-20% of total daily energy intake [28]. Li et al. [25] reported that protein contributed 17% of daily energy intake among people with DM, which was within the recommended range. In contrast, protein contributed a higher proportion of daily energy intake in our study ($22.36 \pm 6.61\%$). Although this intake was higher than that reported by Li et al. [25], the clinical significance of this difference should be interpreted cautiously, as protein requirements may vary depending on individual characteristics, including age, body weight, nutritional status, and the presence of chronic kidney disease. Therefore, protein intake should be appropriately individualised, particularly in people with DM who have impaired renal function [29].

From a DM perspective, making the right food choices helps to maintain long-term health, has a therapeutic and preventive effect, and helps to control blood sugar levels, blood fats, blood pressure, and body weight. It also promotes the efficient use of insulin and ensures the body receives the necessary vitamins and minerals. A nutritional approach should be tailored to the individual, taking into account their personal preferences, socioeconomic status, cultural background and comorbidities [29, 30].

Strengths and limitations of the study

A major strength of this study is its focus on current issues related to nutrition, which represents an integral component of diabetes mellitus (DM) management. Another important advantage is the detailed analysis of patients' dietary intake, providing valuable insights that may be applicable in clinical practice. Furthermore, the use of standardized software for dietary assessment (Planeat) ensured consistent and uniform processing of the collected data.

The main limitations of this study include the relatively small sample size ($n = 40$), which may limit the generalizability of the findings. The sample size was based on the availability of eligible participants, and no formal sample size calculation was performed. Another limitation is the unequal gender distribution, which may have affected the results due to differences in metabolic parameters, dietary habits, and body composition between men and women. In addition, the use of participant-reported data on food intake, body weight, and other variables (obtained from their medical records) may have introduced bias due to potential inaccuracies in reporting and estimation.

CONCLUSIONS

Although the overall dietary intake of the participants was generally consistent with current nutritional recommendations, the observed imbalance

in the relative contribution of macronutrients suggests that dietary habits remain suboptimal among many people with DM. These findings underscore the need for individualized nutritional counselling that addresses not only total energy intake but also the quality and distribution of macronutrients in accordance with current evidence-based recommendations.

Regular dietary assessment should be incorporated into routine diabetes care, as it may help identify inappropriate dietary patterns, optimize metabolic control, and reduce the risk of long-term diabetes-related complications. A personalized nutritional approach, combined with ongoing patient education and lifestyle modification, remains essential for achieving optimal glycaemic control and improving overall health outcomes in people with DM.

Future studies involving larger and more diverse populations are warranted to confirm these findings and further elucidate the relationship between dietary intake, metabolic control, and long-term clinical outcomes. Nevertheless, the findings of this pilot study highlight the important role of nutritional therapy as an integral component of diabetes management.

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Conflict of interest

All authors declare that they have no conflict of interest.

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RADIOCAESIUM ACTIVITY IN POLISH *IMLERIA BADIA* MUSHROOMS: CONTAMINATION LEVELS AND TRENDS OVER THE LAST THREE DECADES

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ABSTRACT

Background. The Bay Bolete (*Imleria badia* Vizzini) is a prized edible wild mushroom. The fungus is unfortunately, also prone to mycelial uptake of anthropogenic radiocaesium (^{134/137}Cs) from contaminated substrates, which accumulates in the fruiting bodies.

Objective. To investigate, in light of historical atmospheric releases (including from Chernobyl) of radionuclides, the temporal and spatial distribution of radiocaesium and radiopotassium (⁴⁰K) activities in this species from eleven regions of Poland over the period 1995 to 2023. Literature data on this species over the same period were reviewed to supplement and support the findings.

Material and Methods. *Imleria badia* samples collected across eleven regions of Poland affected by radioactive fallout were determined for ¹³⁷Cs and ⁴⁰K activity by gamma spectrometry using a coaxial high purity germanium detector. The activity measurements were verified by using a reference solution of gamma emitting isotopes (BW/Z-62/27/07) for calibration.

Results. ¹³⁷Cs activity was detected in all but one sample with values ranging from < 6.4 to 11000 Bq·kg⁻¹ dw. ¹³⁴Cs activity was not detected – in line with its shorter half-life. ⁴⁰K activity remained relatively stable despite the variable amounts of ¹³⁷Cs activity, confirming the validity of the measurements.

Conclusions. The high values of BCF calculated (up to 134) confirm the propensity of *I. badia* to accumulate harmful ¹³⁷Cs activity. In some cases, the measured activity was above the regulatory tolerance limits set for human dietary exposure. Although individual regional sampling sites varied in number, the mean data for the regions indicated that the North Eastern part of Poland was most affected by ¹³⁷Cs contamination. The temporal trend shows a decline in mean ¹³⁷Cs activity from 5617 Bq·kg⁻¹ dw in the 1990s to 1095 Bq·kg⁻¹ dw in 2020.

Keywords: radiation exposure, Chernobyl accident, Bay Bolete, *Xerocomus badius*, ¹³⁷Cs and ¹³⁴Cs, edible wild mushrooms

INTRODUCTION

The Bay Bolete, current Latin name *Imleria badia* (Fr.) Vizzini, is a relatively common and widespread edible fungus in temperate to colder latitudes, particularly in Europe and northeastern North America. When growing conditions are favorable the fruiting bodies (mushrooms) can be found in abundance in pine and spruce forests but also to a lesser extent, in mixed forests under chestnut, oak and beech. Culinarily, it is generally considered as a prized wild edible species. The genus *Imleria* was established by Alfredo Vizzini in 2014 as a renaming of *Boletus badius* or *Xerocomus badius* and consists of eight members of

which the most known is *I. badia*. Other members include: *I. floridana* Farid, A.R. Franck & J. Bolin; *I. heteroderma* (J. Blum) T. Rödiger; *I. obscurebrunnea* (Hongo) Xue T. Zhu & Zhu L. Yang; *I. pallida* (Frost) Farid, A.R. Franck & J. Bolin; *I. parva* Xue T. Zhu & Zhu L. Yang; *I. spadiceomaculans* (H. Engel & W. Härtl) C. Hahn, and *I. subalpina* Xue T. Zhu & Zhu L. Yang [1]. Earlier literature has used a number of other scientific titles and synonyms of *Imleria badia* including *Boletus badius* (Fr.) Fr., *Boletus castaneus* var. *badius* (Fr.) Fr., *Ixocomus badius* (Fr.) Quél., but it was most popularly referred to as *Xerocomus badius* (Fr.) E.-J. Gilbert.

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When included in the diet, wild mushrooms have been identified, for some time, as a major direct source of artificial radioactivity in humans [2, 3]. This includes *Imleria badia*, which has been identified since the late 1960s as one of a few species that can be characterized by a tendency to efficiently accumulate artificial caesium (in most cases, the ^{137}Cs) radioisotope deposited onto soil from the fallout of atmospheric nuclear weapons tests [4-6]. There is no information available in the literature on whether other members of the *Imleria* genus show a similar tendency.

Atmospheric nuclear weapons testing was recognized as a major threat to global human food supply in the mid-1950s. This realization was specifically driven by the accumulation of radioactive strontium (^{90}Sr) and ^{137}Cs in environmental media followed by transfer into human and animal food webs. The Soviet-era Chernobyl (Czarnobyl, Chornobyl) nuclear power plant disaster on the 26th of April 1986 reinforced this realization with widespread public awareness in the period following the event [7-10]. The accident caused the largest known release of radionuclides to the environment, adversely affecting vast areas of the European continent. Much of the radionuclide contamination affected agricultural land and crops but forests were also impacted, including forest foods such as fruits, nuts, wild game and mushrooms. The awareness of the risk that radionuclide contamination poses to human health was recognized by regulatory authorities worldwide. In Europe, this acknowledgement took the form of regulation, specifying maximum permitted levels of radioactive contamination in food [11]. The regulation covers the most significant radionuclides and includes Strontium-90, Iodine-131, Plutonium-239, Americium-241 and the two most relevant radionuclides of Caesium, ^{137}Cs and ^{134}Cs (^{135}Cs is also produced in small amounts in reactors, it is mildly radioactive and is used diagnostically to fingerprint radiation sources, so is not included here) [11, 12]. The regulation covers a range of foods that can potentially be affected, including forest or wild mushrooms.

The range of wild mushrooms, whether edible, inedible or poisonous to humans, forms an important part of the diet of wild animals including game and can also be occasionally consumed by domestic ruminants. This constitutes an indirect source of dietary artificial radioactivity, largely from ^{137}Cs , which is considered as the major radioactive contaminant in the human food web [13-14].

The objective of this study was to evaluate the contamination from radiocaesium (nuclides ^{137}Cs and ^{134}Cs), of *I. badia* mushrooms obtained from locations in Poland during 1995 to 2023 and the potential human dietary exposure to consumers. In

view of the Chernobyl incident, the temporal range of the collected samples also allows any trends in contamination to be investigated. Although *I. badia* has been investigated for the presence of ^{137}Cs and ^{134}Cs contamination since the Chernobyl accident, this is the first study on the species from Poland that encompasses such a representative period of time (approximately 30 years, with respect to the half-life of ^{137}Cs) and large parts of the country. As part of the evaluation, available literature data from Poland was also used, as well as some limited information on the contamination of local forest topsoils. Results on the intensity of natural ^{40}K radioactivity was examined in parallel to radiocaesium, not only for the additional information but also as a measure of the integrity of the radiocaesium data. Further, data for two composite samples of *I. badia* collected from two spatially diverse neighboring regions to the east of Poland, in Belarus were also included.

MATERIALS AND METHODS

The Bay Bolete fruiting bodies that were used for the study included specimens collected from different regions of Poland that were identified as being affected, to various degrees, by fallout from the radioactive plume resulting from the collapse of the nuclear reactor at the Chernobyl Power Plant. These regions, numbered from 1 to 11 are indicated on the map in Figure 1 which shows the parts of Poland affected by the plume. Locations within these regions were sampled ($n = 86$) and the year of sample collection and quantity of mushrooms collected/analysed are given in Table 1. The principle adopted for each sampling area (forested sites were targeted in order to increase the likelihood of finding mushrooms) was that fruiting bodies were collected from 15 + 1 separate (more or less distant) spots. Practically, the number of fruiting bodies collected per site depended on the abundance at the time of collection. For the majority of sites, several (around 10 to 135) specimens were obtained. For a small handful (6) of the 86 samples, abundances were considerably lower resulting in the collection of two to six specimens. The fruiting bodies within each site were verified as *I. badia*, then combined to obtain a pool consisting of all individuals collected. This approach reduces the variability within sites that can arise from inhomogeneity of contaminant distribution, size of the fruiting body and stage of development. Typically, fruiting bodies were separated into caps and stems and then combined separately (knowledge of the biomass share may enable calculation of results for the entire fruiting body) or examined as a whole specimen (Table 1). Separating the fruiting body (or bodies) into caps and stems allows for additional quality control of the measurements (as does co-determination of

