

Earthing and Human Health: Integrating Electrical, Microbial, Immunological, and Environmental Pathways

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DOI: <https://doi.org/10.5281/zenodo.22827397>

Published Date: 18-September-2026

Abstract: Earthing, or grounding, refers to direct conductive contact between the human body and the Earth. Although research has primarily examined its electrical and physiological effects, the potential health value of earthing may extend to biological processes involved in immune development and regulation. This integrative review examined the potential contribution of earthing and direct human–Earth interaction to human health, with particular attention to immunocompetence. A structured multidisciplinary search and PRISMA-informed selection process identified 25 sources for integrative synthesis. Earthing studies provide preliminary evidence of effects involving inflammation-related processes, sleep, stress, pain, autonomic and cardiovascular function, and physical recovery, although methodological limitations and limited independent replication constrain clinical conclusions. Complementary evidence from environmental microbiome and immunological research indicates that exposure to diverse environmental microorganisms can influence microbiome development, immune maturation, immune regulation, and immunological tolerance, particularly during childhood. Collectively, the evidence suggests that direct human–Earth interaction may have health relevance through interconnected electrical, physiological, microbial, immunological, and environmental pathways. The review therefore proposes immunocompetence as an important but underexplored dimension of the potential health value of earthing. Further controlled and longitudinal research is needed to determine whether and under what conditions natural-ground interaction contributes to measurable immune development, regulation, and health outcomes.

Keywords: earthing; grounding; immunocompetence; immune regulation; environmental microbiome; human–Earth interaction; natural-ground exposure.

1. INTRODUCTION

Human health has developed through continuous interaction with the Earth and its natural environments. For much of human history, everyday activities involved direct contact with soil, vegetation, animals, sunlight, and diverse environmental microorganisms. Modernization, including insulated footwear, constructed surfaces, elevated buildings, urbanization, and increased indoor living, has substantially altered these interactions and reduced routine conductive contact with natural ground (Ober et al., 2014). These changes raise an important question: Does direct human interaction with the Earth contribute to health, and, if so, through what biological and environmental pathways?

Contemporary scientific interest in this question has been advanced through earthing or grounding, generally referring to conductive contact between the human body and the Earth's surface. Ober et al. (2014) proposed that increasing physical and electrical separation from the Earth may have physiological consequences and that restoring this connection could influence health-related processes. Subsequent studies have investigated grounding in relation to sleep, stress, pain, inflammation-related processes, cardiovascular physiology, and physical recovery (Brown et al., 2010; Chevalier et al., 2013, 2019; Ghaly & Teplitz, 2004; Lin et al., 2022; Müller et al., 2019; Park et al., 2025). Reviews have further examined electrical and biophysical mechanisms that may underlie these effects (Jamieson, 2023; Menigoz et al., 2020; Oschman et al., 2015).

The potential health significance of human–Earth interaction, however, may involve more than electrical conductivity. Natural ground is both a conductive surface and a biologically diverse ecosystem through which humans encounter microorganisms and other environmental stimuli. Research indicates that exposure to biodiverse environments can influence human-associated microbial communities and immune-regulatory processes, particularly during childhood (Newman et al., 2024; Nurminen et al., 2022). This evidence suggests that electrical, microbial, immunological, physiological, environmental, and behavioral processes may represent complementary pathways through which direct human–Earth interaction contributes to health, rather than competing explanations.

This perspective is particularly relevant to immune development and immunocompetence. Environmental microbial exposure can contribute to microbiome development, immune maturation, regulation, and immunological tolerance. Immunocompetence in this context refers not simply to increased immune activity but to the capacity for effective defense accompanied by appropriate regulation and tolerance. Experimental evidence showing microbiota and immune-regulatory changes following exposure to microbially diverse environmental materials supports the biological relevance of such environmental interaction during childhood (Nurminen et al., 2022).

Human–Earth interaction also has historical and cross-cultural significance. Direct contact with natural ground preceded modern grounding technologies and scientific understanding of electricity, microorganisms, and immunity. Routine ground contact may remain more common in some rural, agricultural, traditional, and remote environments than in highly urbanized settings. African childhood environments provide an important context because sitting, crawling, playing, and walking on natural ground may simultaneously involve electrical, microbial, ecological, sensory, and behavioral exposures. Evidence of differences in immune development across rural and urban South African childhood environments further demonstrates the relevance of ecological conditions to biological development (Lunjani et al., 2024). Although such evidence does not establish ground contact as the causal mechanism, it provides an important context for investigating the combined health significance of human–Earth interaction.

Despite growing scholarship on earthing, physiological regulation, environmental microbial diversity, microbiome development, and immune function, these areas have largely developed as separate bodies of knowledge. Earthing research has primarily examined electrical and physiological effects of conductive contact with the Earth, whereas environmental microbiome and immunological research has focused on biodiversity, microbial exposure, microbiome development, and immune regulation. Consequently, a significant gap remains in understanding earthing and direct human–Earth interaction as a multidimensional health exposure in which electrical, physiological, microbial, immunological, environmental, and behavioral pathways may operate independently, complementarily, or interactively. This gap is particularly relevant to childhood and African contexts, where routine natural-ground interaction may combine several exposures that remain largely disconnected from conventional earthing research.

The purpose of this integrative review is therefore to critically examine the potential contribution of earthing and direct human–Earth interaction to human health by integrating evidence across these complementary pathways. Particular attention is given to physiological regulation, environmental microbial exposure, microbiome and immune development, immunocompetence, and African childhood environments. The review evaluates the strength and limitations of the available evidence, potential benefits and risks, and implications for future research and evidence-informed preventive and integrative health approaches.

Research Questions

Consistent with the purpose of the integrative review, the study is guided by the following research questions:

RQ1. What electrical, physiological, microbial, immunological, environmental, and behavioral mechanisms may explain the potential health value of earthing and direct human–Earth interaction?

RQ2. What evidence exists regarding the effects of earthing on health-related outcomes, including inflammation, pain, sleep, stress, autonomic regulation, cardiovascular function, and physical recovery?

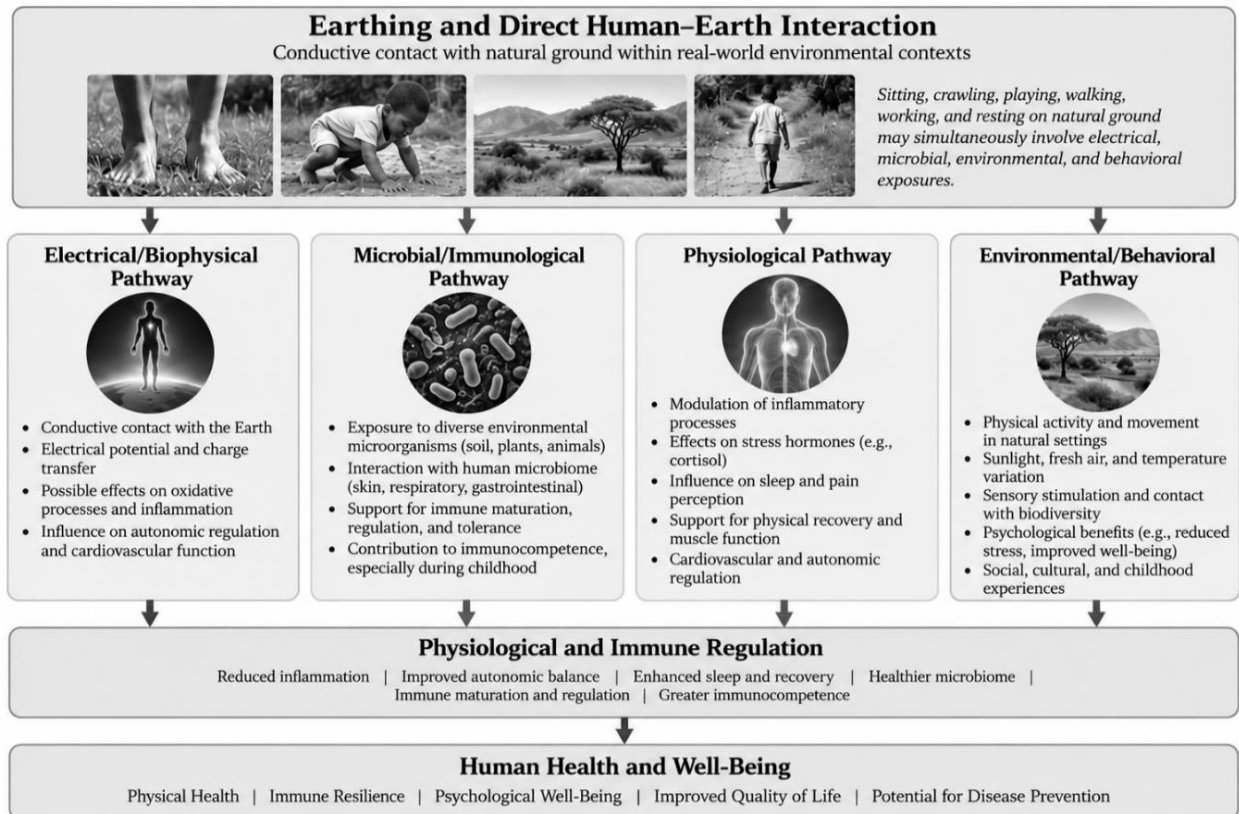
RQ3. How may direct interaction with natural ground, including exposure to environmental microbial diversity, contribute to microbiome development, immune maturation, immune regulation, and immunocompetence?

