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Grounding (earthing) as related to electromagnetic hygiene: An integrative review

Isaac A. Jamieson *

Design, Business and Technology Management Program, Faculty of Architecture and Planning, Thammasat University, Rangsit Campus, Klong Luang, Pathumthani, Thailand

Prof. Isaac A. Jamieson

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ABSTRACT

There are a growing number of studies investigating how grounding (earthing) the body may benefit biological performance and aid the treatment of non-communicable diseases. Research also indicates how biological grounding initiatives can sometimes be compromised, or inappropriate, and the need to take additional factors into account as potential contributory factors, or confounders, to expected results. It is proposed that expanding electromagnetic hygiene measures beyond biological grounding alone may help reduce spread of communicable diseases, incidence of respiratory conditions, neurodegenerative disease and all-cause mortality. Identifying potential synergies that exist could enable multilevel interventions to further increase the efficacy of measures. It is hoped that this review will help act as a catalyst to inspire and inform multi-disciplinary research within these topic areas, best practices and policies to help drive medical innovation, reduce health burdens, improve bioelectromagnetic-based therapies, and influence the general design of the built environment and next-generation technologies.

Introduction

Grounding is generally associated with the field of electrical engineering where '*ground*' is defined as "*a conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth or to some conducting body of relatively large extent that serves in place of the earth* [1]". Electrical grounding is a strategy undertaken to protect individuals and electrical equipment from raised alternating current (AC) and direct current (DC) voltages and shock hazards. It provides a low electrical resistance pathway for electricity to flow to ground whilst reducing the build-up of excess charge. 'Biological grounding' can be defined as the deliberate grounding of the body intended to enhance biological functioning [2]. Properly undertaken, it presents considerable promise as a measure to promote wellbeing and aid patient treatments [2–4].

Abbreviations: dB, decibel; Ω, ohm; m, meter.

* *Corresponding author.*
E-mail address: isaac@ap.tu.ac.th.

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Extensive reviews on biological grounding have already been undertaken [5,6]. However, complicated/multiple causal pathways and synergies, as well as some potential confounders (e.g., placebo effects, spatial and temporal variations, control/intervention, and 'electromagnetic hygiene' issues) have not been generally considered. This article, therefore, provides an overview of biological grounding and aspects of 'electromagnetic hygiene' and related variables that could influence their efficacy. 'Electromagnetic hygiene' measures are defined in this present work as practices or conditions conducive to maintaining and enhancing health and wellbeing and preventing illness through helping optimise the bio-friendliness of electromagnetic environments.

In most modern studies the body is grounded indirectly using conductive materials connected to ground via wire through the ground ports of electric power outlets or ground rod electrodes inserted into the soil [5], and there is little in the way of detailed research investigating the effects of directly grounding the body. This review therefore additionally discusses research and anecdotal evidence from patient treatments involving direct contact with the ground [4,5,7–10]. It also suggests the need for greater consideration to be given to the possible effects of anthropogenic electromagnetic field (EMF) exposures [11], and the need for increased research into how to biologically-optimise exposures to electromagnetic phenomena [12].

Walking barefoot and biological grounding

Walking barefoot in nature is one of the simplest and cheapest (it can often be done for free) methods of biological grounding. The perceived benefits of being in contact with the ground were originally suggested far back in antiquity [8], and until the relatively recent past it was far more common to go barefoot outdoors, especially in rural areas [9]. There are still countries where going barefoot outdoors is often the norm for many people, even in cities. Australia and New Zealand are two such countries [13,14]. There are also countries where it is a cultural norm to be barefoot or in stockinged feet indoors. Moreover, a growing number of countries have public barefoot parks as more people seek greater connection with nature [15].

In the nineteenth century, Monsignor Sebastian Kneipp [9], one of the forefathers of naturopathic medicine, was chiefly responsible for reviving the popularity of barefoot walking in many nations. He reported that undertaking this activity in nature was the easiest and most effective way to harden the body and improve blood circulation Others such as Adolf Just [8], Arnold Rikli [7], and Benedict Lust [8] also advocated walking barefoot for health reasons. Kneipp's overall holistic approach to treatment, which is still practiced today, incorporates five foundational pillars: exercise; nutrition; hydrotherapy; phytotherapy; and balance of mind and body. The simplicity and effectiveness of his treatments were major reasons for his high popularity [9,16]. Kneipp [9], who treated up to 200 patients daily [17], specifically advocated individuals walking on dewy grass first thing in the morning, and if that was not achievable, to walk on grass moistened through either rain or watering. He often advised patients to walk barefoot outdoors in nature at least three times per day if possible. The importance of moistening the skin and the surface of the ground outdoors to obtain good biological grounding has been highlighted by Sokal & Sokal [18]. With regard to recovery from COVID-19, Mousa [10] reports that biological grounding has the greatest efficacy when undertaken on "wet muddy earth".