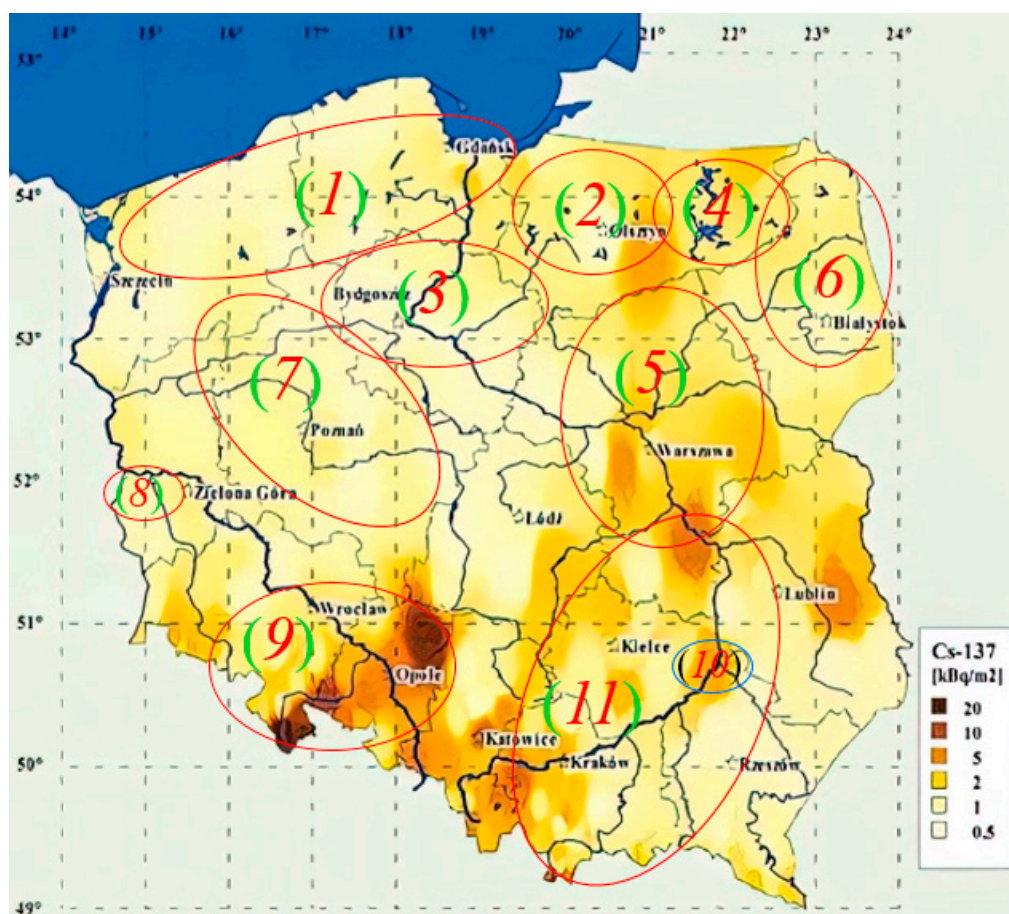


Figure 1. Map of Poland showing the distribution of ^{137}Cs background activity in soil ($\text{kBq}\cdot\text{m}^{-2}$) as simulated for year 2011 (as described earlier [20]; adapted). The *Imleria badia* sampling regions are roughly indicated as follows: Pomerania (1), Warmia (2), Kuyavia (3), Masuria (4), Mazovia (5), Podlachia (6), Greater Poland (7), Terra Lubucensis (8), Lower Silesia (9), Terra Sandomiriensis (10) and Lesser Poland (11)

^{40}K activity). The *I. badia* samples from Belarus were collected in September, 2010 from the Chojniki site ($n = 38$) in the highly polluted Homel (Gomel) region, and from the outskirts of the Staroje Janycha site ($n = 34$) in Borysów district in the Minsk region.

The samples were sliced using a plastic or ceramic knife and initially dried for one to two days at room temperature, followed by drying for 24–48 hours in an electrically heated commercial vegetable dryer (model: MSG-01 dehydrator by MPM Product, Milanówek, Poland) at around 65°C . Dried samples were ground to a fine powder either using a porcelain mortar or a vibrating grinder with a zirconium bowl (LMK – W/S; Testchem, Poland). Ground samples were sealed in polyethylene bags. Individual bagged samples from a site were placed in larger plastic bags and stored separately, sealed under dry and clean conditions in a large plastic container until further analysis.

Apart from *I. badia* fruiting bodies, forest topsoil (0–10 cm layer) was also collected at a few locations (Parchowo – 2010, Lubichowo – 2008 and Włoszczowa – 2007) and measured for ^{137}Cs and ^{40}K .

Air dried topsoil samples (free of stones, plant roots and branches) were ground using a porcelain mortar, graded to < 2 mm particle size through a plastic sieve and then stored in fresh polyethylene bags in tightly closed plastic containers. Before analysis, soil samples were additionally lyophilized for 48 h before measurement.

The methodology used to quantitatively determine nuclide activity in this study has been published in detail earlier [15–18]. In brief, a gamma spectrometer fitted with a coaxial high purity germanium (HPGe) detector with a relative efficiency of 40% and a resolution of 1.8 keV for a peak of 1332 keV of ^{60}Co , coupled to an 8192-channel computer analyzer, was used to measure the nuclide activity. The analyses of the radioactivity spectra, registered in 8000 channels, was carried out using Genie-2000 software. The instrument was calibrated with a multi-isotope standard using a fully validated method [18]. Measurements were carried out using sample aliquots of 10–20 g of dehydrated (ground) fungal material that were additionally lyophilized for 72 h before measurement. Measurement uncertainty is associated with each analytical result and includes

several components, including correction of sample geometry. The ^{137}Cs data (^{134}Cs was not detected) were decay corrected back to the time of mushrooms/soil collection. Measurements were validated using a standard solution of gamma emitting isotopes, 'code BW/Z-62/27/07' produced by IBJ-Świerk, Otwock, Poland. This standard was used to prepare reference samples for spectrometer calibration. The background activity (80000 s or 250000 s) determined before analysis, was subtracted (using the GENIE 2000 software) from the individual measurements of the samples. Potassium (total K) content can be calculated using the mean value of the activity concentration of ^{40}K in natural K which is in the range of 27.33 to 31.31 $\text{Bq}\cdot\text{g}^{-1}$ of K, as described earlier [19].

RESULTS

^{137}Cs and ^{40}K in *I. badia* mushrooms collected in Poland over time

^{137}Cs activity was detected in every pool of *I. badia* collected across Poland (Table 1), over the period from 1995 to 2022, except for a pool of three specimens sampled in the Kociewie region in 2023 which was below the detection limit of $6.4 \text{ Bq}\cdot\text{kg}^{-1}$ dry weight (dw). Overall, positive detections of ^{137}Cs were, as expected (Figure 1), highly variable between the regions of the country. Overall, ^{137}Cs concentrations in the studied mushrooms ranged from 87 ± 3 to

$8800 \pm 80 \text{ Bq}\cdot\text{kg}^{-1}$ dw for the whole fruiting bodies, from 290 ± 21 to $11000 \pm 89 \text{ Bq}\cdot\text{kg}^{-1}$ dw for caps, and from 330 ± 8 to $7600 \pm 130 \text{ Bq}\cdot\text{kg}^{-1}$ dw for stems (Table 1). Radioactivity from the shorter lived and less persistent nuclide, ^{134}Cs , was not detected (on the day of measurement) in any of the *I. badia* pools. It is known that *I. badia* is among several species of fungi that have a high potential for mycelial uptake and accumulation of radiocaesium in the fruiting body [4, 21-38]. Other fungal species with similarly high potential from genera such as *Amanita*, *Cortinarius*, *Lactarius*, *Paxillus*, *Sarcodon*, *Suillus*, *Tricholoma* or *Xerocomellus* are also native to the Northern Hemisphere [15, 19, 28, 29, 39-43]. The capabilities of tropical mushrooms for radiocaesium uptake are unknown.

Fungal fruiting bodies are rich in potassium, which is the major cation in cells, regulating osmosis and the cellular water balance at high levels (> 80%), and so this element undergoes strict regulation of uptake and retention by species [44]. Stijve [44] has reported on the species-specificity content of K in the fruiting bodies of various fungi. The occurrence of ^{40}K in studied *I. badia* was highly uniform (Table 1), and obtained values of BCF indirectly confirm this regulation of uptake [45]. The dose of radioactivity from natural ^{40}K isotope contained in the fruiting body is a part of background radiation received by all consumers of the mushrooms.

Table 1. Activity intensities of ^{137}Cs and ^{40}K ($\text{Bq}\cdot\text{kg}^{-1}$ dw; mean value $\pm$ measurement uncertainty) in cap, stem or a whole fruiting body of fungus *Imleria badia* collected occasionally in Poland in the period from 1995 to 2023 (all data rounded to show only two significant figures if different from zero)

Location, quantity of fruiting bodies in a composite sample and year of collection		^{137}Cs ($\text{Bq}\cdot\text{kg}^{-1}$ dw)	^{40}K ($\text{Bq}\cdot\text{kg}^{-1}$ dw)
		Cap // Stem	Cap // Stem
		(Whole fruiting body)	(Whole fruiting body)
<i>Pomerania (I)*</i>			
Kashubia, Kierzkowo [3]**	2020	$790 \pm 15 // 380 \pm 9$	$2500 \pm 230 // 1700 \pm 160$
Gdańsk Coast, Sobieszewo Island [60]	2020	(720 ± 9)	(1000 ± 88)
Gdańsk Coast, Sobieszewo Island [15]	2011	$930 \pm 13 // 1200 \pm 11$	$840 \pm 31 // 930 \pm 26$
Kashubia, Parchowo [12]	2010	$1400 \pm 17 // 1200 \pm 15$	$1300 \pm 100 // 1200 \pm 110$
Kashubia, Coastal Landscape Park [32]	2007	$1300 \pm 17 // 1100 \pm 15$	$1800 \pm 120 // 1400 \pm 110$
Kashubia, Sierakowice/Mojusz [12]	2007	$1900 \pm 22 // 1700 \pm 25$	$1500 \pm 110 // 1000 \pm 230$
Kashubia, Lipusz [18]	2006	$2300 \pm 25 // 2000 \pm 25$	$1400 \pm 100 // 1400 \pm 140$
Szczecinek County [20]	2003	$1300 \pm 16 // 1000 \pm 23$	$1700 \pm 100 // 1700 \pm 330$
Szczecinek County [19]	2002	$1700 \pm 21 // 1200 \pm 18$	$1300 \pm 100 // 790 \pm 140$
Kashubia, Coastal Landscape Park, Ostrowo [15]	2002	$2700 \pm 21 // 1700 \pm 16$	$1300 \pm 33 // 1000 \pm 31$
Kashubia, Rzecznica [113]	2002	$1700 \pm 17 // 1400 \pm 16$	$1500 \pm 45 // 1100 \pm 47$
Gdańsk Coast, Moraine Hills, Polanki [135]	2002	$1200 \pm 15 // 960 \pm 17$	$1600 \pm 90 // 1700 \pm 180$
Gdańsk Coast, Moraine Hills, Niedźwiednik [3]	2002	$1200 \pm 15 // 850 \pm 14$	$1700 \pm 90 // 1600 \pm 130$
Kashubia, Borowo [21]	2002	$1100 \pm 15 // 680 \pm 16$	$1700 \pm 230 // 1400 \pm 120$
Gdańsk Coast, Moraine Hills, Niedźwiednik [3]	2001	$600 \pm 49 // 610 \pm 140$	$1200 \pm 600 // \text{WD}$