RQ4. How do African childhood experiences involving direct interaction with natural ground inform understanding of the relationship among human–Earth interaction, immune development, immunocompetence, physiological regulation, and health?

Conceptual and Theoretical Foundations

Earthing and human health cannot be adequately understood through a single disciplinary perspective. Direct human–Earth interaction may simultaneously involve electrical conductivity, physiological responses, environmental microorganisms, immune processes, and broader ecological and behavioral influences. Accordingly, this review integrates four complementary perspectives: (a) human–Earth electrical interaction, (b) environmental microbiome and immune development, (c) environmental and physiological interaction, and (d) ecological and childhood context. These perspectives are not competing explanations; rather, they provide complementary pathways for examining how earthing and natural-ground interaction may contribute to health. See Figure 1.

Figure 1. Integrative Framework of Complementary Pathways Linking Earthing to Human Health



Note. This framework conceptualizes earthing and direct human–Earth interaction as a multidimensional exposure involving complementary electrical/biophysical, microbial/immunological, physiological, and environmental/behavioral pathways. These pathways may operate independently or interactively and may influence physiological and immune regulation and, ultimately, health and well-being. The framework distinguishes proposed mechanisms analytically while recognizing their potential convergence during natural-ground contact. The relationships shown represent theoretically and empirically informed pathways and should not be interpreted as establishing causality or therapeutic efficacy.

Human–Earth Electrical Interaction

The contemporary earthing hypothesis proposes that conductive contact between the human body and the Earth's surface establishes an electrical connection capable of influencing physiological processes. Ober et al. (2014) advanced this perspective by arguing that insulating footwear, elevated structures, and indoor living have reduced routine electrical contact with the Earth. Because the human body is electrically conductive, direct contact with conductive natural surfaces—or experimentally through grounding devices, may alter measurable electrical characteristics and potentially influence biological functioning (Jamieson, 2023; Menigoz et al., 2020).

Proposed mechanisms include effects on electrical potential, oxidative processes, inflammation, autonomic regulation, and other physiological functions (Oschman et al., 2015). Empirical studies have reported changes in cortisol and sleep (Ghaly & Teplitz, 2004), delayed-onset muscle soreness (Brown et al., 2010), blood rheology (Chevalier et al., 2013), pain and

quality of life (Chevalier et al., 2019), physical recovery (Müller et al., 2019), and sleep-related outcomes (Lin et al., 2022; Park et al., 2025). These findings provide a physiological basis for investigating electrical grounding as one important pathway linking human–Earth contact with health, although the strength and clinical significance of the evidence require continued evaluation.

Environmental Microbiome and Immune Development

Natural ground is not solely an electrically conductive surface; it is also a biologically complex environment containing diverse microbial communities. Human interaction with soil, vegetation, animals, and other natural materials can therefore provide microbial exposures capable of interacting with skin, respiratory, gastrointestinal, and other human-associated microbial communities. Environmental biodiversity research increasingly suggests that such interactions may influence microbiome composition and immune regulation (Newman et al., 2024; Nurminen et al., 2022).

This pathway may be particularly important during childhood, when microbial exposures contribute to immune maturation and the development of regulatory and tolerance mechanisms. Experimental evidence demonstrates that exposure to microbially diverse environmental materials can produce measurable changes in human-associated microbiota and selected immune-regulatory indicators in young children (Nurminen et al., 2022). Within the present framework, microbial exposure is therefore conceptualized as a complementary biological pathway of natural human–Earth interaction, potentially contributing to immunocompetence alongside other physiological mechanisms.

Environmental and Physiological Interaction

Direct interaction with natural ground occurs within a broader environmental setting. Walking, sitting, playing, working, or resting on natural surfaces may combine grounding with physical activity, sunlight, sensory stimulation, vegetation, temperature variation, microbial exposure, and psychological engagement with the environment. Nature-exposure research has associated interaction with natural environments with outcomes involving stress, anxiety, psychological well-being, and other dimensions of health (Paredes-Céspedes et al., 2024).

These environmental influences need not be viewed as confounders that diminish the significance of earthing. Rather, under natural conditions they may operate alongside electrical and microbial pathways, producing a multidimensional human–Earth interaction. Artificial grounding devices are useful for isolating electrical effects, whereas direct contact with natural ground provides an ecological context in which several potentially health-relevant exposures may converge. Distinguishing these mechanisms analytically while recognizing their possible complementarity is therefore important for understanding how earthing may contribute to human health.

Ecological and Childhood Context

The complementary-pathways perspective is particularly relevant to childhood and populations in which routine natural-ground contact remains common. Early-life activities such as crawling, sitting, playing, and walking on natural ground can simultaneously involve conductive contact, microbial exposure, physical activity, sensory interaction, and other environmental influences. Such experiences provide a useful ecological context for investigating cumulative and interacting pathways of human–Earth exposure.

African childhood environments are particularly relevant to this inquiry but should not be treated as homogeneous or inherently protective. Lunjani et al. (2024), for example, demonstrated differences in immune-development patterns associated with rural and urban exposures among South African children, illustrating the biological relevance of environmental context without establishing natural-ground contact as the specific causal factor. Such settings nevertheless provide valuable opportunities to examine how changing patterns of urbanization, biodiversity, environmental microbial exposure, and direct Earth contact may relate to immune development and health.

Collectively, these perspectives support a conceptualization of earthing as a multidimensional human–Earth interaction with potentially complementary health pathways. Rather than limiting the phenomenon to a single proposed mechanism, the framework recognizes that direct Earth contact may engage electrical/biophysical, physiological, microbial/immunological, and environmental/behavioral processes. These pathways may function independently, complementarily, or interactively and may converge on outcomes involving physiological regulation, immune development and immunocompetence, psychological well-being, and broader human health.

These complementary perspectives provide the conceptual basis for examining earthing as a multidimensional human–Earth interaction rather than as an exclusively electrical phenomenon. As illustrated in Figure 1, direct Earth contact may engage electrical/biophysical, microbial/immunological, physiological, and environmental/behavioral pathways that operate independently or interactively, potentially influencing physiological and immune regulation and, ultimately, human health and well-being.

2. METHODOLOGY

This study employed an integrative review and conceptual synthesis design to examine the potential contribution of earthing and direct human–Earth interaction to human health. An integrative approach was appropriate because the research questions encompass heterogeneous evidence from bioelectrical grounding, physiological regulation, environmental microbial exposure, microbiome development, immune maturation and regulation, environmental health, and childhood ecological exposure. Integrative reviews permit synthesis across empirical and theoretical literature, methodological designs, and disciplinary traditions when the purpose extends beyond estimating the effectiveness of a single intervention (Snyder, 2019; Torraco, 2016; Whitemore & Knafl, 2005).

The review was guided by the proposition that direct human–Earth interaction may constitute a multidimensional exposure involving complementary electrical/biophysical, physiological, microbial/immunological, and environmental/behavioral pathways. Evidence was therefore examined both within and across these domains to identify convergence, complementarity, divergence, and uncertainty. Importantly, the synthesis did not assume equivalence among electrical grounding, microbial exposure, immune development, and broader environmental interaction; rather, it evaluated how these distinct areas of evidence may collectively inform understanding of the potential health significance of human–Earth interaction.

Literature Search Strategy

A structured, iterative literature search was conducted to identify evidence relevant to the proposed pathways of human–Earth interaction. Searches focused primarily on literature published between 2015 and 2026, while earlier publications were retained when they represented foundational evidence or were necessary to explain the historical development of earthing or relevant biological mechanisms. The literature search was updated through September 3, 2026, to identify recently published studies relevant to the review.

Sources were identified through PubMed/MEDLINE, Scopus, Web of Science, CINAHL, Google Scholar, and African Journals Online (AJOL). Search terms were combined according to the major conceptual domains and included *earthing*, *grounding*, *electrical grounding*, *ground contact*, *human–Earth interaction*, *physiological grounding*, *inflammation*, *pain*, *sleep*, *stress*, *autonomic regulation*, *cardiovascular function*, *physical recovery*, *environmental microbiome*, *soil microbiome*, *microbial diversity*, *biodiversity*, *human microbiome*, *immune development*, *immune regulation*, *immunocompetence*, *childhood environmental exposure*, *rural–urban exposure*, and *Africa*. Reference lists of relevant studies and reviews were also examined to identify additional foundational and empirical sources.

Complementary searches across these domains were necessary because environmental microbiome and immunological research generally does not employ the terminology of *earthing* or *grounding*, whereas conventional earthing research predominantly examines electrical and physiological mechanisms. The search strategy was therefore intentionally multidisciplinary to capture evidence relevant to the distinct but potentially complementary pathways represented in the conceptual framework.

Eligibility and Study Selection

Sources were eligible when they contributed directly to at least one component of the human–Earth interaction framework: (a) electrical or biophysical grounding, (b) physiological responses associated with earthing, (c) environmental microbial exposure and human microbiome interaction, (d) immune maturation or regulation, or (e) environmental and behavioral dimensions of direct natural-ground interaction. Peer-reviewed empirical studies and relevant reviews were prioritized, while selected foundational or conceptual works were retained when necessary to establish the historical or theoretical development of the field.