Interestingly, when soil is moist it has reduced electrical resistivity which permits more effective grounding [1].

Reflexology walking

Biological grounding is not the only factor that can improve health when walking outdoors. As an example, Reflexology and Chinese medicine recognize that walking on uneven surfaces can stimulate and regulate acupoints on the feet. Such stimulation is receivable outdoors on cobblestone foot-reflexology paths [19]. Walking barefoot in nature, barefoot parks and sensation paths [15] can also cause such stimulation.

A 16-week randomized trial by Li et al. [20] studied the relative effects of older adults undertaking either 60-min cobblestone mat walking indoors three times a week without shoes ($n = 54$) or undertaking a regular walking comparison ($n = 54$). It reported that cobblestone mat walking reduced blood pressure and enhanced physical function more than conventional walking: 15.24-m (50-foot) walk ($p = 0.01$); balance measures ($p = 0.01$); chair stands ($p < 0.001$); and blood pressure ($p = 0.01$). The observed benefits could have been even greater if the assessment had been undertaken outdoors on real stones in nature instead of indoors on mats that used plastic replicas of river stones.

Kneipp [9] reported that walking on wet stones helps draw the blood down to the feet and improves general circulation. Wetting stones reduces their electrical resistivity [21] and improves conditions for biological grounding. Furthermore, the microcurrents that can be created in the body by grounding where electrical resistivity is low may stimulate acupressure meridians. It has already been observed that the combination of acupressure and grounding appears more efficient than either of these measures alone [22].

Walking barefoot in cold water

Kneipp [9] additionally advocated walking in cold water that came above the ankles. Saz Peiró [23] further advocates individuals walking in seawater at the beach, or if that is not possible, in small streams or even ditches. Immersion in cold water results in peripheral vasoconstriction which causes blood to centrally pool, followed by peripheral vasodilation directly after removal from the water, thereby enhancing circulation [24]. Its effects could possibly be increased through biological grounding.

Undertaking exercise when in contact with the ground

Despite the high success rates previously reported for patients who received biological grounding walking outdoors barefoot as part of their treatment protocols [7–9]; there appears to be no detailed modern research specifically investigating the effects of direct biological grounding when exercising outdoors. There has however been research on undertaking exercise when barefoot, though not necessarily on surfaces that would enable biological grounding. With regards to running, faster times have been observed when running barefoot [25], along with reduced oxygen cost [23,26], and possible enhancement of working memory [27]. Research also demonstrates exercise alone can create many of the benefits associated with biological grounding. Examples include improved immune system functioning [28], improved blood pressure [29], and enhanced sleep quality [30]. Furthermore, going barefoot can result in physiological improvements of the feet themselves [23].

Grounding footwear providing indirect contact with the ground

It is important to know when the use of grounding footwear is appropriate, how to wear such footwear, and when it is likely to provide little, if any, benefit. The double-blind study by Muniz-Pardos et al. [31] investigated whether wearing conductive training shoes, would improve the performance of athletes ($N = 10$). No differences were observed for the energy costs of running or physiological/perceptual responses when grounded or sham-grounded. Several factors may have contributed to this. As an example, brand new socks were used in each running economy trial to avoid high levels of humidity within the footwear [31]. However, best practice electrostatic discharge footwear measures require cotton socks to be worn for at least 2-h before testing to build-up moisture levels to improve conductivity. Moreover, applying a suitable moisturizing lotion to the feet would have improved their electrical conductance to ground [32]. Additionally, the electrical resistivity of the dirt track's surface could have acted as a confounder. It can be affected by a variety of factors including soil type, soil moisture content, and temperature [1,33].