Location, quantity of fruiting bodies in a composite sample and year of collection		¹³⁷ Cs (Bq·kg ⁻¹ dw)	⁴⁰ K (Bq·kg ⁻¹ dw)
		Cap // Stem	Cap // Stem
		(Whole fruiting body)	(Whole fruiting body)
Gdańsk Coast, Moraine Hills, Osowa [2]	2001	1300 ± 22 // 930 ± 45	1800 ± 220 // 950 ± 89
Gdańsk Coast, Sobieszewo Island [8]	2000	2200 ± 25 // 1800 ± 24	1200 ± 100 // 1300 ± 140
Kashubia, Wdzydze Landscape Park [16]	1998	1100 ± 17 // 790 ± 14	1500 ± 120 // 1300 ± 140
Kashubia, Wdzydze Landscape Park [10]	1998	9600 ± 100 // 5500 ± 59	1900 ± 180 // 940 ± 100
Kashubia, Wdzydze Landscape Park [6]	1998	7200 ± 77 // 6300 ± 71	1300 ± 150 // 1300 ± 190
Kashubia, Wdzydze Landscape Park [15]	1997	5600 ± 63 // 3400 ± 50	1300 ± 180 // 950 ± 330
Kociewie, Pomlewo outskirts [3]	2023	(< 6.4)	(1600 ± 310)
Kociewie, Pomlewo outskirts [21]	2022	(1100 ± 13)	(1700 ± 320)
Kociewie, Pomlewo outskirts [12]	2021	(87 ± 3)	(1000 ± 88)
Kociewie, Pomlewo outskirts [3]	2020	(250 ± 8)	(1300 ± 220)
Kociewie, Tuchola Pinewoods, Tleń [19]	2020	1400 ± 17 // WD	2000 ± 380 // WD
Kociewie, Tuchola Pinewoods, Śliwice [16]	2010	2500 ± 28 // WD	1300 ± 130 // WD
Kociewie, Tuchola Pinewoods, Śliwice [10]	2010	2100 ± 24 // 1400 ± 31	1500 ± 130 // 1500 ± 120
Kociewie, Tuchola Pinewoods, Lubichowo [23]	2008	3700 ± 37 // 2700 ± 30	1100 ± 120 // 1100 ± 120
Kociewie, Tuchola Pinewoods, Kasparus [15]	2000	5100 ± 45 // 4600 ± 48	1300 ± 52 // 1100 ± 43
Kociewie, Tuchola Pinewoods, Śliwice [20]	2000	4300 ± 46 // WD	1500 ± 110 // WD
Kociewie, Tuchola Pinewoods, Osiek [19]	2001	4500 ± 48 // 4300 ± 53	1800 ± 150 // 1600 ± 260
Kociewie, Tuchola Pinewoods, Osiek [19]	2000	4000 ± 44 // 3800 ± 41	1500 ± 110 // 1200 ± 110
Kociewie, Tuchola Pinewoods, Łuby [16]	1999	2600 ± 31 // 1800 ± 32	1600 ± 110 // 1100 ± 100
Kociewie, Zaborski Landscape Park [10]	1998	4400 ± 51 // 3300 ± 47	1600 ± 160 // 930 ± 300
<i>Warmia (2)</i>			
Commune Olsztynek, Orzechowo [30]	2007	4700 ± 48 // 4700 ± 47	1300 ± 100 // 990 ± 100
Kaszuny outskirts [10]	2003	5100 ± 47 // 2840 ± 26	1600 ± 49 // 1200 ± 40
Napiwodzko-Ramucka Forest [13]	2002	(7300 ± 73)	(1400 ± 100)
Olsztynek outskirts [16]	2002	2400 ± 20 // 1400 ± 12	1300 ± 35 // 920 ± 31
Puchałowo [16]	2001	3200 ± 33 // 5500 ± 53	1500 ± 59 // 1400 ± 65
Morąg outskirts [15]	2002	1600 ± 20 // 850 ± 14	1700 ± 110 // 1900 ± 140
Pasym outskirts [15]	1999	(8800 ± 80)	(1300 ± 55)
Morąg outskirts [16]	1998	(5200 ± 52)	(1300 ± 40)
Olsztyn outskirts [12]	1998	5800 ± 62 // 4900 ± 62	1100 ± 100 // ±1100 ± 80
<i>Kuyavia (3)</i>			
Toruń forests [15]	2006	760 ± 11 // 640 ± 13	1300 ± 52 // 1200 ± 68
Bukowiec [15]	2006	1500 ± 15 // 730 ± 15	1300 ± 40 // 970 ± 63
Chełmno outskirts [10]	2002	1600 ± 14 // 730 ± 11	1700 ± 40 // 1400 ± 50
Gostynińsko-Włocławskie forests, Goreń [70]	2001	3900 ± 35 // 3200 ± 27	1300 ± 51 // 1100 ± 36
Chełmno outskirts [15]	2001	1500 ± 19 // 1800 ± 24	1500 ± 100 // 1300 ± 150
Kobylarnia near Bydgoszcz [60]	2000	(2200 ± 28)	(1200 ± 46)
Kobylarnia near Bydgoszcz [60]	2000	2600 ± 29 // 2000 ± 32	1100 ± 85 // 1100 ± 80
<i>Masuria (4)</i>			
Piska Forest [23]	2003	5600 ± 57 // 3900 ± 41	1400 ± 100 // 980 ± 100
Piska Forest [15]	2002	7300 ± 73 // 3000 ± 51	1300 ± 110 // 920 ± 94
Szczytno outskirts [16]	2002	9100 ± 90 // WD	1600 ± 99 // WD
Giżycko region, Pieczarki [34]	2000	(2700 ± 28)	(1000 ± 50)
Giżycko outskirts [15]	2000	11000 ± 89 // 7600 ± 130	880 ± 45 // 620 ± 40
Kętrzyn, Commune Pożarki [43] juvenile specimens	2000	8100 ± 81 // 2300 ± 25	1400 ± 92 // 1100 ± 69
Commune Mrągowo, Cierzpięta [22] mature – large	1999	1200 ± 16 // 3700 ± 42	1200 ± 86 // 680 ± 120

Location, quantity of fruiting bodies in a composite sample and year of collection		¹³⁷ Cs (Bq·kg ⁻¹ dw)	⁴⁰ K (Bq·kg ⁻¹ dw)
		Cap // Stem	Cap // Stem
		(Whole fruiting body)	(Whole fruiting body)
<i>Mazovia (5)</i>			
Commune Olszewo-Borki [15]	2007	5700 ± 57 // 4100 ± 44	1400 ± 120 // 1500 ± 170
Commune Lutocin, Chrapoń [15]	2000	3100 ± 55 // 3100 ± 49	1600 ± 120 // 2600 ± 41
Commune Lutocin, Chrapoń [26]	1999	6400 ± 67 // 5600 ± 64	1400 ± 120 // 1100 ± 210
<i>Podlachia (6)</i>			
Wasilków village outskirts [6]	2013	1100 ± 22 // WD	1300 ± 350 // WD
Augustów Primeval Forest [15]	2007	4600 ± 46 // 3000 ± 30	1200 ± 97 // 1300 ± 120
Augustów Primeval Forest [15]	2000	3400 ± 31 // 2200 ± 23	1300 ± 43 // 920 ± 46
Augustów Primeval Forest [15]	1998	6600 ± 73 // 5800 ± 64	1200 ± 180 // 1100 ± 160
<i>Greater Poland (7)</i>			
Terra Siradiae, Uniejów [21]	2022	(910 ± 11)	(1400 ± 270)
Terra Siradiae, Dłutów [22]	2022	400 ± 6 // WD	1400 ± 270 // WD
Terra Siradiae, Uniejów [21]	2021	780 ± 10 // WD	1600 ± 300 // WD
Terra Siradiae, Dłutów [19]	2021	860 ± 10 // WD	(700 ± 330 // WD
Notecka Wilderness, Jesionna [15]	2008	970 ± 8 // 690 ± 19	1100 ± 28 // 710 ± 52
Notecka Wilderness [15]	2008	1300 ± 16 // 850 ± 8	1300 ± 100 // 830 ± 75
Rogalin outskirts [14]	2008	710 ± 10 // 520 ± 8	950 ± 81 // 870 ± 79
Porażyn outskirts [29]	2008	430 ± 8 // 330 ± 8	1100 ± 94 // 840 ± 130
Terra Siradiae, Turek [11]	2003	1700 ± 22 // 1400 ± 27	1200 ± 120 // 1300 ± 320
<i>Terra Lubucensis (8)</i>			
Gubin outskirts [13]	1995	(1700 ± 22)	(1500 ± 97)
<i>Lower Silesia (9)</i>			
Lower Silesia Forests [11]	2008	(1900 ± 53)	(930 ± 60)
Złotoryja [9]	2008	(460 ± 11)	(1000 ± 55)
Złotoryja [9]	2008	700 ± 11 // WD	1300 ± 120 // WD
Sudety Mts., Karpacz [31]	2008	1700 ± 13 // 890 ± 12	940 ± 28 // 770 ± 27
Sudety Mts., Kłodzka Dale [5]	2001	290 ± 21 // WD	2000 ± 500 // WD
<i>Terra Sandomiriensis (10)</i>			
Starachowice forests, Lipie [15]	2008	1100 ± 9 // 1200 ± 13	1100 ± 27 // 1400 ± 32
Włoszczowa [15]	2007	1500 ± 21 // 920 ± 14	1600 ± 180 // 890 ± 130
<i>Lesser Poland (11)</i>			
Tatra Mts., Chochołowska Valley [9]	2000	WD // 1400 ± 25	WD // 860 ± 240
Lubelska Upland, Poniatowa [15]	2000	1300 ± 18 // 820 ± 27	1900 ± 140 // 2000 ± 200
Tatra Mts., Chochołowska Valley [10]	1999	2100 ± 28 // 1100 ± 110	1400 ± 150 // 1700 ± 210

Note: *Sampling site id number; **Quantity of fruiting bodies in a composite sample; WD – without data

As part of the study, two sets of *I. badia* mushrooms were also collected from Belarus in 2010 and analysed along with the Polish samples. These sets from Chojniki and Staroje Janycha (Staroje Jančyna) differed substantially in the levels of ¹³⁷Cs contamination from the samples from Poland. Mushroom activity levels (caps // stems) were 21000 ± 200 // 15000 ± 120 Bq·kg⁻¹ dw and 1400 ± 18 // 1400 ± 9 Bq·kg⁻¹ dw, respectively for Chojniki and Staroje Janycha.

In this study ¹³⁷Cs and ⁴⁰K were determined in forest topsoils (0-10 cm layer) collected from the Parchowo (2010), Lubichowo (2008) and Włoszczowa

(2007) locations, from beneath or from points adjacent to the sampled fruiting bodies. ¹³⁷C activity concentrations in these topsoils were 21 ± 1, 28 ± 1 and 69 ± 2 Bq·kg⁻¹ dw, respectively.

Spatial distribution of activity

The variable distribution of the samples collected over the eleven sampling regions (Figure 1) makes spatial analysis difficult. This was not only due to the different numbers of samples for each site but also due to the differences in the years of sampling. The latter difficulty is mitigated to some extent as

the great majority of samples were collected from 1998 to 2007. Thus, any spatial analysis of the ^{137}Cs activity in *I. badia* from this data is at best, indicative. Despite these limitations, it was evident from the average ^{137}Cs activity for each of the eleven sampling regions that the highest mean activities were seen for the North East regions of Poland – Masuria, Mazovia, Warmia, Podlachia (regions 2, 5, 4 and 6 respectively, in Figure 1) with ^{137}Cs activities ranging from $3925 \pm 2300 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$ (Podlachia – region 6) to $6429 \pm 3500 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$ (Masuria – region 4; as derived from data in Table 1). In contrast, the lowest values of ^{137}Cs activities were recorded for locations in the Western part of Poland – Greater Poland (region 7) and Lower Silesia (region 9) with mean values of 896 ± 407 and $1012 \pm 737 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$, respectively. Unfortunately, there was only a single sample for the Western-most location (Terra Lubucensis – region 8), also with a relatively low value of $1700 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$. The *I. badia* mushrooms from regions such as Kashubia, Kociewie, Warmia, Masuria, Mazovia and Podlachia originated from sites that were substantially contaminated with radiocaesium until around 2007 (Tables 1 and 2), which at least in part, does not correlate to the simulated pattern of soil background activity distribution that was shown in Figure 1.