Evidence involving childhood and African environments was eligible when it contributed to understanding developmental timing, natural-ground interaction, microbial exposure, immune development, or rural–urban ecological variation. Such studies were not classified as direct evidence of earthing efficacy unless grounding was specifically investigated; instead,

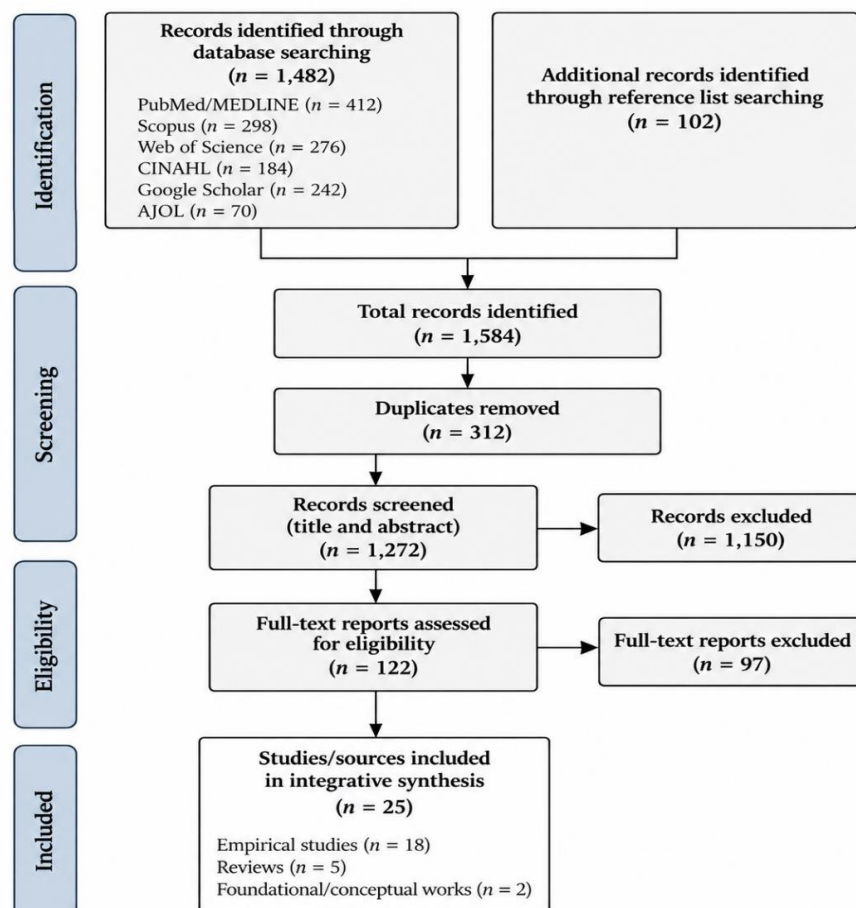
they were used to examine biological and environmental pathways that may accompany natural human–Earth interaction. Sources were excluded when they lacked direct relevance to the research questions, involved an inappropriate population or setting, provided insufficient methodological or conceptual information for critical evaluation, were non-peer-reviewed, or consisted primarily of promotional or non-scientific therapeutic claims.

To enhance transparency, study identification and selection were documented using a PRISMA 2020-informed flow process (Page et al., 2021). Use of the PRISMA framework was limited to documenting identification, screening, eligibility assessment, and inclusion and did not alter the integrative design of the review. The search identified 1,482 database records and 102 additional records through reference-list searching ($N = 1,584$). After removal of 312 duplicates, 1,272 records underwent title and abstract screening, of which 1,150 were excluded. The full texts of 122 reports were assessed for eligibility, and 97 were excluded, resulting in 25 sources included in the final integrative synthesis.

Full-text exclusions were based on the primary reason for exclusion: lack of direct relevance to the research questions ($n = 38$), inappropriate population or setting ($n = 18$), insufficient methodological or conceptual detail ($n = 16$), non-peer-reviewed publication type ($n = 12$), or primarily promotional or non-scientific content ($n = 13$). When a report met more than one criterion, the principal reason for exclusion was recorded.

The final evidence base comprised 25 sources representing empirical, review, and foundational or conceptual scholarship. Collectively, these sources contributed evidence to one or more dimensions of the proposed human–Earth interaction framework, including electrical/biophysical, physiological, microbial/immunological, and environmental/behavioral pathways. (See Figure2).

Figure 2. PRISMA-Informed Flow Diagram of Study Selection



Note. PRISMA 2020-informed flow diagram illustrating identification, screening, eligibility assessment, and inclusion of sources in the integrative review. Use of the PRISMA framework enhances transparency in reporting study selection and does not alter the integrative review design. AJOL = African Journals Online. Adapted conceptually from the PRISMA 2020 statement (Page et al., 2021).

Evidence Extraction and Organization

Data were extracted from included sources according to study design, population, exposure or intervention, exposure duration where applicable, proposed mechanism, outcome measures, principal findings, methodological limitations, and relevance to the research questions. Evidence was organized into four analytical domains corresponding to the conceptual framework: electrical/biophysical, physiological, microbial/immunological, and environmental pathways.

For studies involving childhood and African populations, extraction additionally considered developmental and ecological factors capable of influencing interpretation, including age, rural–urban environment, microbial biodiversity, diet, sanitation, housing, animal exposure, socioeconomic conditions, and related environmental conditions. These factors were treated as potential contextual influences or confounders rather than presumed consequences of ground contact.

Integrative Analysis and Evidence Interpretation

Because the included literature encompassed experimental, clinical, observational, environmental, microbiological, immunological, review, and conceptual evidence, statistical pooling was neither appropriate nor undertaken. Instead, analysis proceeded through a two-stage integrative synthesis. First, evidence was evaluated within each analytical domain to determine the degree of support for the proposed mechanisms and health-related effects. Second, findings were compared across domains to identify convergence, complementarity, independence, inconsistency, and remaining evidentiary gaps.

Interpretation followed an evidence continuum distinguishing biological plausibility, measurable biological or physiological effects, clinically meaningful health outcomes, and evidence sufficiently replicated to support health application. Greater interpretive weight was given to controlled designs, objective outcome measures, replicated findings, and evidence supported across independent investigations. Small pilot studies, observational comparisons, mechanistic studies, subjective outcomes, short intervention periods, heterogeneous grounding protocols, limited independent replication, potential conflicts of interest, and substantial potential for confounding were interpreted more cautiously.

A further analytical distinction was maintained between artificial grounding and natural-ground interaction. Artificial grounding studies were particularly informative for evaluating electrical or biophysical mechanisms because they can reduce environmental co-exposures. Natural-ground interaction was treated as a more complex exposure in which conductivity may occur concurrently with microbial contact, physical activity, sunlight, vegetation, sensory stimulation, and other environmental or behavioral factors. Evidence supporting one pathway was therefore not interpreted as automatically establishing another.

Finally, findings were mapped to the four research questions and integrated into the conceptual framework presented in Figure 1. The synthesis therefore evaluates whether distinct pathways may operate independently or concurrently during human–Earth interaction while maintaining a critical evidentiary distinction: microbial exposure associated with immune development does not establish an immune effect of electrical grounding, and physiological effects associated with electrical grounding do not establish the microbial or ecological effects of natural-ground interaction.

3. LITERATURE REVIEW

The literature on earthing provides the primary empirical foundation for examining whether direct conductive contact with the Earth produces measurable biological and physiological effects relevant to human health.

Earthing: Mechanisms and Physiological Evidence

The empirical foundation of earthing research centers on the proposition that conductive contact with the Earth may produce measurable physiological effects. Although proposed mechanisms remain under investigation, studies have examined electrical potential, inflammatory and oxidative processes, neuroendocrine activity, autonomic regulation, blood rheology, sleep, pain, and physical recovery. Collectively, this literature provides preliminary evidence of physiological activity associated with grounding, but methodological limitations—including small samples, heterogeneous protocols, short intervention periods, and limited independent replication—constrain conclusions regarding clinical effectiveness (Jamieson, 2023; Menigoz et al., 2020; Oschman et al., 2015).

Electrical, Oxidative, and Inflammatory Mechanisms

The principal biophysical explanation for earthing is that conductive contact permits electrical interaction between the body and the Earth's surface, a mechanism that has been central to the development of contemporary grounding theory (Chevalier et al., 2012; Ober et al., 2014). Ober et al. (2014) proposed that this connection may influence the body's electrical

environment, while subsequent scholarship has explored whether charge transfer could affect oxidative and inflammatory processes (Jamieson, 2023; Oschman et al., 2015). Oschman et al. (2015), for example, proposed that grounding may influence inflammatory responses and tissue repair through electrical mechanisms involving mobile electrons. These mechanisms remain hypotheses requiring stronger experimental confirmation, but they provide a biological rationale for investigating measurable physiological effects of grounding.

Early experimental evidence includes Brown et al. (2010), who examined grounding following eccentric exercise in a small pilot study and reported differences in delayed-onset muscle soreness and selected physiological markers between grounded and control conditions. Müller et al. (2019) subsequently investigated grounded sleeping following intensive eccentric muscle loading and reported differences in several recovery-related measures. Although these studies suggest a possible relationship between grounding and recovery or inflammation-related processes, their findings should be interpreted as evidence of potential physiological effects rather than proof of anti-inflammatory or therapeutic efficacy.

Sleep, Stress, and Autonomic Regulation

Sleep and stress regulation represent another recurring area of investigation. Ghaly and Teplitz (2004) reported changes in nighttime cortisol patterns and subjective sleep, pain, and stress following grounding during sleep. More recently, Lin et al. (2022) reported improved sleep-related outcomes in a pilot study involving patients with mild Alzheimer's disease, while Park et al. (2025) examined grounding-mat use in a randomized, double-blind, placebo-controlled study and reported improvements in selected subjective sleep and stress outcomes, alongside objective sleep assessment.