Effect of direct barefoot contact with the ground on blood pressure

S Teli et al. [4] investigated the immediate effects on pre-hypertensive individuals of sitting for an hour (hr) barefoot and in direct contact with ground ($n = 28$), or acting as controls under similar conditions wearing footwear ($n = 25$). They observed a significant decrease in diastolic blood pressure (DBP) ($p < 0.0014$), systolic blood pressure (SBP) ($p < 0.0001$) and mean blood pressure (MBP) ($p < 0.0001$) in those who were barefoot. No significant changes were observed for those ungrounded. They concluded that remaining barefoot whenever possible is a simple, innovative and cost-effective intervention to help prevent hypertension. It is proposed that such findings could have been even more impressive if test-subjects had instead walked barefoot outdoors in nature under biologically-optimized conditions.

Sand treatments and biological grounding

Neoh [34], when investigating how natural ground electric current can flow through human body, reported that whilst no current was recorded when standing with dry feet on a sandy beach, moistening the feet reduced body electrical resistance by 94%, and created a ground potential difference across the feet that drove a micro-ampere current through the body. In the grounding review undertaken by Menigoz et al. [5], Dr Cimone Kamei stated that he often has patients who have edema, as a result of failing kidneys or cancer, sit on a beach with their lower legs in a hole which is then backfilled with wet sand. He states that after this intervention, which usually lasts around 20 min, the edema typically vanishes. Just [8] also undertook sand treatments and stipulated that the ground must not be too dry, again indicating the role ground conductivity can play in influencing results.

Sleeping grounded

Just [8] observed that sleeping on the ground was highly beneficial for treating acute and chronic diseases, improving digestion, bowel movements and sleep quality, and reinvigorating energy and strength levels.

Atmospheric electricity

Just [8] stated the therapeutic results observed could be further improved if undertaken outdoors in nature and declared: “This power [that the sky creates], in conjunction with the earth power, produces the most wonderful curative effects.” He found the effects of sleeping directly on the ground were optimized out in the open in nature. The next best results were obtained sleeping in light-framed dwelling units, which he noted were more healthful than heavily constructed buildings. It appears the degree to which individuals were exposed to nature's fair-weather vertical atmospheric electric fields had a role to play in the differences observed. These fields can be between 100 and 300 V per meter (V/m) in magnitude [35] and blocked to differing degrees by the type of building construction used. Kritzinger [36] reported traditional timber dwellings could allow ≈70–75% transmission of such fields through their structures. They can be substantially blocked by some modern building materials that can create Faraday cage like conditions that reduce exposure to electromagnetic radiation from the external environment [37]. Such fields can also be masked by man-made electromagnetic pollution indoors [38–40].

Vertical electric fields can cause biological effects [41,42]. Fischer [43] investigated the influence they may have on immune system functioning. The plaque count method determined the degree of immunization mice had under different field exposures, with increased plaque counts indicating higher rates of immunization. A constant vertical direct current (DC) electric field of 40 V/m increased immune system response (210.2 ± 24.1 plaque counts) in comparison to Faraday cage conditions (111.6 ± 11.0); with field strengths like those found outdoors during fair-weather (200 V/m) increased immune system response (608.0 ± 55.1) above both control chamber (384.0 ± 31.7) and Faraday cage conditions (199.2 ± 16.5).

Later research found the immune response to vaccine of humans sleeping grounded (possibly in Faraday cage like conditions) was better than those who were sham-grounded

[18]. It would be worthwhile to assess how biological grounding is affected by exposure to these variables.

Alignment with cardinal directions

George Starr White [44], who had patients ground themselves when sleeping, additionally placed great importance on the directions in which they slept whilst grounded. Since at least some humans are sensitive to the Earth's geomagnetic field [45], and research indicates some of the possible effects of alignment with the cardinal directions, there appears a need to take this into account as a potential variable.

Shrivastava et al. [46] conducted a study on test-subjects (N = 40) investigating whether alignment with the cardinal directions when sleeping had any effects on their blood pressure, heart rates and serum cortisol levels. Those sleeping with their heads to the south had statistically significant lower DBP, SBP, and heart rate (HR) than when sleeping in other cardinal directions. Additionally, serum cortisol levels were markedly higher for those sleeping with their heads aligned east or west instead of south or north. Such findings suggest the need to assess the validity of White's statements.