DISCUSSION

^{137}Cs and ^{40}K in *I. badia* mushrooms collected in Poland over time

The ^{137}Cs and ^{40}K activities given in Table 1 represent data for the largest number of *I. badia* fungi samples collected in Poland over a period of 30 years. This information is supplemented with data on radiocaesium (^{137}Cs and ^{134}Cs) and ^{40}K activity in *I. badia* on a country-wide scale, which were collated from available literature (Table 2). The data reaches back to 1985, i.e. shortly before the Chernobyl incident, when the source of radiocaesium was atmospheric nuclear weapons testing. The ^{134}Cs isotope has a much shorter physical persistence (half-life of 2.06 years) than ^{137}Cs (half-life of 30.07 years) and post-sampling data on ^{134}Cs are relatively scarce. The ^{134}Cs is not produced in the nuclear bomb explosions. Directly after the Chernobyl disaster ^{134}Cs could be detected in domestic *I. badia* in 1988 with a contribution of up to about 20% of the total $^{134/137}\text{Cs}$, which gradually declined to about 5% in 1994 [29], after which it was either not detected or close to detection limits (Figure 2 and Table 2).

The most contaminated *I. badia* samples were reported, as described earlier [26–28], for the heavily affected region of Homel which in 2010, showed levels of ^{137}Cs activity that was roughly comparable to levels observed twenty years earlier in specimens collected

in the regions of Podlachia, Masuria and especially, the Opole region (where anomalously high levels were experienced following deposition of radionuclides released from the Chernobyl fallout during a spell of rainy weather) in Lower Silesia in Poland (Table 2). However, these activity levels for the two sites in Belarus are consistent with their geographical locations relative to Chernobyl. The sample from Staroje Janycha which showed the lower of the two ^{137}Cs activity levels was from the North-East of Minsk and much further away from Chojniki in Homel which is less than 100 km north of Chernobyl. In Poland, higher ^{137}Cs activity levels than these were reported [29] for specimens collected 20 years earlier from the Szczytno region in Masuria and the Augustowska Primeval Forest in Podlachia (Table 2). The report however, lacks more detailed information related to sample size (here assumed as one specimen) and analytical details [29].

Bioconcentration potential of ^{137}Cs in fruiting bodies of studied *I. badia*

Imleria badia is an ectomycorrhizal species with its mycelium hidden in the soil, in symbiosis with forest trees [1]. The life activities of the *I. badia* mycelium, like that of other ectomycorrhizal fungi, are determined by the seasons – growth and mutualistic relationships with the host plant (e.g., supplying the plant with phosphorus and receiving sugars in return, water management) and reproduction – the cyclic emergence of above-ground fruiting bodies (mushrooms) with spores at the end of the growing season. Once mature, the fungus releases these spores into the environment (e.g., the atmosphere) for the expansion and survival of the species. The mycelium absorbs minerals throughout the growing season and may also share some of these nutrients or compounds in general with the plant(s) with which it lives in symbiosis. The ability of a species to absorb minerals from the environment and accumulate them in the body is usually assessed on the basis of the bioconcentration factor (BCF), calculated as the quotient of the dry weight content of a specific component (or its specific chemical form) in the fruiting body, to the content in the substrate (e.g. a layer of soil of a specific thickness; bulk layer 0–10 cm, 0–15 cm or other) [43, 46]. Practically, the soil layer is collected from several points beneath the fruiting body or in its vicinity, and averaged [43].

The BCF (organism *versus* an abiotic part of the environment such as soil, sediment, soil solution, pore water) is analogous to the bioaccumulation factor, BAF (organism *versus* a biotic part of the environment such as food or feed in food webs). For nuclides such as radiocaesium, the fungal potential for uptake and accumulation in fruiting bodies may also be expressed (approximated) as a transfer factor (TF)

or aggregated transfer factor, which takes into account a simulated rate of aerial deposition of a nuclide from fallout (Bq per square meter) for a given area of land (usually large) when it occurred (and if necessary, correct for the rate of physical decay). Temporally, the fallout event is followed by radioactive decay of the radionuclide and its depletion in the soil (substrate) as a result of environmental factors (e.g. surface runoff, washing into the soil profile, accumulation by plants, inadvertent consumption by animals (with their food), release into the atmosphere in spores ejected by fungi). This requires the “fallout status” to be updated, typically based on the radioactive half-life of the nuclide, e.g., as seen for the simulated spatial distribution of the background deposition density of ^{137}Cs in Ukraine on May 10, 1986 and May 10, 2008, as described earlier [46].

Thus, calculated BCF values of ^{137}Cs for the specimens at these locations and time of sampling were 67, 130 and 22 (caps) and 57, 96 and 13 (stems), respectively. Taking into account the consensus on the high predilection of the species to accumulate radiocaesium from fallout, these values suggest a site-specific dependency of the BCF. Using (probably) the largest data set so far on ^{137}Cs in *I. badia* and underlying soil substrata, recently [46], provided BCF values were in the range from 296 (from ^{137}Cs in the whole fruiting bodies from the Chernobyl exclusion zone with activity at $5530000 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$) down to 0.56 (^{137}Cs in the whole fruiting bodies from the Steshchynske forest, quarter 39, in the district of Vyshhorod at $1162 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$).

Activity concentration of ^{40}K in forest topsoils collected from the Parchowo (2010), Lubichowo (2008) and Włoszczowa (2007) locations were at

levels of 330 ± 40 , 220 ± 33 and $250 \pm 38 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$, respectively. Thus, the calculated values of BCF for *I. badia* specimens at these sites were 3.9, 5.0 and 6.4 (caps), and 3.6, 5.0 and 3.6 (stems), respectively. In Poland, the natural occurrence of potassium in topsoils (characterised as ^{40}K) exhibits some spatial diversity, i.e., between 250 and $1000 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$, as described earlier [20]. Thus, the occurrence levels of ^{40}K in forest topsoils in the present study could be towards the lower end of the values reported for all of Poland [20].

^{137}Cs statutory limits and *I. badia*

The activity of ^{137}Cs makes it highly toxic to humans and animals. Following internal exposure, it concentrates in soft tissue. This build-up coupled with emissions of high-energy gamma rays and beta (β^-) particles results in elevated long-term carcinogenic risk due to the resulting severe cellular damage and bone marrow degradation. Dietary exposure to ^{137}Cs is therefore a topic of great interest among mushroomers. Since the Chernobyl incident, affected proximate countries like Poland have disseminated information locally on contamination in various wild fungi and initiated research activities and monitoring programs aimed at understanding the environmental fate of radiocaesium. These included studies on the susceptibility of various fungal species to accumulate radionuclides, regulatory activities aimed at minimizing exposure and assessing the safety of various edible species for human consumers. These studies and wider research confirm that prior to and particularly after, the Chernobyl incident in April 1986, the consumption of wild fungi had become the main source of artificial radioactivity (from radiocaesium) in humans [2, 3, 47, 48].

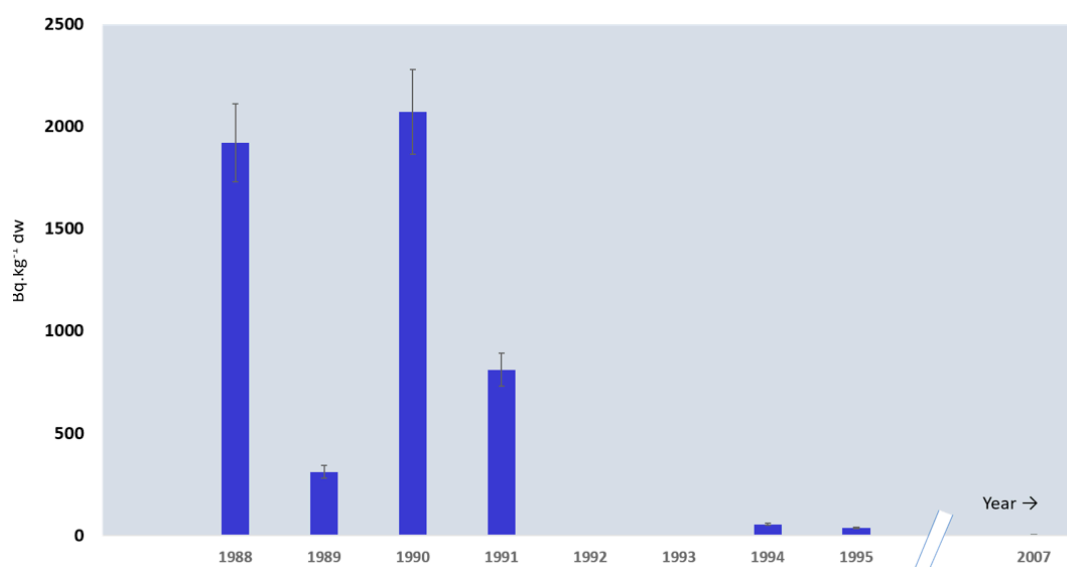


Figure 2. ^{134}Cs activity in *I. badia* from Poland reported in the literature (data for 1990 and 1994 are averaged values)

Table 2. Summary of literature data on chronology of ^{137}Cs , ^{134}Cs and ^{40}K activity intensities in $\text{Bq}\cdot\text{kg}^{-1}$ dw in the cap, stem or whole fruit body of *Imleria badia* for regions of Poland. Mean, median (M), range (total or per sample set) and uncertainty ($\pm$ SD)

Region and place, year of collection and total number [<i>n</i> in bracket] of fruiting bodies in a pool	¹³⁷ Cs	¹³⁴ Cs	⁴⁰ K	Ref.
	Whole fruiting body or cap // stem			
Terra Lublinensis, Rogóžno, 1985 [<i>n</i> = 1]	470	–	1300	[21]
Site unreported, 1985 [<i>n</i> = 1]	1700 [#]	–	WD	[22]
Terra Lublinensis, Rogóžno, 1986 [<i>n</i> = 1]	3600	–	670	[21]
Whole country, 1986 [<i>n</i> = 42]	3800 (600 – 15000) [#]	–	WD	[22]
Terra Lublinensis, Rogóžno, 1987 [<i>n</i> = 1]	1500	–	1000	[21]
Whole country, 1987 [<i>n</i> = 30]	3800 (870 – 23000) [#]	–	WD	[22]
Terra Lublinensis, Rogóžno, 1988 [<i>n</i> = 1]	8900	–	920	[21]
Whole country, 1988 [<i>n</i> = 26]	6300 (570 – 17000) [#]	–	WD	[22]
Lesser Poland, Świętokrzyskie region, Krzyż, 1988 [<i>n</i> = 1; ~50 g dw]	8700 ± 490)	1920 ± 145	WD	[23]
Lesser Poland, Świętokrzyskie region, Niebo, 1989 [<i>n</i> = 1; ~50 g dw]	2030 ± 115	310 ± 20	WD	[23]
Whole country, 1989 [<i>n</i> = 22]	6700 (890 – 24300) [#]	–	WD	[22]
Kashubia, Kościerzyna forests, 1989 [<i>n</i> = 8]	13000	–	WD	[24]
Kociewie, Graniczna Wieś, 1989 [<i>n</i> = 15]	18000	–	WD	[24]
Whole country, 1990 [<i>n</i> = 46]	5500 (360 – 19000) [#]	–	WD	[22]
Podlachia, Augustowska Primeval Forest, 1990 [<i>n</i> = 4]	18550 ^M (18000 ± 1000 – 20000 ± 2000)	2320 ^M (2100 ± 560 – 2400 ± 400)	WD	[25]
Podlachia, Augustowska Primeval Forest, 1990 [<i>n</i> = 1; 39.26 g dw]	18200 ± 1600	1800 ± 400	WD	[26]
Silesia, 1990 [<i>n</i> = 10]	23000 ^M (13600 ± 400 – 156700 ± 6300)	2160 ^M (1130 ± 190 – 16260 ± 200)	WD	[27]
Masuria, 1990 [<i>n</i> = 10]	20600 ^M (3800 ± 800 – 27000 ± 500)	2000 ^M (250 ± 20 – 2500 ± 100)	WD	[27]
Warmia, Olsztyn, 1990 [<i>n</i> = 2]	5620 [#]	WD	WD	[28]
Masuria, Szczytno, 1990 [<i>n</i> = 1]	73120 [#]	WD	WD	[29]
Podlachia, Augustowska Primeval Forest, 1990 [<i>n</i> = 1]	62340 [#]	WD	WD	[29]
Whole country, 1991 [<i>n</i> = 278; each 50-100 g dw]	8100 (120 ± 10 – 157000 ± 6000) 5310 ^M	WD (ca 10% of ¹³⁷ Cs intensity)	1300 ^M	[26]
Whole country, 1991 [<i>n</i> = 31]	5200 (1300 – 13000) [#]	–	WD	[22]
Mazovia, Kampinos National Park, Truskaw, 1994 [<i>n</i> = 10]	2588 ± 1636	58 ± 28	37 ± 11 (K; g·kg ⁻¹)	[30]
Mazovia, Kampinos National Park, Palmiry, 1994 [<i>n</i> = 26]	2434 ± 1081	49 ± 28	39 ± 8 (K; g·kg ⁻¹)	[30]
Warmia, Olsztyn, 1995 [<i>n</i> = 2]	3900 [#]	–	WD	[28]
Warmia, Olsztyn, 1995 [<i>n</i> = 2]	3000 [#]	–	WD	[28]
Warmia, Miodówko near Olsztyn, 1995 [<i>n</i> = 2]	1200 [#]	–	WD	[28]