These findings are consistent with the hypothesis that grounding may interact with neuroendocrine or autonomic regulatory processes. However, differences in populations, grounding protocols, measurement approaches, and study duration limit direct comparison. Larger independently replicated trials using objective sleep, autonomic, and endocrine measures are needed before grounding can be regarded as an established intervention for sleep or stress disorders.

Cardiovascular and Hemorheological Effects

Potential cardiovascular effects have also been investigated. Chevalier et al. (2013) reported increased red blood cell zeta potential and reduced aggregation following grounding, suggesting a possible effect on blood rheology. These findings are physiologically noteworthy because blood viscosity and cellular aggregation are relevant to cardiovascular function. However, changes in surrogate physiological measures do not demonstrate reductions in cardiovascular events or disease risk. The study therefore provides mechanistic evidence warranting further investigation rather than evidence of cardiovascular prevention or treatment.

Related research has explored autonomic and physiological regulation during grounding, contributing to the broader hypothesis that electrical contact with the Earth may affect regulatory processes (Sokal & Sokal, 2011). Taken together, these studies suggest measurable physiological responses but remain insufficient to establish clinically meaningful cardiovascular benefits.

Pain, Recovery, and Quality of Life

Grounding has additionally been investigated in relation to pain, recovery, and quality of life. Brown et al. (2010) and Müller et al. (2019) provide preliminary evidence concerning post-exercise recovery, while Chevalier et al. (2019), in a randomized controlled trial involving bodyworkers, reported improvements in pain and selected quality-of-life outcomes associated with grounding. Oschman et al (2015) also noted that Grounding appears to improve sleep, normalize the day–night cortisol rhythm, reduce pain, reduce stress, shift the autonomic nervous system from sympathetic toward parasympathetic activation, increase heart rate variability, speed wound healing, and reduce blood viscosity. These findings broaden the potential relevance of earthing beyond isolated electrical measures to functional and subjective health outcomes. Nevertheless, this evidence base remains comparatively small. Subjective outcomes may be influenced by expectancy and contextual effects, while small samples reduce statistical precision and generalizability. Controlled designs, credible placebo conditions, objective measures, preregistered outcomes, and independent replication remain particularly important for determining whether reported effects are attributable specifically to grounding.

Existing studies provide signals of possible physiological activity rather than definitive evidence of broad therapeutic effectiveness. The literature includes controlled and randomized investigations, objective physiological measurements, and findings across several health-related domains, supporting continued scientific inquiry (Chevalier et al., 2013, 2019; Müller et al., 2019; Park et al., 2025). At the same time, the evidence is limited by small samples in several foundational studies, heterogeneous grounding procedures, short follow-up periods, reliance on some subjective outcomes, and limited independent replication (Jamieson, 2023; Menigoz et al., 2020).

Electrical conductivity should be understood as one empirically testable pathway through which earthing may contribute to health, rather than as a complete explanation of human–Earth interaction. Direct contact with natural ground may simultaneously involve microbial and ecological exposures with potential implications for microbiome and immune development. These complementary pathways are examined next.

Environmental Microbial Diversity, Human Microbiome, and Immunocompetence

The potential contribution of earthing to health may extend beyond electrical conductivity to the biological characteristics of natural ground. Soil, vegetation, and other natural surfaces contain diverse microbial communities that can interact with the human microbiome through skin contact, inhalation, ingestion, and other environmental exposures. Thus, direct contact with natural ground may simultaneously constitute an electrical and a microbial exposure. This distinction is important because microbial interaction provides a separate but potentially complementary pathway through which human–Earth contact may influence health.

Environmental Biodiversity and Microbial Exposure

Environmental biodiversity contributes to the microbial environments encountered by humans. Contact with soil, plants, animals, and other natural materials can expose individuals to microbial communities that differ substantially from those characteristics of highly built indoor environments. Research on environmental microbiomes increasingly supports associations between biodiversity, human microbial exposure, and health-related biological processes (Gilbert & Hartmann, 2024; Newman et al., 2024).

Newman et al. (2024), for example, demonstrated that soil microbial communities in childcare environments varied according to substrate and surrounding vegetation, illustrating that the microbial characteristics of ground surfaces depend on their ecological context. Consequently, natural-ground exposure should not be conceptualized as biologically uniform. Soil composition, vegetation, climate, land use, contamination, and biodiversity may influence the microbial exposures accompanying direct Earth contact.

Early-Life Microbiome and Immune Development

The microbial pathway is particularly relevant during childhood, when the microbiome and immune system undergo substantial development. Environmental microbial encounters contribute to immune education by exposing the developing immune system to diverse biological signals involved in immune maturation, regulation, and tolerance. This association between environmental microbial diversity and immune regulation is consistent with the biodiversity hypothesis, which proposes that reduced contact with diverse environmental microbiota may impair immunological tolerance and contribute to immune-mediated disease in urbanized populations (Haahtela, 2019). Reduced microbial diversity associated with increasingly sanitized and urbanized environments has generated interest in whether diminished environmental exposure may alter normal immune-development processes.

Experimental evidence provides support for the biological responsiveness of this pathway. In a placebo-controlled, double-blind study, Nurminen et al. (2022) exposed children aged 3–5 years to microbially diverse environmental materials for 20 minutes twice daily over 14 days. Compared with the control condition, the intervention was associated with changes in skin microbiota and immune-regulatory indicators, including regulatory T-cell and cytokine responses. These findings provide evidence that relatively brief interaction with microbially diverse environmental materials can influence measurable microbial and immunological processes in young children.

Such findings do not demonstrate that soil exposure broadly prevents disease or “boosts” immunity. Rather, they support the more specific proposition that environmental microbial diversity can interact with biological systems involved in immune development and regulation.

Immunocompetence as a Regulatory Outcome

Within the present framework, immunocompetence refers to the capacity of the immune system to respond effectively to biological challenges while maintaining appropriate regulation and tolerance. This conception differs from the popular notion that health depends simply on increasing immune activity. Excessive or poorly regulated immune responses can themselves contribute to disease; therefore, maturation, discrimination, tolerance, and regulatory balance are central to effective immune functioning.

The relevance to earthing lies in the nature of direct ground contact. Sitting, crawling, walking, playing, or working on natural surfaces may facilitate interaction with environmentally derived microorganisms while simultaneously providing conductive and other ecological exposures. The microbial–immunological pathway therefore complements the electrical pathway: one concerns electrical interaction with the Earth, whereas the other concerns biological interaction with the Earth's microbial environment. Under natural conditions, both may occur during the same episode of ground contact.

African and Rural–Urban Evidence

Variation between rural and urban environments provides additional evidence that ecological context may influence immune development. Lunjani et al. (2024), studying young South African children across rural and urban environments, identified differences in immune-related profiles associated with environmental context. The findings reinforce the importance of the broader exposome in early immune development but do not establish barefoot contact, soil exposure, or electrical grounding as the causal factor.

This distinction is important for the present review. African childhood environments should not be interpreted as a homogeneous exposure or as evidence that traditional lifestyles are inherently healthier. Rather, settings in which children routinely crawl, sit, play, or walk on natural ground provide valuable contexts for investigating how direct Earth contact, microbial biodiversity, and other environmental exposures may converge during development.

Environmental and Behavioral Pathways of Human–Earth Interaction

Direct contact with the Earth occurs within an environmental context that may introduce additional health-relevant exposures beyond electrical conductivity and microbial interaction. Walking, sitting, playing, working, or resting on natural ground may coincide with physical activity, sunlight, fresh air, vegetation, sensory stimulation, and psychological engagement with natural surroundings. These factors represent complementary environmental and behavioral pathways through which natural earthing may differ from electrically grounded indoor conditions.

Environmental and Psychophysiological Pathways

Exposure to natural environments has been associated with reduced stress, anxiety, and depressive symptoms and with improvements in psychological well-being (Paredes-Céspedes et al., 2024). Such effects may involve multiple mechanisms, including physical movement, sensory stimulation, environmental restoration, and changes in stress-related physiological processes. These findings are relevant to earthing because natural-ground contact frequently occurs within the same environments in which these exposures are experienced.

This overlap also creates an important methodological challenge. An individual walking barefoot outdoors, for example, may simultaneously experience electrical grounding, microbial exposure, physical activity, sunlight, vegetation, and psychological engagement with nature. Improvements in health-related outcomes therefore cannot automatically be attributed to electrical grounding alone. Conversely, the presence of multiple exposures does not make earthing irrelevant; rather, it suggests that natural earthing may function as a multidimensional exposure whose component pathways require careful differentiation.

Natural and Artificial Grounding as Complementary Research Contexts

The distinction between natural and artificial grounding provides a useful approach to studying these pathways. Grounding mats, sheets, patches, and similar conductive systems can help isolate the electrical component under controlled conditions, as demonstrated in several grounding studies (Chevalier et al., 2019; Lin et al., 2022; Müller et al., 2019; Park et al., 2025). Direct natural-ground contact, however, more closely represents the broader human–Earth interaction in which electrical, microbial, environmental, and behavioral exposures may occur together.

These approaches should therefore be considered complementary rather than interchangeable. Controlled grounding studies are valuable for evaluating specific electrical and physiological mechanisms, whereas naturalistic studies can examine the combined exposures characteristic of real-world Earth contact. Comparing these conditions may eventually help determine which effects are attributable to electrical conductivity and which reflect microbial, environmental, behavioral, or interacting mechanisms.