The degree to which radio frequency (RF) radiation could act as a potential confounder should also be considered. Research already shows it can disrupt avian magnetic compasses and that grounding metal sidings added to the walls of the wooden huts to block such electromagnetic pollution enabled the magnetic compasses of birds inside such enclosures to successfully function once more [47].

Sleep research on cortisol levels when grounded

Research on biological grounding often suggests it can help normalize circadian cortisol profiles. This claim appears based on the findings of a single pilot study. Ghaly & Teplitz [48] investigated if the cortisol levels of individuals (N = 12) would be affected by grounding the body during the night. Though the results of that study initially appear impressive, as none of those assessed acted as controls, the placebo effect cannot be ruled out.

Sleep quality when grounded

Lin et al. [49] undertook a prospective, randomized, double-blind study where test-subjects with mild Alzheimer's disease were either grounded (n = 11) or sham-grounded (n = 11) for 30 min a day, five days a week for 12 weeks. After that 12-week period, the Pittsburgh Sleep Quality Index score of those who were grounded was significantly lower than those sham-grounded ($p = 0.006$).

Blood viscosity and biological grounding

Chevalier et al. [50] investigated whether grounding reduces blood viscosity. Each test-subject (N = 10) provided blood samples then sat in a relaxed atmosphere whilst being grounded for 2 hours. At the end of that period, blood samples were taken when the subject was still grounded. Though they concluded that biological grounding reduced blood viscosity, there were no-controls. Previous research by Magora et al. [51] investigating the effect of electrical sleep on blood viscosity, which did have a control group, indicated that decreases can be associated with relaxation alone. Brown & Chevalier [52] later investigated how biological grounding during yoga exercise can affect blood viscosity (N = 28). Those that had been grounded (n = 14) had noticeably reduced diastolic blood viscosity ($p = 0.031$) and systolic blood viscosity ($p = 0.032$) post-exercise compared to those sham-grounded (n = 14).

Medical thermography case studies on grounding effectiveness

It has been long documented that poor circulation can result in individuals having cold feet, and that walking barefoot in suitable environments can help address this [7–9]. Amalu [3] similarly noted, and provided thermal imagery to demonstrate, how sleeping biologically grounded greatly improved the circulation of a test-subject who had previously suffered from extremely cold feet as long as she could remember. He also provided thermal imagery indicating improved blood circulation in many others resultant from biological grounding.

Biological grounding and pain reduction

Müller et al. [53] assessed the efficacy of individuals sleeping grounded (n = 12), versus sham-grounded (n = 10) on recovery time with regard to athletic performance and muscle soreness after intensive eccentric muscle loading. In comparison to sham-grounded test-subjects, those who slept grounded exhibited less pronounced reduction in performance, lower increase of creatine kinase blood levels, and improved recovery as indicated by reduction of muscle damage-associated inflammation markers and retaining constant hemoconcentration. Improved pain relief and reduced inflammation resultant from biological grounding after exercise were additionally reported for grounded versus sham-grounded test-subjects in research by others [54,55]. Increased pain relief has also been reported in COVID-19 patients after grounding [10].

The case studies by Amalu [3] provide further evidence on the efficacy of effective biological grounding on inflammation and pain reduction. He additionally stated that biological grounding holds: “incredible promise as one of the most significant advances in the treatment of both acute and chronic inflammatory conditions.” Such findings are not new, however. Kneipp [56] declared that a “very large number of people” informed him they completely owed their alleviation of pain to being in direct contact with the ground.

Body voltage and grounding

Brown [57] investigated the effects of biological grounding on the AC body voltage of individuals (N = 50) in a home-office environment. On average, a 45.5-fold reduction was observed when they touched an electrical item when they were grounded, as compared to ungrounded. The reductions were statistically significant ($p < 0.001$). A discussion on the need for caution when wishing to undertake biological grounding in areas where electromagnetic pollution exists is provided by Virnich & Schauer [58].