Region and place, year of collection and total number [<i>n</i> in bracket] of fruiting bodies in a pool	¹³⁷ Cs	¹³⁴ Cs	⁴⁰ K	Ref.
	Whole fruiting body or cap // stem			
Warmia, Zgniłocha near Olsztyn, 1995 [<i>n</i> = 2]	2700 [#]	–	WD	[28]
Warmia, Zgniłocha near Olsztyn, 1995 [<i>n</i> = 2]	2500 [#]	–	WD	[28]
Warmia, Uniszewo near Olsztyn, 1995 [<i>n</i> = 2]	1870 [#]	–	WD	[28]
Warmia, Łańsk near Olsztyn, 1995 [<i>n</i> = 2]	956 [#]	–	WD	[28]
Warmia, Butryny near Olsztyn, 1995 [<i>n</i> = 2]	1420 [#]	–	WD	[28]
Warmia, Mojdy near Olsztyn, 1995 [<i>n</i> = 2]	864 [#]	–	WD	[28]
Warmia, Dadaj lake site, 1995 [<i>n</i> = 2]	320 [#]	–	WD	[28]
Warmia, Pluski, 1995 [<i>n</i> = 2]	3220 [#]	–	WD	[28]
Warmia, Pasłek, 1995 [<i>n</i> = 2]	420 [#]	–	WD	[28]
Warmia, Kalwia near Pasym, 1995 [<i>n</i> = 2]	4090 [#]	–	WD	[28]
Warmia, Barczewo, 1995 [<i>n</i> = 2]	3460 [#]	–	WD	[28]
Warmia, Tylkowo, 1995 [<i>n</i> = 2]	1120 [#]	–	WD	[28]
Kuyavia, Golub-Dobrzyń, 1995 [<i>n</i> = 2]	524 [#]	–	WD	[28]
Mazovia, Rozogi near Myszyniec, 1995 [<i>n</i> = 2]	1930 [#]	–	WD	[28]
Podlachia, Białystok, 1995 [<i>n</i> = 2]	540 [#]	–	WD	[28]
Podlachia, north-eastern region, 1995 [<i>n</i> = 19]	1950 ± 12500 (321 – 4090) [#]	–	WD	[28]
Place of collection unknown, 1995 [<i>n</i> = 1; kg fresh weight]	2600 ± 200	36 ± 2	1570 ± 90	[31]
Pomerania, Wdzydze Landscape Park, 1996 [<i>n</i> = 15]	4600 ± 61 (4260 – 5400) // 2180 ± 190 (1390 – 3620)	–	1000 ± 170 // 1260 ± 660	[32]
Pomerania, Kołobrzeg outskirts, 1997 [<i>n</i> = 7]	2300 ± 83 (1430 – 3110) // 2040 ± 72 (1590 – 2500)	–	700 ± 320 // 1200 ± 380	[32]
Podlachia, Augustowska Primeval Forest, 1998 [<i>n</i> = 16]	3960 ± 106 (3270 – 4440) // 3500 ± 87 (1690 – 4270)	–	1120 ± 420 // 910 ± 390	[32]
Podlachia, Białowieża Forest, 1998 [<i>n</i> = 16]	2740 ± 110 (1990 – 3510) // 1860 ± 82 (1240 – 2770)	–	950 ± 590 // 730 ± 410	[32]
Warmia, Borecka Forest, 1998 [<i>n</i> = 15]	3160 ± 68 (330 – 6670) // 2620 ± 86 (580 – 4360)	–	1100 ± 260 // 890 ± 390	[32]
Warmia, Morag, 1998 [<i>n</i> = 16]	2470 ± 58 (470 – 5080) // 1750 ± 110 (190 – 3400)	–	1070 ± 270 // 470 ± 220	[32]
Lower Silesia, Opole region, 1998 [<i>n</i> = 29]	25227 ± 965 (2600 – 64825) 21457 ^M	WD	WD	[33]
Kociewie, Tuchola Pinewoods, 2000 [<i>n</i> = 19]	5100 ± 45 // 4600 ± 48	–	1300 ± 52 // 1100 ± 43	[34]
Kuyavia, Aleksandrów Kujawski, 2004 [<i>n</i> = 1]	2700 ± 140 // 2500 ± 140	–	1120 ± 9 // 930 ± 80	[35]
Kuyavia, Aleksandrów Kujawski, 2004 [<i>n</i> = 1]	813 ± 47 // 768 ± 44	–	1586 ± 301 // 1761 ± 340	[35]
Commercial specimens, ~ 2004 [<i>n</i> = 42 // 30]	1470 ± 117 – 4290 ± 344 // 1070 ± 220 – 1520 ± 249	–	840 ± 83 – 1240 ± 87 // 460 ± 75 – 1130 ± 145	[32]
Lower Silesia, Łambinowice forest, 2006 [<i>n</i> = 1]	8900 ± 110	–	1457 ± 89	[36]

Region and place, year of collection and total number [<i>n</i> in bracket] of fruiting bodies in a pool	¹³⁷ Cs	¹³⁴ Cs	⁴⁰ K	Ref.
	Whole fruiting body or cap // stem			
Lower Silesia, Łambinowice forest, 2007 [<i>n</i> = 2]	6100 ± 86	4.3 ± 1.1	1690 ± 64	[36]
Greater Poland, Puszcza Notecka, Jesionna, 2008 [<i>n</i> = 32]	970 ± 8 // 690 ± 19	–	1060 ± 28 // 710 ± 52	[34]
Greater Poland, Porążyn, 2008 [<i>n</i> = 29]	45 ± 2 // WD	–	1240 ± 55 // WD	[34]
Pomerania, Jarosławiec, 2019 [<i>n</i> = 6]	368 ± 12	–	1398 ± 176	[37]
Pomerania, Przechlewo, 2019 [<i>n</i> = 5]	1085 ± 40	–	1026 ± 152	[37]
Warmia, Gady, 2019 [<i>n</i> = 4]	959 ± 34	–	903 ± 137	[37]
Masuria, Ełk, 2019 [<i>n</i> = 3]	368 ± 14	–	1204 ± 169	[37]
Lower Silesia, Szumirad, 2019 [<i>n</i> = 7]	17143 ± 614	–	Not found	[37]
Lower Silesia, Sowin/Łambinowice, 2019 [<i>n</i> = 5]	3878 ± 140	–	Not found	[37]
North-Eastern Poland, 2017-2021 [<i>n</i> = 31]	696 ^M (394 – 855)	–	1110 (938 – 1140)	[38]

[#]Adapted, assuming moisture content at 90%; WD – without data; ^Mmedian; – not measured or not reported; Not found – undetected.

The mineral or metalloid content (in this case, radiocaesium) of a food may increase or decrease during the process of cooking. The final cooked product (here, a mushroom dish) will however, reflect the potential dose of radiocaesium present in the raw mushrooms [28, 49-53]. The particular edible species used in the dish, amount consumed and the resulting radiocaesium exposure thus becomes a primary food safety issue. In addition to being an edible species, *I. badia* is also prized for its taste and so, is eagerly foraged. It is also suitable for being preserved, processed and transported [54]. Thus, its propensity to readily accumulate radiocaesium is of particular concern.

There are various statutory limits for radiocaesium contents in foods depending on the type, the regulatory body and the country. European regulatory bodies limit forest edibles at 600 Bq·kg⁻¹ wet (fresh) weight (ww) [11] which is equivalent to 6000 Bq·kg⁻¹ dw for wild mushrooms (assuming moisture at 90%). The tolerance limit in foodstuffs recommended by the International Atomic Energy Agency (IAEA) is 1000 Bq·kg⁻¹ ww (equivalent to 10000 Bq·kg⁻¹ dw in forest mushrooms). The tolerance limit for mushrooms in Ukraine (from 2006) is 2500 Bq·kg⁻¹ dw (~250 Bq·kg⁻¹ ww), while in Japan, the limit for foods including wild mushrooms, is 100 Bq·kg⁻¹ ww (~1000 Bq·kg⁻¹ dw), as described earlier [46]. The collated data presented in Tables 1 and 2 leaves no doubt as to the scale of radiocaesium contamination in *I. badia* samples collected over the years in various regions of the country, and in some cases on the exceedance of the above-mentioned tolerance limits.

Time trend of ¹³⁷Cs depletion in *I. badia*

Radiocaesium occurs to a high degree of variability in soils [55] globally and can range over orders of magnitude (e.g., 0.075–55 Bq·kg⁻¹ dw [56]). In addition to variable fallout rates, the distribution in soils is also governed by factors such as the mineralogy, soil chemistry, climate, and topography. Some soil minerals such as illite are highly selective at binding ¹³⁷Cs, effectively immobilizing it [56]. Although the Chernobyl incident had a strong influence on soil contents, particularly of proximate countries, the depositions complemented earlier ¹³⁷Cs levels originating from past atmospheric nuclear weapons testing. This soil variability also affects the levels in fungal fruiting bodies (including *I. badia*) as seen in Tables 1 and 2.

When considered collectively, the reported ¹³⁷Cs activity levels seen in *I. badia* appear to occur at variable levels depending on the sampling location and period (Tables 1 and 2). However, if sufficient volume of data is available for a particular region over a sustained period, then some indications of the occurrence trend may be observed. Among the ¹³⁷Cs activity levels presented in Table 1, there were 43 samples of *I. badia* caps located in Northern Poland (mostly for the regions, or *voivodeships* of Pomerania, Masuria and Warmia). ¹³⁷Cs activities for this data set plotted over the period from 1997 to 2020, show a declining trend in *I. badia* concentrations (Figure 3). This trend is consistent with the expected decline resulting partly from the half-life of ¹³⁷Cs and also from the absence of any new inputs. The most recent globally known release of radioactivity from the Fukushima-Daichi plant in 2011 was not considered

to have any effect on the occurrence of radiocaesium in wild mushrooms in continental Asia or Europe [34].

In addition to radioactive decay rates and tolerance limits, another practical element of food safety for wild mushroom consumers is the real (effective) removal rate (over time) or the “ecological half-life” of ^{137}Cs [57, 58]. Based on physical ^{137}Cs decay which is considered as persistent ($T_{1/2}$ 30.7 y), activity in *I. badia* sampled from defined sites in this study, i.e. the Sobieszewo Island, over 20 years (2000–2020) and from the Tuchola Pinewoods over 22 years (1998–2020), is projected to be 1000 $\text{Bq}\cdot\text{kg}^{-1}$ dw at Sobieszewo Island area in 2030 and up to 2200 $\text{Bq}\cdot\text{kg}^{-1}$ dw at the Tuchola Pinewoods in 2028. In practice, the effective decline of ^{137}Cs in *I. badia* both at the Sobieszewo and Tuchola Pinewoods areas as predicted based on time-trend data appears to be substantially faster (Figure 4).