Ecological Context and Exposure Quality

The biological characteristics of natural-ground exposure also vary substantially across environments. Soil microbial communities are influenced by vegetation and substrate characteristics (Newman et al., 2024), while indoor and built

environments create distinct patterns of human microbial exposure (Gilbert & Hartmann, 2024). Consequently, the health significance of ground contact may depend not only on whether contact occurs but also on where, how frequently, for how long, and under what environmental conditions.

This ecological variability also requires attention to safety. Natural soil can contain beneficial or neutral microorganisms but may also harbor pathogens, parasites, chemical contaminants, or physical hazards. The appropriate scientific question is therefore not whether unrestricted ground exposure is universally beneficial, but which forms of safe human–Earth interaction, under which environmental conditions, produce measurable biological or health effects.

African Childhood and Human–Earth Interaction

African childhood environments provide an important context for examining how sustained interaction with natural ground may combine the complementary pathways proposed in this review. In some rural and less highly built environments, children may routinely sit, crawl, play, and walk on natural surfaces, creating repeated opportunities for conductive contact, microbial exposure, physical activity, and broader ecological interaction. These experiences are particularly relevant during early life, when the microbiome, immune system, and physiological regulatory processes are developing.

Rural–Urban Context and Immune Development

Evidence from South Africa demonstrates that childhood environmental context is associated with measurable differences in immune development. Lunjani et al. (2024) identified distinct immune-related profiles among young children from rural and urban environments, supporting the broader proposition that environmental exposures contribute to early immune development. Such findings are consistent with experimental evidence demonstrating that exposure to microbially diverse environmental materials can alter skin microbiota and immune-regulatory indicators in young children (Nurminen et al., 2022).

These studies do not establish direct ground contact as the cause of observed immune differences. Rural and urban childhood environments vary simultaneously in microbial biodiversity, housing, diet, animals, sanitation, pollution, socioeconomic conditions, healthcare access, and other exposures. Nevertheless, they demonstrate that environmental context is biologically relevant and support more focused investigation of direct human–Earth interaction as one component of the childhood exposome.

African Childhood as a Context for Earthing Research

The significance of African childhood to earthing research therefore lies not in assuming that African environments are uniformly beneficial, but in the opportunity to investigate forms of natural human–Earth interaction that may be less frequent in highly urbanized settings. Unlike artificial grounding, routine contact with natural ground may simultaneously involve electrical conductivity, environmental microorganisms, ecological biodiversity, movement, and sensory interaction. African settings characterized by differing degrees of urbanization may consequently provide valuable comparative contexts for determining how these exposures operate individually or together.

This perspective also avoids a simplistic contrast between “traditional” and “modern” lifestyles. Urbanization can provide substantial improvements in sanitation, housing, healthcare, and protection from environmental hazards while simultaneously changing patterns of microbial biodiversity and direct ground contact. The relevant research question is therefore not whether traditional environments are healthier, but which specific environmental exposures contribute to healthy biological development and how beneficial exposures can be distinguished from preventable risks.

4. RESULTS AND INTEGRATIVE SYNTHESIS

The evidence was synthesized across the six research questions to determine how electrical, physiological, microbial, immunological, environmental, and behavioral pathways may contribute to the relationship between earthing and human health. Because the evidence spans heterogeneous study designs and outcomes, the synthesis emphasizes patterns of evidence, strength of support, and convergence across pathways rather than statistical pooling.

Characteristics of the Included Evidence

The final synthesis included 25 sources representing empirical, review, and foundational or conceptual evidence across the principal domains of human–Earth interaction. Table 1 summarizes the characteristics, primary findings or contributions, and conceptual relevance of the included evidence.

Table 1. Characteristics and Contributions of Sources Included in the Integrative Review

No.	Author, Year	Source Type	Population/Context	Primary Focus	Principal Finding/Contribution	Analytical Domain
1	Brown et al. (2010)	Empirical—pilot	Adults following eccentric exercise	Grounding and exercise recovery	Grounding was associated with differences in DOMS and recovery-related physiological measures	Physiological
2	Chevalier et al. (2013)	Empirical	Adults	Grounding and blood rheology	Grounding increased RBC zeta potential and reduced RBC aggregation	Electrical/Physiological
3	Chevalier et al. (2015)	Empirical	Adults	Grounding, inflammation, and blood flow	Short-term grounding produced changes in measures associated with blood flow and inflammation	Electrical/Physiological
4	Chevalier et al. (2019)	Empirical—RCT	Bodyworkers	Grounding, pain, and quality of life	Grounding was associated with improvement in pain and quality-of-life.	Physiological
5	Ghaly & Teplitz (2004)	Empirical	Adults	Grounding during sleep	Reported changes in cortisol patterns, subjective sleep, pain, and stress	Electrical/Physiological
6	Lin et al. (2022)	Empirical—pilot	Patients with mild Alzheimer’s disease	Grounding and sleep	Grounding was associated with improved sleep-related outcomes	Physiological
7	Müller et al. (2019)	Empirical	Physically active adults	Grounded sleep following exercise	Reported differences in physiological markers associated with post-exercise recovery	Physiological
8	Park et al. (2025)	Empirical	Adults	Earthing mat and sleep	Evidence show improvement in sleep-related outcomes	Electrical/Physiological
9	Sokal & Sokal (2011)	Empirical	Adults	Earthing and physiological processes	Reported measurable physiological changes associated with grounding	Electrical/Physiological
10	Nurminen et al. (2022)	Empirical	Children aged 3–5 years	Biodiverse environmental microbial exposure	Exposure altered skin microbiota and immune-regulatory indicators, including T-regulatory-cell responses	Microbial/Immunological
11	Roslund et al. (2020)	Empirical—biodiversity intervention	Daycare children	Environmental biodiversity exposure	Biodiversity intervention enhanced health-associated microbiota and immune regulation	Microbial/Immunological
12	Roslund et al. (2021)	Empirical—longitudinal intervention	Urban daycare children	Long-term biodiversity intervention	Sustained biodiversity exposure shaped health-associated commensal microbiota	Microbial/Immunological
13	Roslund et al. (2024)	Empirical—randomized intervention	Adults	Direct skin exposure to microbially rich soil	Soil-microbiota exposure altered commensal bacterial communities and aspects of cell-mediated immune responsiveness	Microbial/Immunological
14	Saarenpää et al. (2024)	Empirical—placebo-controlled, double-blind	Adults	Microbially rich indoor gardening material	Exposure diversified skin microbiota and was associated with enhanced immune-regulatory responses	Microbial/Immunological

15	Soininen et al. (2022)	Empirical—randomized trial	Urban office workers	Indoor green-wall biodiversity exposure	Exposure affected health-associated skin microbiota and immune-regulatory measures	Microbial/Immunological/Environmental
16	Mills et al. (2023)	Empirical	Children	Biodiverse environmental exposure	Biodiverse forest exposure was associated with stronger short-term enrichment and recovery of disturbed skin microbiota	Microbial/Environmental
17	Lunjani et al. (2024)	Empirical—comparative	South African children	Rural–urban environmental exposure	Rural and urban environmental conditions were associated with differences in early-life immune development	Microbial/Immunological/Environmental
18	De Filippo et al. (2010)	Empirical—comparative	European and rural African children	Diet, environment, and gut microbiota	Demonstrated marked differences in gut microbial composition across contrasting childhood environments and diets	Microbial/Environmental
19	Jamieson (2023)	Integrative review	Earthing literature	Grounding and electromagnetic hygiene	Synthesized evidence and proposed mechanisms concerning grounding and health-related physiological effects	Electrical/Physiological
20	Menigoz et al. (2020)	Review	Earthing literature	Earthing and integrative/lifestyle medicine	Synthesized grounding research and clinical observations while identifying potential health applications	Electrical/Physiological
21	Oschman et al. (2015)	Review	Earthing literature	Grounding, inflammation, immune response, and wound healing.	Synthesized and proposed mechanisms connecting grounding with inflammatory and immune processes	Electrical/Physiological/Immunological
22	Andersen et al. (2021)	Systematic review	Nature-exposure literature	Nature exposure and immune function	Found evidence of relationships between nature exposure and immune functions.	Immunological/Environmental
23	Haahtela et al. (2021)	Review/conceptual synthesis	Biodiversity and immune-health literature	Biodiversity and immunological resilience	Provides theoretical and empirical support connecting microbial biodiversity with immune regulation and resilience	Microbial/Immunological
24	Ober et al. (2014)	Foundational/conceptual	Earthing	Developed, conceptualized earthing	Provides the historical, foundation for earthing and the Earth-electron hypothesis	Electrical/Conceptual
25	Sinkkonen et al. (2025)	Conceptual/review	Microbial biodiversity and immune health	Restoration of microbial biodiversity	Restoring microbial biodiversity may contribute to immune health.	Microbial/Immunological/Conceptual

Note. DOMS = delayed-onset muscle soreness; RBC = red blood cell; RCT = randomized controlled trial. Analytical domains are not mutually exclusive because individual sources may contribute evidence to more than one component of the integrative framework. Environmental biodiversity and microbiome studies are included as evidence concerning microbial, immunological, developmental, or environmental pathways potentially associated with natural human–Earth interaction; they should not be interpreted as direct evidence of electrical grounding efficacy.

RQ1. What electrical, physiological, microbial, immunological, environmental, and behavioral mechanisms may explain the potential health value of earthing and direct human–Earth interaction?

The reviewed evidence identifies six complementary pathways, electrical, physiological, microbial, immunological, environmental, and behavioral, through which earthing and direct human–Earth interaction may influence health. These pathways differ in evidentiary strength but collectively support a multidimensional interpretation of human–Earth interaction.