CONCLUSIONS

In line with the tendency of *I. badia* to accumulate radioactivity, ^{137}Cs was detected in all samples collected across Poland except for one site. Values

ranged from < 6.4 to $11000 \text{ Bq}\cdot\text{kg}^{-1}$ dw and varied across regions, showing both the temporal and spatial effects of the radioactive fallout from the Chernobyl accident. The low end of the range represents the most recent sample taken in 2023, while the highest value of $11000 \text{ Bq}\cdot\text{kg}^{-1}$ dw was found in a sample from one of the most impacted areas of Poland, Masuria, 20 years earlier, in 2000. In some cases, the measured activity in this prized edible mushroom was above the regulatory tolerance limits set for human dietary exposure. Spatially, the highest mean activities were indicated in samples from the North East regions of the country – Masuria, Mazovia, Warmia and Podlachia, with mean activities ranging from $3925 \text{ Bq}\cdot\text{kg}^{-1}$ dw to $6429 \text{ Bq}\cdot\text{kg}^{-1}$ dw. Contrastingly, *I. badia* from locations in Western regions – Greater Poland and Lower Silesia were considerably less contaminated with mean values of 896 and $1010 \text{ Bq}\cdot\text{kg}^{-1}$ dw. ^{134}Cs activity was not detected which is consistent with its shorter half-life and also with the earliest samples (1997) collected in this study, relative to the Chernobyl accident. ^{40}K activity remained relatively stable during the period of the study despite the variable amounts of ^{137}Cs activity, confirming the validity of the measurements.

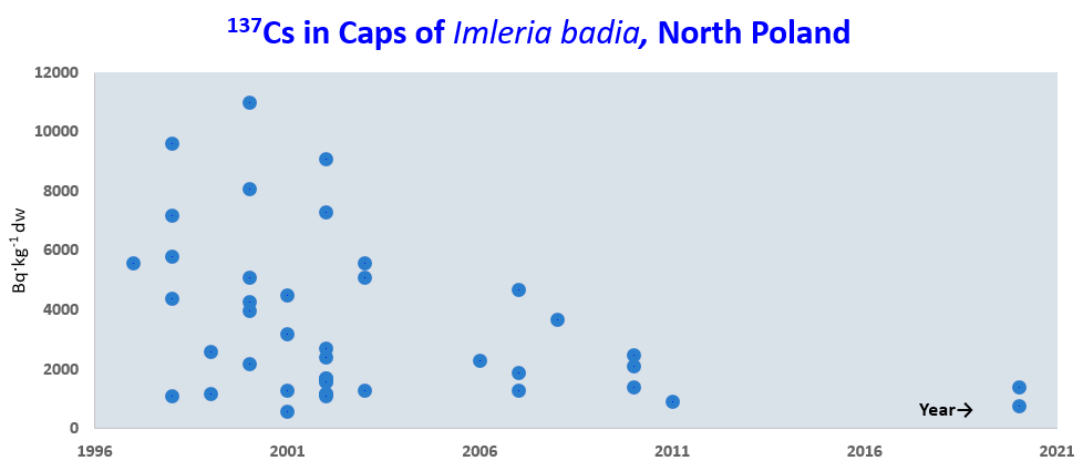


Figure 3. Temporal trend in ^{137}Cs activity in the caps of *I. badia* sampled from locations (Pomerania, Masuria and Warmia regions) in Northern Poland

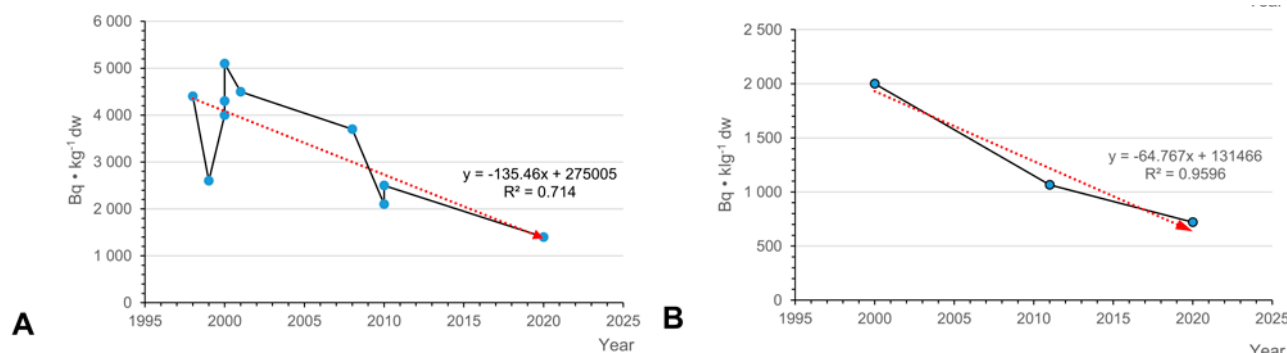


Figure 4. Time trend data of ^{137}Cs in caps of *I. badia* collected from the Tuchola Pinewoods complex (A) and in the whole fruiting bodies of this species collected from Sobieszewo Island (B)

Forty years after the Chernobyl accident, the temporal trend in mean ^{137}Cs activity showed a decline from $5617 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$ in the 1990s to $1095 \text{ Bq}\cdot\text{kg}^{-1} \text{ dw}$ in 2020 – a trend that is consistent with the longer half-life of this radioisotope. Although genotoxic carcinogens like ^{137}Cs have no safe limit of exposure, the observed temporal decline in radionuclide content in this widely foraged and popular mushroom, points to a gradually reducing risk from dietary intake. Consumers should however be aware of the risk from this species, particularly given the high values of the BCF calculated in this study (up to 134), which underline the propensity of *I. badia* to accumulate harmful ^{137}Cs .

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Disclosure conflict of interest

The authors declare that have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript.

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ENHANCING NURSING STUDENTS' LEARNING OF NUTRITION THROUGH PODCASTING: AN ACTIVE APPROACH FOR GENERATION Z STUDENTS IN MOROCCO

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ABSTRACT

Background. Student-generated video podcasting may support active learning in nursing education, but evidence from low- and middle-income settings remains limited.

Material and Methods. This two-academic-year, non-randomized consecutive-cohort study was conducted at the Taza annex of the Higher Institute of Nursing and Health Techniques, Fes, Morocco. The 2024-2025 cohort (n = 135) completed a collaborative student-generated video-podcast activity for the therapeutic diets unit, involving group content research, script preparation, recording, presentation, peer viewing, and supervised discussion, whereas the 2025-2026 cohort (n = 119) received traditional instruction. In both cohorts, the nutrition unit was taught and assessed first, followed by the therapeutic diets unit. Each unit was evaluated by an end-of-unit written examination graded on a 10-point scale, and the overall module grade was the mean of the two unit scores. The nutrition score therefore preceded the therapeutic-diets intervention and was used as a pre-intervention academic comparator. The therapeutic-diets written examinations used different questions across academic years but assessed the same construct and learning objectives; item difficulty indices were used to minimize differences in examination difficulty. Welch t-tests and an ANCOVA model adjusted for nutrition score were used.

Results. Cohorts were comparable for gender, program, age, and pre-intervention nutrition score (6.16 ± 1.37 vs. 6.18 ± 1.35 ; $p = 0.907$). The intervention cohort achieved a higher therapeutic-diets written examination score than the traditional cohort (7.20 ± 1.21 vs. 6.24 ± 1.30 ; mean difference = 0.96, 95% CI 0.65 to 1.27; $p < 0.001$; $d = 0.77$). The adjusted mean difference was 0.97 points (95% CI 0.69 to 1.25; $p < 0.001$). Satisfaction was favorable, but internal consistency was below the conventional 0.70 threshold (Cronbach's $\alpha = 0.69$), so item-level interpretation was retained.

Conclusions. The implemented video-based collaborative learning activity was associated with a higher therapeutic-diets written examination score. Because the intervention was multicomponent and cohorts were not randomized, the observed association cannot be attributed specifically to video podcasting. Prospective controlled replication using a common or item-banked examination is needed.

Keywords: active learning, video podcasting, collaborative learning, nursing education, nutrition education, Morocco, quasi-experimental study

INTRODUCTION

Higher education has undergone rapid digital transformation, especially after the COVID-19 pandemic accelerated the use of online, asynchronous, and multimedia learning resources [1]. In health professions education, this transformation has encouraged instructors to move beyond lecture-only formats toward approaches that combine flexible digital resources with structured classroom interaction.

Generation Z students now form a large part of nursing cohorts. Many are familiar with mobile

learning, social media, and short multimedia formats and may value autonomy, rapid feedback, and flexible access to content [2-5]. However, digital familiarity should not be equated with academic readiness. Educational technologies are most useful when they are embedded in clear learning objectives, guided by faculty feedback, and linked to assessment.

Nutrition education is essential in nursing training because nurses contribute to patient education, disease prevention, nutritional screening, and support for people with chronic illnesses. Previous literature has reported gaps in nutrition knowledge among

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nursing students, supporting the need for approaches that improve engagement and application-oriented learning [6]. Therapeutic diet is a particularly relevant unit because it requires students to translate nutrition principles into disease-specific dietary guidance.

Podcasts and video podcasts are increasingly used in health education because they allow flexible revision and may support motivation, self-directed learning, and knowledge retention [7-11]. Student-generated video podcasting adds an active production dimension: students do not only consume content, but also select evidence, write scripts, explain dietary principles, communicate visually, and present material to peers. In practice, such activities may also incorporate collaborative learning, peer teaching, and faculty-guided discussion.

In Morocco, nursing education is progressively integrating digital tools while still facing challenges related to infrastructure, access, and pedagogical support [12]. Evidence from student-generated questioning, active podcast production, and podcasting in nursing and health-professions education supports the value of active and participatory approaches [13-15]. The pedagogical rationale for the present activity is grounded in active learning, constructivist learning, and student-generated content. Students are expected to construct understanding by organizing information into an explanatory product, negotiating meaning within groups, and receiving feedback during supervised viewing. The Interactive-Constructive-Active-Passive (ICAP) framework distinguishes increasingly engaged modes of learning and suggests that constructive and interactive activities can be more cognitively engaging than passive reception [16, 17]. Earlier nursing research also suggested that podcast-based learning may support knowledge retention and application [18], although the present study did not directly measure cognitive processes.

Empirical evidence remains limited on student-generated video-podcasting activities in Moroccan nursing nutrition education. This study examined whether a collaborative video-based learning activity centered on student-generated podcasts for a therapeutic diets unit was associated with higher academic performance than traditional instruction in a comparable consecutive cohort.

MATERIALS AND METHODS

Study design

This study employed a non-randomized, quasi-experimental comparative design involving non-equivalent consecutive cohorts. Given that exposure to the video-podcasting intervention was determined by academic year rather than by random allocation, the study should be interpreted as a natural

educational experiment rather than as a randomized or fully controlled trial. Reporting was guided, where applicable, by the STROBE statement for observational comparative studies [19].

Setting and participants

The study was carried out at the Higher Institute of Nursing and Health Techniques (ISPITS) of Fes, Taza Annex, during the 2024-2025 and 2025-2026 academic years. The total sample included 254 undergraduate nursing students enrolled in the Nutrition and Dietary Regimens module. The 2024-2025 cohort received the student-generated video-podcasting activity ($n = 135$), and the 2025-2026 cohort received traditional instruction for the same therapeutic diets content ($n = 119$).

Eligible students were those with complete demographic data and complete nutrition and therapeutic-diets written examination scores. The sample was based on intact academic cohorts, and no random allocation, matching, or post hoc exclusion for performance was applied.

Educational intervention

In the 2024-2025 intervention cohort, students were divided into small groups and completed a structured, collaborative video-podcasting activity on therapeutic diet topics. Topics included diabetic, renal, low-sodium, hypolipidemic, hypoproteic, hyperproteic, hypocaloric, fiber-free, residue-free, and gluten-free diets. Students researched and developed scientifically accurate content, prepared a scenario and script, recorded the video podcast, and presented the final product in class. The intervention therefore comprised several linked active-learning components rather than video production alone.

Before production, the professor provided a structured video-podcast rubric covering scenario quality, scientific content accuracy, innovation and creativity, and speech delivery with overall presentation. The rubric was used to guide and evaluate the video-podcast activity itself and was separate from the academic outcome analyzed in this study. The therapeutic-diets academic score used in the statistical analyses was obtained from the end-of-unit written examination, as in the comparison cohort. Engagement, perceived usefulness, creativity stimulation, autonomy, and overall satisfaction were assessed separately through the post-activity perception questionnaire and did not contribute to the written examination score.

Traditional comparison condition

The 2025-2026 cohort received the same therapeutic diets curriculum content through traditional professor-led instruction and classroom explanation,

without the student-generated video-podcasting activity. The same professor, institutional setting, syllabus content, contact-hour structure, learning objectives, 10-point grading scale, and written end-of-unit assessment format were maintained across the two academic years. Thus, the principal difference between cohorts concerned the teaching approach used for the therapeutic diets unit: collaborative video-podcasting in 2024-2025 versus traditional instruction in 2025-2026.

In-class viewing and peer learning

All final video podcasts were presented and viewed in class under the professor's supervision. Before viewing sessions, groups authorized the educational sharing of their videos with peers. Classroom viewing was not treated as a passive projection exercise; rather, it functioned as a peer-learning session in which students compared approaches, clarified misconceptions, and linked the videos to the therapeutic diets learning objectives. Thus, the intervention combined group work, content research, script preparation, video production, presentation, peer viewing, and supervised discussion.

Evaluation procedure and outcomes

The module was delivered sequentially in both academic years. The nutrition unit was taught first through traditional instruction and was assessed by a written examination immediately after completion of that unit. The therapeutic diets unit was taught afterward. Thus, the nutrition assessment occurred before the therapeutic-diets intervention in both cohorts and served as a pre-intervention academic

comparator. After completion of the therapeutic diets unit, both cohorts completed a written end-of-unit examination graded on the same 10-point scale. The overall module grade was calculated as the mean of the nutrition and therapeutic-diets examination scores. The therapeutic-diets written examination score was the primary outcome analyzed in this study. The video-podcast rubric and the post-activity perception questionnaire were separated from this academic examination outcome.

The therapeutic-diets written examinations were not identical across the two academic years. Different questions were used, but both examinations were constructed to assess the same therapeutic-diets learning construct, syllabus content, and learning objectives, using the same grading scale and general examination format.

Because different examination questions were used across the two academic years, item difficulty was examined post hoc to assess the comparability of the two examination forms. For each item, the classical difficulty index (P) was calculated as the proportion of students who answered the item correctly. The distribution of item difficulty indices was then examined across the two examination forms to determine whether the examinations showed broadly comparable difficulty profiles. This analysis was used as a post hoc comparability check rather than as evidence of strict equivalence, because item difficulty may also be influenced by differences in cohort ability.

A relative unit difference score was also calculated as therapeutic diets written examination score minus nutrition score. This variable was used only as a descriptive internal comparator to show

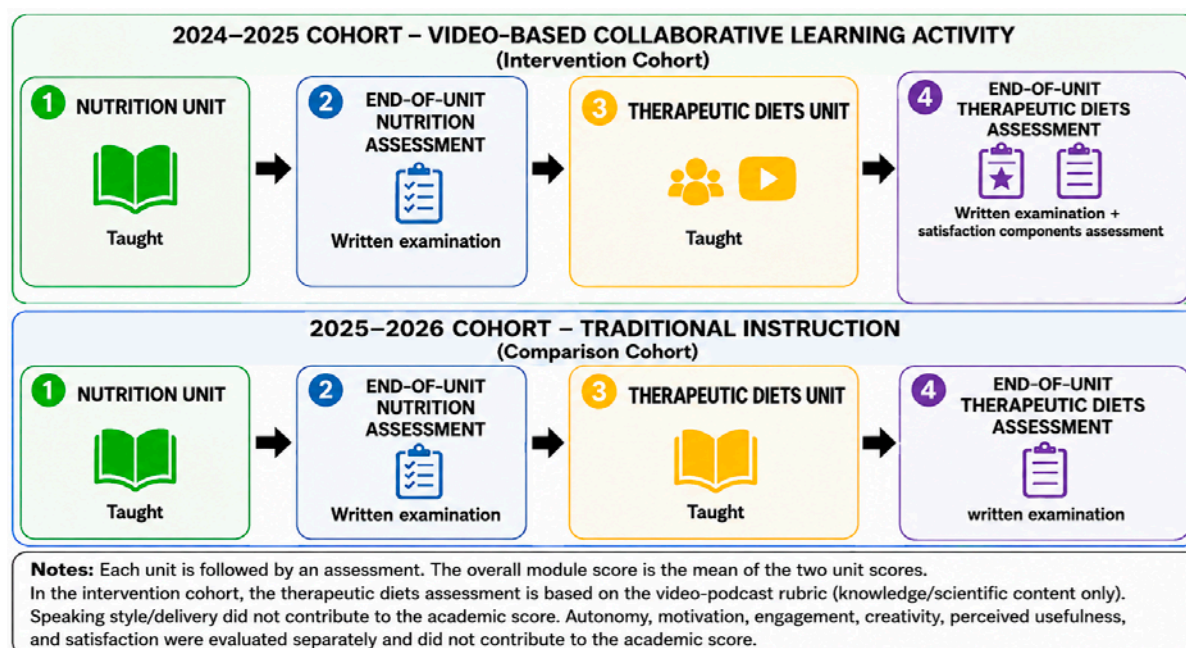


Figure 1. Study design and assessment timeline

how performance in the targeted unit differed from performance in a traditionally taught component. Because nutrition and therapeutic diets assess related but non-identical content, this difference score was not interpreted as a true pre-post learning gain for the same construct.

In the intervention cohort only, students completed a structured satisfaction questionnaire after the video-podcasting activity and in-class viewing. Items used a 1-5 Likert-type response format, with higher scores indicating more favorable perceptions. Because satisfaction was measured only after the intervention and only in the podcasting cohort, these data were analyzed descriptively and were not used to infer comparative effectiveness.

Bias and control measures

Several measures were used to reduce bias and improve transparency. Both cohorts were drawn from the same institution and module and were taught by the same professor. The curriculum content, learning objectives, contact-hour structure, 10-point grading scale, and written end-of-unit assessment format were maintained across academic years. Different therapeutic-diets examination questions targeted the same construct and learning objectives, and item difficulty indices were used to minimize differences in examination difficulty. Demographic variables and the pre-intervention nutrition score were compared between cohorts to assess baseline comparability. These measures improved comparability, although they could not establish exact equivalence between the two examination forms.

As examinations contained different questions across academic years, item difficulty indices were calculated post hoc for each examination form. The resulting difficulty profiles were examined to assess whether substantial differences in examination difficulty were apparent between cohorts. This approach reduced uncertainty concerning examination comparability but cannot establish exact equivalence because observed item difficulty is partly dependent on cohort performance.

Despite these stabilizing features, the design remains vulnerable to residual bias because the cohorts belonged to different academic years and were not randomized. Possible cohort or generational differences include differences in prior academic preparation, motivation, peer culture, digital readiness, assessment behavior, and unmeasured academic support. In addition, although the therapeutic-diets examinations assessed the same construct and were matched as closely as possible for difficulty, they contained different questions. These issues were explicitly considered when interpreting the findings, and the analysis avoided causal language.

Statistical analysis

Categorical variables were reported as frequencies and percentages. Continuous variables were reported as means and standard deviations. Baseline comparability between cohorts was examined using *Chi-square* tests for categorical variables and Welch independent-samples *t*-tests for continuous variables. The primary between-cohort comparison focused on the therapeutic-diets written examination score. Effect sizes were reported as Cohen's *d* and interpreted cautiously because the design was non-randomized.

The relative unit difference score was compared between cohorts as a sensitivity descriptor but was not analyzed with within-cohort paired tests because the two scores reflected related but different academic units. A linear ANCOVA model was specified with therapeutic-diets written examination score as the dependent variable, cohort as the exposure variable, and nutrition score as the pre-intervention academic covariate. This model estimated whether the between-cohort examination-score difference persisted after adjustment for prior academic performance; it cannot correct for unmeasured cohort differences or guarantee equivalence of the two examination forms.

Satisfaction was reported item by item using means and standard deviations. The five post-activity perception items were examined for internal consistency before any aggregation. Because Cronbach's α was below the conventional 0.70 threshold, a global score was not used. Exploratory Pearson correlations were calculated between each perception item and the therapeutic-diets written examination score within the intervention cohort. Given the Likert-type nature of the items, multiple item-level testing, and post-intervention timing, correlations were interpreted as descriptive and non-causal. A Bonferroni reference threshold of 0.01 was used for the five exploratory correlations.

Ethical considerations

The study involved educational evaluation with adult students and did not include clinical experimentation, patient data, or interventions posing physical risk. Data were processed anonymously and confidentially, and results were reported in aggregate form. Students in the intervention cohort authorized the in-class educational sharing of their video podcasts with peers. Institutional ethics approval, waiver, and consent details are reported in declarations.

RESULTS

Participant characteristics

The database included 254 undergraduate nursing students: 135 in the 2024-2025 video-podcasting

Table 1. Sociodemographic characteristics by cohort

Variable	2024-2025 video-podcasting cohort (n = 135)	2025-2026 traditional cohort (n = 119)	p-value
Gender, n (%)			0.984
Female	94 (69.6)	83 (69.7)	
Male	41 (30.4)	36 (30.3)	
Program, n (%)			0.659
General Nursing	93 (68.9)	85 (71.4)	
Family and Community Health Nursing	42 (31.1)	34 (28.6)	
Age (years), mean $\pm$ SD	21.71 $\pm$ 1.69	21.98 $\pm$ 1.87	0.234

p-values are from *Chi*-square tests for categorical variables and Welch t-tests for continuous variables.

cohort and 119 in the 2025-2026 traditional cohort. The two cohorts were similar in gender distribution, program distribution, and age. The nutrition score, obtained before the therapeutic diets unit and taught traditionally in both cohorts, was also nearly identical between groups and supported pre-intervention academic comparability.

Academic outcomes

Pre-intervention nutrition scores were nearly identical between the video-podcasting and traditional cohorts (6.16 $\pm$ 1.37 vs. 6.18 $\pm$ 1.35; mean difference = -0.02, 95% CI -0.36 to 0.32; p = 0.907). The therapeutic-diets written examination score was higher in the video-podcasting cohort than in the traditional cohort (7.20 $\pm$ 1.21 vs. 6.24 $\pm$ 1.30; mean difference = 0.96, 95% CI 0.65 to 1.27; p < 0.001; d = 0.77). In both cohorts, these scores were obtained from written end-of-unit examinations graded on the

same 10-point scale. The examinations contained different questions across academic years but assessed the same therapeutic-diets construct and were reviewed using item difficulty indices to minimize differences in examination difficulty.

The relative unit difference score was 1.04 $\pm$ 1.42 in the video-podcasting cohort and 0.06 $\pm$ 1.36 in the traditional cohort. This descriptive pattern indicates that the intervention cohort performed higher in the targeted therapeutic diets unit relative to its own traditionally taught nutrition component. Because the two academic components are not identical constructs, this finding should not be read as a within-student pre-post gain.