Electrical mechanisms. Conductive contact with the Earth's surface provides a pathway through which body electrical potential may equilibrate with that of the Earth (Ober et al., 2014; Sokal & Sokal, 2011). Proposed mechanisms include transfer of mobile electrons, reduction of body voltage, and alteration of voltages induced by surrounding electrical fields, including the proposed “umbrella effect” (Jamieson, 2023; Menigoz et al., 2020).

Physiological mechanisms. Grounding has been associated with measurable changes in blood rheology, autonomic regulation, cortisol patterns, sleep, muscle recovery, and other physiological parameters (Chevalier et al., 2013; Ghaly & Teplitz, 2004; Müller et al., 2019; Sokal & Sokal, 2011). Chevalier et al. (2013), for example, reported increased red blood cell zeta potential and reduced aggregation following grounding. Giulivi and Kotz (2025) further reported lower mitochondrial reactive oxygen species under grounded than nongrounded conditions, suggesting a potential oxidative-stress-related mechanism.

Microbial mechanisms. Unlike artificial electrical grounding, natural-ground contact may simultaneously expose individuals to microorganisms associated with soil, vegetation, sand, and other surfaces. Environmental microbial diversity can influence human-associated microbial communities, while the composition of ground microbiota varies with substrate and surrounding ecological conditions (Newman et al., 2024; Nurminen et al., 2022). Microbial exposure therefore represents a distinct but potentially complementary pathway of natural human–Earth interaction.

Immunological mechanisms. Two related pathways emerge. Electrical grounding has been proposed to influence oxidative and inflammatory processes through electron-mediated mechanisms, although this remains mechanistically uncertain (Oschman et al., 2015). Separately, environmental microbial exposure may influence immune maturation and regulation through microbiome–immune interactions. Experimental exposure to microbially diverse materials has produced changes in regulatory T cells, cytokines, and microbial characteristics (Nurminen et al., 2022), while grounding studies have reported differences in inflammatory and immune-related indicators during physical recovery (Brown et al., 2010; Oschman et al., 2015).

Environmental mechanisms. Natural earthing occurs within broader ecological environments involving vegetation, daylight, outdoor air, temperature, and sensory stimulation. Nature-exposure research associates such environments with psychological and stress-related benefits (Paredes-Céspedes et al., 2024). These effects may accompany natural earthing but should not be attributed specifically to electrical grounding.

Behavioral mechanisms. Barefoot walking, gardening, sitting or resting outdoors, and related forms of ground contact may involve physical activity, relaxation, sensory engagement, and increased time outdoors. These behavioral influences are difficult to separate from the environmental context and therefore represent complementary rather than grounding-specific pathways.

Overall, RQ1 indicates that earthing is not adequately explained by a single mechanism. Electrical contact represents its defining biophysical pathway, with physiological changes providing measurable responses to grounding. During natural-ground interaction, microbial and immunological processes may occur concurrently, while environmental and behavioral exposures provide additional health-relevant influences. The evidence therefore supports conceptualizing earthing as a multidimensional human–Earth interaction involving complementary pathways that may influence physiological and immune regulation, although the relative contribution and interaction of these mechanisms remain incompletely established.

RQ2. What evidence exists regarding the effects of earthing on health-related outcomes, including inflammation, pain, sleep, stress, autonomic regulation, cardiovascular function, and physical recovery?

The empirical literature reports potential effects of earthing across four principal outcome domains: inflammation and pain, sleep and stress, autonomic and cardiovascular regulation, and physical recovery. Across these domains, findings indicate measurable physiological and subjective responses to grounding; however, the evidence remains preliminary because much of the literature consists of small pilot studies, short interventions, heterogeneous protocols, and a limited number of independently replicated randomized controlled trials (Jamieson, 2023; Menigoz et al., 2020).

Inflammation and pain. Grounding studies have reported changes in inflammatory and immune-related measures, including leukocyte responses associated with recovery from delayed-onset muscle soreness (Brown et al., 2010; Oschman et al., 2015). Oschman et al. (2015) synthesized experimental and clinical observations suggesting that grounding may influence inflammatory responses, tissue repair, and wound-healing processes. Pain-related findings have also been reported. In a randomized controlled trial of bodyworkers, Chevalier et al. (2019) found improvements in pain and selected quality-of-life measures during grounding. Collectively, these findings suggest a possible relationship between grounding, inflammatory processes, and perceived pain, although the evidence is insufficient to establish treatment efficacy for inflammatory or chronic pain disorders.

Sleep and stress. Evidence also indicates potential effects on sleep and neuroendocrine regulation. Ghaly and Teplitz (2004) reported changes in 24-hour cortisol profiles accompanied by improvements in subjective sleep, pain, and stress during grounded sleep. Lin et al. (2022) subsequently reported improved sleep quality in patients with mild Alzheimer's disease in a pilot grounding study. More recently, Park et al. (2025), using a randomized, double-blind, placebo-controlled design, reported improvements in selected sleep- and stress-related outcomes following grounding-mat use. Chevalier et al. (2019) additionally observed improvements in fatigue, mood, and related quality-of-life measures among bodyworkers. Likewise, Kondo et al. (2018) found that heart rate, blood pressure, and self-report measures provide the most convincing evidence that spending time in outdoor environments, particularly those with green space, may reduce the experience of stress, and ultimately improve health. These studies provide converging preliminary evidence that grounding may influence sleep and stress-related processes, although larger independent trials are required.

Autonomic and cardiovascular regulation. Physiological studies have reported changes consistent with autonomic and cardiovascular effects. Grounding has been associated with changes in electrophysiological and autonomic measures, suggesting possible modulation of sympathetic–parasympathetic activity (Sokal & Sokal, 2011). Cardiovascular evidence includes the study by Chevalier et al. (2013), which found increased red blood cell zeta potential and reduced red blood cell aggregation following grounding. These findings suggest an effect on blood rheology and provide a potential physiological mechanism relevant to circulation. They should not, however, be interpreted as evidence that grounding prevents cardiovascular events or treats cardiovascular disease because clinical cardiovascular outcomes were not established.

Physical recovery. Experimental research provides additional evidence concerning recovery following physical stress. Brown et al. (2010) reported differences in soreness and selected physiological and immune-related measures following eccentric exercise in grounded versus control conditions. Müller et al. (2019) subsequently found differences in several recovery-related measures after intensive eccentric muscle loading among participants who slept grounded. Oschman et al. (2015) also reviewed observations involving wound healing and localized inflammatory responses. Together, these findings suggest a potential effect on recovery-related processes, but the small evidence base and limited replication prevent firm conclusions regarding the magnitude or clinical importance of these effects.

Addressing RQ2, empirical evidence indicates that earthing is associated with measurable changes across inflammation and pain, sleep and stress, autonomic and cardiovascular physiology, and physical recovery. The strongest conclusion supported by the current evidence is not that earthing has established therapeutic efficacy, but that grounding produces sufficiently consistent physiological and health-related signals across several domains to warrant larger, independently conducted, adequately powered randomized controlled trials.

RQ3. How may direct interaction with natural ground, including exposure to environmental microbial diversity, contribute to microbiome development, immune maturation, immune regulation, and immunocompetence?

The evidence indicates that interaction with biodiverse natural environments may contribute to immune development by increasing exposure to environmental microorganisms that interact with the human microbiome. This relationship is consistent with the biodiversity hypothesis, which proposes that sustained interaction with diverse environmental microbiota contributes to appropriate immune maturation and regulation (Haahtela, 2019; Haahtela et al., 2021). Within the present framework, natural-ground contact represents one potential route for such microbial interaction.

Immune maturation. Early childhood is a critical period for microbiome and immune development. Contact with soil, vegetation, and other biodiverse materials can expose the skin, respiratory tract, and gastrointestinal system to environmental microorganisms capable of interacting with innate and adaptive immune processes. Such exposure may contribute to immune calibration rather than simply increasing immune activity. Experimental evidence supports this pathway. Nurminen et al. (2022) found that controlled exposure of children aged 3–5 years to microbially diverse materials

altered skin microbiota and immune-related indicators, including regulatory T-cell and cytokine responses. Biodiversity interventions in daycare environments have similarly produced changes in health-associated microbiota and immune regulation (Roslund et al., 2020, 2021).

Immune regulation and tolerance. Diverse microbial exposure may also contribute to immunological tolerance by influencing regulatory pathways that restrain inappropriate inflammatory responses. Changes in regulatory T cells following biodiversity exposure provide experimental support for this relationship (Nurminen et al., 2022). This regulatory dimension is central to immunocompetence, which requires both effective responses to biological threats and appropriate control of excessive or unnecessary immune activity (Haahtela et al., 2021).

Microbiome development and barrier defense. Environmental microorganisms may further influence immunocompetence through interactions with human-associated microbial communities. These interactions can affect colonization, microbial competition, metabolite production, epithelial integrity, and immune regulation. Importantly, recent experimental evidence extends this pathway beyond generalized nature exposure: direct skin exposure to microbially rich soil has been associated with changes in commensal bacterial communities and cell-mediated immune responses (Roslund et al., 2024), while exposure to microbially diverse gardening materials has been associated with greater skin microbial diversity and immune-regulatory changes (Saarenpää et al., 2024).

The biological significance of ground contact also depends on environmental quality. Soil and vegetation are reservoirs of microbial diversity, but their microbial composition varies according to substrate and surrounding ecological conditions (Newman et al., 2024). Consequently, contact with natural ground should not be treated as a uniform exposure; its microbial and immunological significance may vary with biodiversity and environmental characteristics.