In the adjusted ANCOVA model, cohort remained associated with the therapeutic-diets written examination score after controlling for the pre-intervention nutrition score (adjusted mean difference = 0.97 points on the 10-point scale,

Table 2. Academic outcomes by cohort

Outcome	2024-2025 video-podcasting cohort	2025-2026 traditional cohort	Statistical result
Nutrition written examination score /10 (pre-intervention comparator; written examination in both cohorts)	6.16 $\pm$ 1.37	6.18 $\pm$ 1.35	Mean difference = -0.02; 95% CI -0.36 to 0.32; Welch t = -0.12; p = 0.907; d = -0.01
Therapeutic-diets written examination score /10 (written end-of-unit examination in both cohorts)	7.20 $\pm$ 1.21	6.24 $\pm$ 1.30	Mean difference = 0.96; 95% CI 0.65 to 1.27; Welch t = 6.06; p < 0.001; d = 0.77
Relative unit difference score (therapeutic diets – Nutrition)	1.04 $\pm$ 1.42	0.06 $\pm$ 1.36	Mean difference = 0.98; 95% CI 0.64 to 1.32; Welch t = 5.63; p < 0.001; d = 0.71
Adjusted model for therapeutic-diets written examination score	--	--	Adjusted mean difference = 0.97; 95% CI 0.69 to 1.25; t = 6.81; p < 0.001

95% CI 0.69 to 1.25; $t = 6.81$; $p < 0.001$). This model shows that the examination-score difference persisted after adjustment for prior academic performance, but it does not establish causality and cannot eliminate residual bias arising from the non-randomized consecutive-cohort design or from non-identical examination questions.

Values are mean $\pm$ SD unless otherwise stated. The relative unit difference score is descriptive rather than a true pre-post gain. The adjusted model included cohort and pre-intervention nutrition score as predictors of the therapeutic-diets written examination score.

Satisfaction findings in the video-podcasting cohort

Students in the video-podcasting cohort reported favorable item-level perceptions of the activity. The highest rating was observed for autonomy, followed by perceived usefulness and overall satisfaction. Because the five items showed weak internal consistency (Cronbach's $\alpha = 0.69$), results are presented at the item level and were not aggregated into a single satisfaction scale.

Items were rated from 1 to 5, with higher scores indicating more favorable perceptions. Cronbach's α across the five items was 0.69; item-level interpretation is therefore preferred over a summed scale.

Correlation between satisfaction items and therapeutic-diets written examination score

Exploratory Pearson correlations within the video-podcasting cohort showed positive associations between all post-activity perception items and the

therapeutic-diets written examination score. The strongest association was observed for the item related to autonomy/learning at one's own pace ($r = 0.42$, $p < 0.001$), followed by engagement ($r = 0.34$, $p < 0.001$) and overall satisfaction ($r = 0.33$, $p < 0.001$). These perception items were not part of the academic score. Because they were measured after the activity, the correlations should be interpreted as descriptive associations rather than evidence that the perceptions caused performance differences.

Pearson correlations were calculated in the video-podcasting cohort only ($n = 135$). The Bonferroni reference threshold for five exploratory correlations was $p < 0.01$. Post-activity perceptions were assessed after the intervention; correlations are non-causal.

DISCUSSION

This two-academic-year consecutive-cohort study found that students exposed to the implemented video-based collaborative learning activity for the therapeutic diets unit achieved higher written end-of-unit examination scores than students who received traditional instruction. The difference was close to one point on a 10-point scale and remained after adjustment for the nutrition score obtained before therapeutic diets instruction began. The same professor, curriculum content, contact-hour structure, learning objectives, grading scale, and written assessment format were maintained across academic years. The two therapeutic-diets examinations used different questions, but they targeted the same construct and were reviewed using item difficulty indices to achieve comparable difficulty. These features strengthen

Table 3. Satisfaction components and questionnaire items in the video-podcasting cohort

Satisfaction component	Questionnaire item	Mean $\pm$ SD
Engagement	The podcasting sessions kept me actively engaged.	3.88 $\pm$ 0.87
Perceived usefulness	The podcasting method helped me understand therapeutic diets better.	4.18 $\pm$ 0.67
Creativity stimulation	Creating or watching the podcasts stimulated my creativity.	3.79 $\pm$ 0.78
Autonomy	Podcasting allowed me to learn at my own pace.	4.50 $\pm$ 0.30
Overall satisfaction	Overall, I am satisfied with the podcasting learning experience.	4.04 $\pm$ 0.67

Table 4. Correlation between satisfaction components and therapeutic-diets written examination performance

Satisfaction component	Correlation with therapeutic-diets written examination score	p-value
Engagement	$r = 0.34$	< 0.001
Perceived usefulness	$r = 0.26$	0.002
Creativity stimulation	$r = 0.24$	0.006
Autonomy	$r = 0.42$	< 0.001
Overall satisfaction	$r = 0.33$	< 0.001

comparability, although the non-randomized design and non-identical examination forms prevent a causal interpretation.

A central methodological distinction is that the nutrition score was a pre-intervention academic comparator, not an intervention outcome. It was collected after completion of the nutrition unit and before the therapeutic diets unit began in both cohorts. The overall module grade was the mean of the two written end-of-unit examination scores, but the present analysis treated the nutrition score as the prior academic comparator and the therapeutic-diets written examination score as the outcome. Because the two units assess related but non-identical content, the relative unit difference should not be interpreted as a classic pre-post gain.

The intervention should not be interpreted as video podcasting in isolation. It combined group work, content research, script preparation, video recording, presentation, viewing of other groups' videos, peer learning, and professor-supervised discussion. Any observed association may therefore reflect one or several of these components, including active production, collaboration, peer explanation, or increased time on task. The present design cannot disentangle their individual contributions. Accordingly, the findings are more appropriately interpreted as evidence concerning the implemented video-based collaborative learning activity rather than a specific isolated effect of the video-podcasting medium.

The findings are consistent with literature suggesting that active production tasks can promote engagement and deeper processing compared with passive content reception [13-18]. From a constructivist perspective, creating a video podcast requires students to identify essential dietary principles, organize evidence, translate content into accessible language, and anticipate peer questions. Supervised viewing and discussion may add further interactive processing. These mechanisms are plausible, but the present study did not directly measure cognitive engagement, peer interaction quality, or time on task.

The intervention also aligns with some preferences described among contemporary nursing students, including visual learning, autonomy, interactivity, and collaborative work [20-22]. However, the 'digital native' concept should be used cautiously. Comfort with digital platforms does not guarantee educational benefit. The positive association observed here is more defensibly linked to a guided, assessment-linked active-learning activity than to students' generational membership itself.

The satisfaction findings add a limited motivational and perceptual perspective. The item related to autonomy/learning at one's own pace was the highest rated and had the strongest correlation

with the therapeutic-diets written examination score. Engagement and overall satisfaction were also positively associated with the score. Importantly, engagement, perceived usefulness, creativity stimulation, autonomy, and overall satisfaction were assessed separately and did not contribute points to the academic therapeutic-diets examination score. The direction of the observed associations remains uncertain, and both perceptions and performance may have been influenced by unmeasured factors.

The weak internal consistency of the five satisfaction items is important. A low Cronbach's alpha indicates that the items should not be treated as a single validated satisfaction construct. Reporting item-level findings avoids overinterpreting a composite score and provides more transparent information about which aspects of the activity students valued.

This study has several limitations. First, cohorts were not randomized, and the comparison involved different academic years; residual cohort or generational differences may therefore remain despite stable teaching conditions. Second, although post hoc item difficulty analysis indicated broadly comparable examination difficulty, the examinations contained different questions and were administered to different cohorts. Therefore, exact equivalence between the two examination forms cannot be established. Third, the intervention itself was multicomponent, combining group work, content research, script preparation, video production, presentation, peer viewing, and supervised discussion; the design cannot isolate the contribution of video podcasting from the other active-learning components. Fourth, the nutrition score was a useful pre-intervention academic comparator but assessed related rather than identical content. Fifth, post-activity perception items were measured only after the intervention and only in the video-podcasting cohort. Sixth, the study was conducted in one Moroccan nursing institution, limiting generalizability.

Despite these limitations, the study has practical implications. A structured video-based collaborative learning activity incorporating student-generated podcasts may be considered a feasible active-learning option in nursing nutrition education when guided by a clear rubric, supervised by the professor, and integrated into classroom discussion. The present findings should be viewed as preliminary because the cohorts were non-randomized and the written examination questions were not identical across academic years. Future studies should use prospective parallel-group or crossover designs in which both groups complete the same independent written knowledge examination or an item-banked equivalent, while podcast-production quality and post-activity perceptions are assessed separately.

CONCLUSIONS

The implemented video-based collaborative learning activity was associated with a higher therapeutic-diets written examination score than traditional instruction in this non-randomized consecutive-cohort study. The nutrition assessment was completed before the therapeutic diets unit in both cohorts, and both cohorts were assessed with written end-of-unit examinations on the same 10-point scale. Although different therapeutic-diets questions were used across academic years, the examinations targeted the same construct and were reviewed using item difficulty indices to achieve comparable difficulty. Because the intervention combined several active-learning components and cohorts were not randomized, the observed score difference cannot be attributed specifically to video podcasting. Prospective controlled studies using the same or item-banked written examination in both groups are needed.

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Conflict of interest

The author declares no financial or non-financial competing interests related to this work.

Ethics approval

The requirement for formal ethics approval was waived because the study used anonymized routine educational evaluation data from adult students and did not involve patient data or clinical intervention.

Consent to participate

Students were informed about the educational activity and anonymized use of aggregate educational data; participation in the satisfaction questionnaire was voluntary.

Data availability

The anonymized data supporting the findings of this study are available from the corresponding author upon reasonable request.

Use of AI tools

AI-assisted tools were used to support language editing. No AI tool is listed as an author.

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INSTRUCTION FOR AUTHORS

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6. Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives (Text with EEA relevance). OJ L 354, 31.12.2008, p. 16–33. Available from: <http://data.europa.eu/eli/reg/2008/1333/oj>.

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ROCZNIKI PAŃSTWOWEGO ZAKŁADU HIGIENY

[ANNALS OF THE NATIONAL INSTITUTE OF HYGIENE]

Volume 77

2026

Number 2

Editorial Introduction	91
Intrauterine growth restriction outcomes at the age of 2 in resource – limited settings: a systematic review <i>Najat Ababsi, Halima Ibrahim, Ilham Elouardighi, Nihal Abitiu, Amina Essamett, Latifa Mochhoury, Milouda Chebabe</i>	93
Boundaries of the therapeutic relationship in nursing – between empathy and emotional burden <i>Dominika Szynal, Tomasz Olszowski</i>	101
Lead poisoning among children in Nigeria: A review of evidence, gaps, and interventions <i>Idris Muhammad Yakubu, Kefas Gurama Jibir, Abdullahi Adobanyi Musa, Rabi Muhammad Dansabo, Muhammad-Hadi Folarin Oyerinde</i>	113
Association between Expanded Disability Status Scale Score and Mediterranean diet adherence according to disease duration in patients with multiple sclerosis <i>Mária Kijovská, Martina Gažarová, Petra Lenártová</i>	127
Analysis of energy and macronutrients intake in patients with type 1 and type 2 diabetes mellitus: A pilot study <i>Lucia Šubová, Petra Lenártová, Marta Habánová, Martina Gažarová</i>	137
Radiocaesium activity in Polish <i>Imleria badia</i> mushrooms: Contamination levels and trends over the last three decades <i>Jerzy Falandysz, Alwyn R. Fernandes, Adam J. Daragó, Michał Saniewski</i>	145
Enhancing nursing students' learning of nutrition through podcasting: An active approach for Generation Z students in Morocco <i>Said Boucheфра</i>	161
Instruction for Authors	171