These findings also distinguish microbial–immunological mechanisms from electrical grounding while demonstrating their potential convergence. Artificial grounding can provide conductive Earth connection without substantial microbial exposure, whereas sitting, crawling, playing, gardening, or walking on natural ground may provide both. Natural earthing may therefore constitute a compound human–Earth exposure in which electrical, microbial, and ecological pathways occur concurrently but remain biologically distinguishable.

In answer to RQ3, the evidence supports a pathway in which biodiverse environmental contact can influence human-associated microbiota and immune-regulatory processes, particularly during early development, thereby contributing to immune maturation, tolerance, and immunocompetence. Direct natural-ground interaction represents one potential route of such exposure. Current evidence, however, more directly establishes the biological importance of environmental microbial exposure than an immune benefit attributable specifically to earthing. Research measuring ground contact, environmental microbiota, human microbiome changes, and immune outcomes concurrently is needed to establish that connection.

RQ4. How do African childhood experiences involving direct interaction with natural ground inform understanding of the relationship among human–Earth interaction, immune development, immunocompetence, physiological regulation, and health?

African childhood environments provide an important context for examining human–Earth interaction because, in some rural, agrarian, and less highly built settings, children may experience frequent contact with natural surfaces during critical developmental periods. Sitting, crawling, playing, walking barefoot, agricultural activities, and proximity to soil, vegetation, and animals may create repeated opportunities for electrical contact, microbial exposure, ecological interaction, physical activity, and sensory stimulation. These environments therefore provide a natural context in which several pathways identified in the present framework may occur concurrently.

Early-life ground interaction and microbial exposure. Direct interaction with natural surfaces may expose the skin and, through hand-to-mouth behavior, the gastrointestinal system to environmental microorganisms during periods of substantial microbiome and immune development. Ground contact, however, occurs within a broader childhood exposome that includes animals, water, diet, vegetation, household surfaces, siblings, sanitation, and other environmental conditions. Natural-ground interaction should therefore be considered one potentially important component of a complex exposure environment rather than the sole source of microbial acquisition.

Microbiome and immune development. Comparative African research demonstrates that childhood microbiome composition varies substantially across ecological and lifestyle environments. De Filippo et al. (2010) identified marked differences between children in rural Burkina Faso and European children, while subsequent research reinforced relationships among diet, environment, lifestyle, and gut microbiome composition (De Filippo et al., 2017). South African

evidence similarly demonstrates associations between rural–urban environmental conditions and early immune development (Lunjani et al., 2024). When considered alongside experimental biodiversity interventions showing changes in children's microbiota and immune-regulatory responses (Nurminen et al., 2022; Roslund et al., 2020, 2021), these findings support the broader proposition that environmentally derived microbial diversity can participate in microbiome development, immune maturation, regulation, and tolerance.

These relationships are relevant to immunocompetence, particularly because repeated microbial encounters during early development may contribute to the regulatory processes through which the immune system differentiates harmful from innocuous biological stimuli. African childhood environments therefore complement experimental biodiversity research by providing real-world contexts in which microbial, ecological, and other human–Earth exposures may occur naturally and repeatedly.

Rural–urban transitions. Urbanization can simultaneously alter ground contact, microbial biodiversity, diet, animal exposure, housing, sanitation, pollution, physical activity, and other components of the childhood exposome. Rural–urban differences should therefore not be reduced to an “Earth-connected versus Earth-insulated” comparison, nor do they establish that rural childhood is inherently healthier. Rather, such variation provides an important research context for determining which specific environmental exposures are associated with microbiome development, immune regulation, physiological processes, and health.

In answer to RQ4, African childhood experiences demonstrate that direct human–Earth interaction can occur repeatedly during important developmental periods and within environments involving simultaneous electrical, microbial, ecological, and behavioral exposures. Rural–urban research further demonstrates that environmental context is associated with differences in childhood microbiome composition and immune development (De Filippo et al., 2010, 2017; Lunjani et al., 2024). Although current evidence does not isolate natural-ground contact as the cause of these differences, African childhood environments provide an important context for investigating whether sustained Earth contact contributes independently or interactively to microbiome development, immunocompetence, physiological regulation, and longer-term health.

5. DISCUSSION

This integrative review examined earthing and direct human–Earth interaction across electrical, physiological, microbial, immunological, environmental, and behavioral pathways. The central finding is that the potential health significance of Earth contact is not adequately represented by a single mechanism. Electrical conductivity remains fundamental to conventional earthing theory, but natural-ground interaction constitutes a broader exposure in which electrical contact may occur alongside microbial exposure, physiological responses, ecological conditions, physical activity, and sensory and behavioral experiences. The principal contribution of this review is therefore the integration of these previously fragmented areas of evidence into a multidimensional framework while preserving important distinctions in their mechanisms and evidentiary strength.

Earthing as a Multidimensional Human–Earth Interaction

Contemporary earthing research has predominantly examined whether conductive contact with the Earth produces measurable physiological effects. Reported findings involving cortisol patterns, sleep, pain, blood rheology, autonomic activity, inflammatory processes, and physical recovery provide a basis for continued investigation of the electrical pathway (Brown et al., 2010; Chevalier et al., 2013, 2019; Ghaly & Teplitz, 2004; Müller et al., 2019; Oschman et al., 2015). These findings are consistent with the modern earthing hypothesis advanced by Ober et al. (2014), although the underlying mechanisms and clinical significance remain incompletely established.

Natural earthing, however, differs conceptually from electrical grounding performed through conductive devices. Walking barefoot, sitting, crawling, gardening, or otherwise contacting natural ground may simultaneously involve soil and environmental microorganisms, vegetation, sunlight, physical movement, sensory stimulation, and other ecological influences. Natural-ground interaction can therefore be understood as a compound human–environment exposure, with electrical conductivity representing one component rather than necessarily the only biologically relevant pathway.

This distinction has methodological importance. Artificial grounding may be particularly useful for isolating electrical effects, whereas naturalistic studies are necessary for understanding the combined exposures associated with real-world Earth contact. Neither approach should replace the other. Instead, they address different components of the framework and provide complementary strategies for determining which effects are specifically attributable to electrical grounding and which emerge from broader natural-ground interaction.

Convergence of Physiological, Microbial, and Immunological Pathways

The reviewed evidence also reveals substantial differences in scientific maturity among the proposed pathways. Bioelectrical grounding studies provide preliminary evidence of measurable physiological responses, but the literature remains characterized by relatively small samples, heterogeneous protocols, short intervention periods, and limited independent replication (Jamieson, 2023; Menigoz et al., 2020). Proposed mechanisms involving electron transfer, oxidative processes, and inflammation remain biologically plausible hypotheses requiring stronger experimental confirmation (Oschman et al., 2015).

The microbial and immunological pathway is supported by a broader evidence base demonstrating that environmental microbial diversity can influence human-associated microbiota and immune regulation. Experimental biodiversity interventions have produced changes in microbial communities and immune-related indicators, including regulatory T-cell and cytokine responses (Nurminen et al., 2022; Roslund et al., 2020). Such findings are particularly relevant during childhood, when microbial colonization and immune development remain highly responsive to environmental conditions.

Within this framework, immunocompetence should not be interpreted simply as heightened immune activity. Effective immunity requires both the capacity to respond to pathogens and the regulatory capacity to limit inappropriate or excessive responses. Environmental microbial interaction may contribute to this developmental calibration through microbiome-immune relationships involving immune maturation, tolerance, and regulation. Consequently, natural-ground interaction warrants investigation not because contact with soil inherently “boosts immunity,” but because biodiverse environmental exposure may constitute one component of the ecological conditions under which immune systems develop.

Importantly, these findings do not establish that the microbial effects of natural environments are caused by electrical grounding, nor do physiological grounding studies establish microbial or immunological effects. The pathways are complementary rather than interchangeable. Their potential convergence becomes scientifically relevant because they may occur simultaneously during natural Earth contact. Future research should therefore determine whether these pathways operate independently, additively, or interactively rather than assuming that evidence supporting one mechanism validates the others.

Developmental and African Contexts

The developmental perspective further extends the significance of human–Earth interaction. During childhood, sitting, crawling, playing, and walking on natural surfaces can produce repeated contact with soil, vegetation, microorganisms, and other ecological features during periods of substantial microbiome, physiological, and immune development. Unlike brief experimental grounding interventions, these interactions may occur repeatedly over months or years, making developmental timing, frequency, duration, and environmental quality important considerations.

African childhood environments provide a particularly informative context for investigating these relationships, although they should not be treated as homogeneous or inherently health-promoting. Studies comparing rural and urban African populations demonstrate that ecological conditions, diet, lifestyle, and other environmental exposures are associated with differences in childhood microbiome composition and immune development (De Filippo et al., 2010, 2017; Lunjani et al., 2024). These findings do not isolate direct ground contact as the causal factor. Rather, they demonstrate that biological development occurs within complex environmental systems and support closer examination of natural-ground interaction as one potentially relevant component.

This perspective also avoids constructing an artificial opposition between traditional and modern environments. Urbanization has produced major improvements in sanitation, housing, healthcare access, infrastructure, and protection from environmental hazards. At the same time, modernization may alter patterns of microbial biodiversity, outdoor activity, and routine contact with natural surfaces. The relevant scientific question is therefore not whether traditional environments are healthier than modern ones, but which components of human–environment interaction remain biologically important, under what conditions, and how beneficial exposures might be maintained without reintroducing preventable environmental risks.

Interpreting the Evidence for Health Application

A central implication of the review is the need to distinguish carefully between biological plausibility, measurable biological effects, clinically meaningful outcomes, and demonstrated health benefits. Evidence that grounding changes a physiological marker does not establish prevention or treatment of disease. Similarly, evidence that environmental microbial exposure alters microbiota or immune-regulatory markers does not demonstrate that direct ground contact prevents specific illnesses.

The current evidence therefore supports different levels of inference across the framework. Environmental biodiversity research provides comparatively stronger experimental and mechanistic support for microbiome and immune-regulatory effects, whereas bioelectrical earthing research provides promising but preliminary evidence of physiological activity. Claims regarding disease prevention or therapeutic effectiveness require substantially stronger evidence than is currently available.

This distinction is particularly important for interpreting earthing within preventive and integrative health. Safe natural-ground interaction may coincide with several potentially beneficial exposures, including physical activity, outdoor environments, microbial biodiversity, and electrical contact, but the relative contribution of each component remains uncertain. Accordingly, earthing is more appropriately considered a potentially health-modulating exposure and research domain than an established therapeutic intervention.

Advancing the Science of Human–Earth Interaction

The framework developed in this review suggests a research agenda that moves beyond asking simply whether earthing “works.” Future studies should instead determine which components of Earth contact produce measurable biological effects, through which mechanisms, under what exposure conditions, in which populations, and whether those effects translate into clinically meaningful outcomes.

Electrical mechanisms can be examined through controlled grounding studies that isolate conductivity while standardizing exposure duration, grounding method, and physiological outcomes. Naturalistic studies should simultaneously characterize ground conductivity, environmental microbial diversity, human microbiome responses, immune markers, physical activity, and relevant environmental conditions. Longitudinal studies beginning in childhood would be particularly valuable for examining whether frequency and duration of natural-ground interaction predict microbiome, immune, physiological, or health trajectories while accounting for diet, sanitation, housing, animal exposure, socioeconomic conditions, pollution, and healthcare access.

The distinction between artificial grounding and natural-ground interaction may ultimately prove especially useful. Artificial grounding provides a means of testing the electrical component under controlled conditions, whereas natural-ground studies permit investigation of the multidimensional exposure represented in the proposed framework. Comparing these approaches could help determine whether observed effects are attributable primarily to conductivity, environmental microbial exposure, accompanying behaviors, or interactions among these factors.

Overall, the evidence does not yet establish earthing as a treatment or disease-prevention strategy. It does, however, support continued investigation of direct human–Earth interaction as a biologically complex exposure whose components span traditionally separate areas of research. By integrating electrical, physiological, microbial, immunological, environmental, and behavioral pathways while distinguishing their evidentiary foundations, the present framework provides a basis for moving earthing research toward a more rigorous and interdisciplinary science of human–Earth interaction.

Implications for Research, Prevention, and Integrative Healthcare

The findings of this review have implications for future research, preventive health, and integrative healthcare. Most importantly, earthing should be investigated as a multidimensional human–Earth interaction rather than exclusively as an electrical phenomenon. This broader perspective creates opportunities to examine how electrical, physiological, microbial, immunological, environmental, and behavioral pathways operate independently and in combination.

Implications for Research. Future research should determine more precisely how, when, and under what conditions direct Earth contact contributes to health. Larger, adequately powered, independently conducted randomized controlled trials are needed to replicate reported effects of electrical grounding on sleep, autonomic regulation, inflammation-related processes, pain, cardiovascular physiology, and physical recovery. Standardization of grounding protocols, exposure duration, conductive surfaces, outcome measures, and control conditions would improve comparability across studies.

Research on natural-ground interaction should additionally measure environmental and biological exposures rather than treating ground contact as a single variable. Studies could simultaneously assess electrical conductivity, environmental microbial diversity, human microbiome characteristics, immune markers, physiological responses, and relevant health outcomes. Such designs would help determine whether observed effects arise primarily from electrical grounding, microbial exposure, environmental context, or interactions among these pathways.

Childhood represents a particularly important research context. Longitudinal studies could examine whether the frequency, duration, timing, and characteristics of natural-ground interaction are associated with microbiome development, immune maturation, physiological regulation, and subsequent health. Rural–urban comparisons within African settings may be especially informative because they provide naturally occurring variation in environmental exposures, while requiring careful measurement of diet, sanitation, housing, animal contact, socioeconomic conditions, pollution, healthcare access, and other potential confounders.

Implications for Prevention. The findings also support greater consideration of safe interaction with biodiverse natural environments within preventive health research. Environmental microbial diversity has demonstrated relevance to microbiome and immune regulation, while preliminary earthing studies suggest additional physiological pathways that warrant investigation. Natural-ground interaction may therefore represent one component of a broader pattern of environmental exposures potentially supportive of human biological regulation.

Preventive recommendations must nevertheless reflect the strength of the evidence. Current research does not establish a clinically validated frequency or duration of earthing, nor does it demonstrate that grounding prevents specific chronic diseases. Consequently, prescriptive claims regarding how long individuals should remain grounded are premature. Environmental safety is equally important because soil contact may involve biological, chemical, or physical hazards depending on location and individual susceptibility.

Implications for Integrative Healthcare. Within integrative healthcare, earthing may be considered a potentially supportive lifestyle practice rather than an established therapeutic intervention. Its accessibility and compatibility with outdoor movement and interaction with natural environments make it relevant to broader discussions of lifestyle and environmental health. However, its incorporation into healthcare should remain proportionate to the evidence and should not replace established preventive measures, diagnostic evaluation, or indicated medical treatment.

The multidimensional framework developed in this review provides a foundation for moving the field beyond the question of whether earthing is simply beneficial or ineffective. A more productive scientific agenda is to determine which forms of human–Earth interaction influence biological functioning, through which mechanisms, under what environmental and developmental conditions, and whether those effects translate into meaningful health outcomes. Such an approach could position earthing within a broader interdisciplinary science of human–environment interaction while maintaining the evidentiary standards necessary for preventive and integrative healthcare.

6. LIMITATIONS

Several limitations should guide interpretation of this review. First, the evidence base for bioelectrical earthing remains relatively small and heterogeneous. Many studies involve limited sample sizes, short intervention periods, varying grounding protocols, and subjective or intermediate physiological outcomes, with relatively few large, independently replicated randomized controlled trials (Jamieson, 2023; Menigoz et al., 2020). Some studies also involve investigators with disclosed professional or commercial relationships to grounding products, reinforcing the need for independent replication.

Second, the review integrates evidence from disciplines with substantially different research traditions and levels of evidentiary maturity. Studies of electrical grounding, environmental microbial diversity, microbiome development, immune regulation, and nature exposure do not investigate identical exposures. Consequently, evidence supporting one pathway cannot be assumed to establish another, and the proposed convergence among pathways remains a framework for further empirical testing.

Third, natural-ground interaction is inherently difficult to isolate because it may simultaneously involve electrical conductivity, microbial exposure, physical activity, sunlight, vegetation, sensory stimulation, and other environmental influences. Similarly, rural–urban and African childhood comparisons involve numerous potential confounders, including diet, sanitation, housing, animal exposure, socioeconomic conditions, pollution, and healthcare access (Lunjani et al., 2024).

Finally, this study employed an integrative review rather than a systematic review or meta-analysis. Although this approach permitted synthesis across heterogeneous bodies of evidence, it does not provide pooled effect estimates or a formal quantitative assessment of intervention effectiveness (Snyder, 2019; Torraco, 2016; Whittemore & Knafl, 2005). The conclusions should therefore be interpreted as an interdisciplinary synthesis of current evidence and a framework for future investigation rather than definitive evidence of the clinical efficacy of earthing.

7. CONCLUSION

This integrative review examined the potential contribution of earthing and direct human–Earth interaction to human health across electrical, physiological, microbial, immunological, environmental, and behavioral pathways. The evidence indicates that Earth contact is biologically more complex than electrical conductivity alone. While electrical grounding represents the defining mechanism within conventional earthing research, natural-ground interaction may simultaneously involve microbial exposure, physiological responses, immune processes, and environmental and behavioral influences that together provide a broader framework for understanding its potential health significance.

The evidence across these pathways is promising but uneven. Bioelectrical grounding studies report measurable changes involving sleep, stress, pain, inflammation-related processes, cardiovascular physiology, autonomic regulation, and physical recovery, although the literature remains limited by relatively small studies and insufficient independent replication. In comparison, environmental biodiversity and microbiome research provides stronger evidence that exposure to diverse environmental microorganisms can influence microbiome development, immune maturation, regulation, and tolerance. These bodies of evidence should not be conflated, but their potential convergence during natural-ground interaction warrants systematic investigation.

The developmental perspective is particularly important. Childhood interaction with natural ground, including sitting, crawling, playing, and walking barefoot, may provide repeated opportunities for electrical, microbial, ecological, and behavioral exposures during periods of substantial physiological and immune development. African childhood environments offer an important context for investigating these relationships, particularly across rural–urban transitions, while recognizing the substantial ecological, socioeconomic, cultural, and environmental variation within and across African settings.

Overall, earthing may be conceptualized as a potentially health-modulating human–Earth interaction whose effects may arise through multiple complementary pathways. Establishing its contribution to human health will require research capable of distinguishing these mechanisms, determining their interactions, and demonstrating whether observed biological effects translate into reproducible and clinically meaningful outcomes. Such investigation can move earthing beyond isolated mechanistic or therapeutic claims toward a more comprehensive science of human–Earth interaction and its potential place within preventive and integrative health.

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