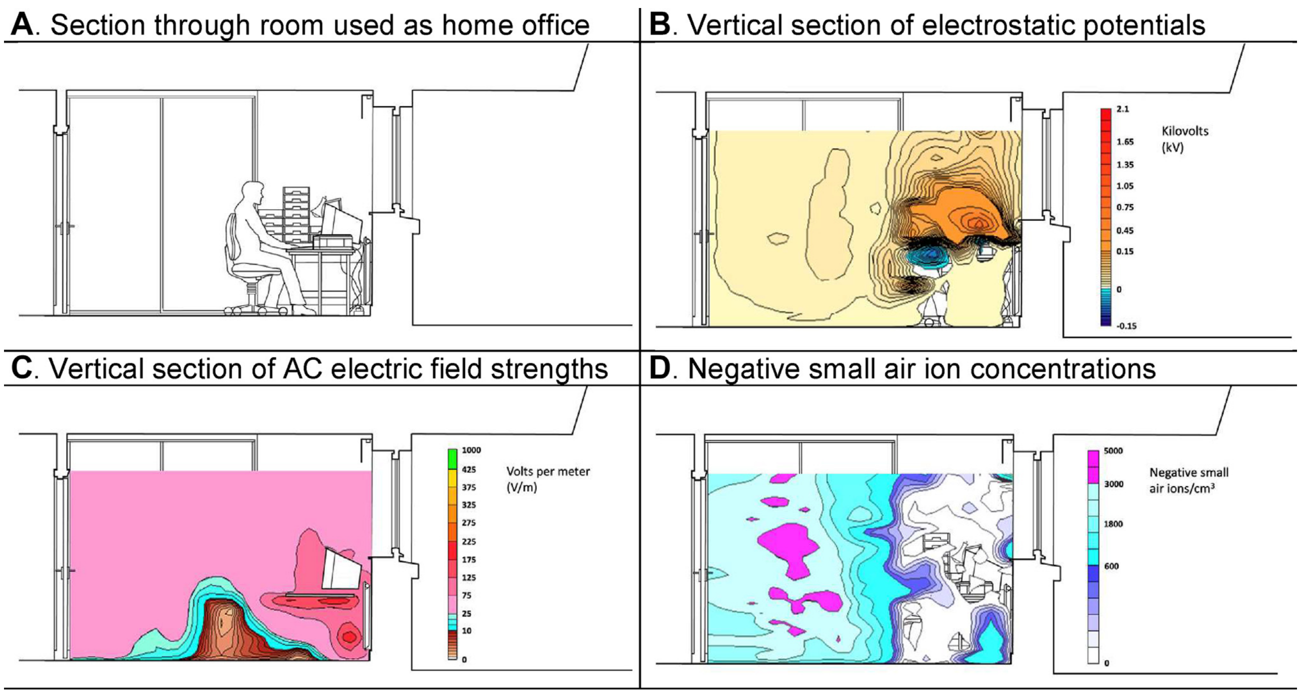

Fig. 1 Cross-section through room used as a home office [39]. The possible effects of poor electromagnetic hygiene on biological grounding initiatives are discussed below.

Ideally, biological grounding should be undertaken in environments with good electromagnetic hygiene [39,59,60]. Fig. 1 provides an indication of the kinds of environmental characteristics that can be found when such measures are not undertaken. Fig. 1B illustrates that raised electrostatic potentials can often be found in areas where individuals work. The isopleths in Fig. 1C show the AC electric fields (10–2,000 Hz ±3 dB) in the room. Fig. 1D, when assessed along with the findings from Fig. 1B and C, shows that very low concentrations of small air ions are found in areas where high fields arise. This indirectly indicates the presence of increased concentrations of charged particles that can be harmful to health in the personal breathing zone of individuals sitting at the workstation.

Retention of induced charge during ground and unground conditions

The human body can act as a good conductor of electricity. However, when individuals are in microenvironments where poor electromagnetic hygiene exists they can carry induced excess charge even when grounded. The charge retention of conductors and insulators (materials that impede free flow of electrons) in unground and grounded conditions is shown in Fig. 2 [38].

Grounding, triboelectric charging and humidity levels

Most modern-day textiles are insulators. Many items of clothing, especially synthetics, are electrically insulative and can generate high levels of excess charge through triboelectric (frictional) charging. The charge that accumulates on them does not necessarily pass to the skin and then to ground when individuals are grounded. Such items can often hold excess charge for prolonged periods of time [61]. The extent to which charge can be generated whilst undertaking everyday activities in high and low relative humidity (RH) is shown in Fig. 3, with significantly higher charge being observed when RH is low [62].

Ideally, humidity levels should be between 40% and 60% RH, as this range can help reduce both the generation of

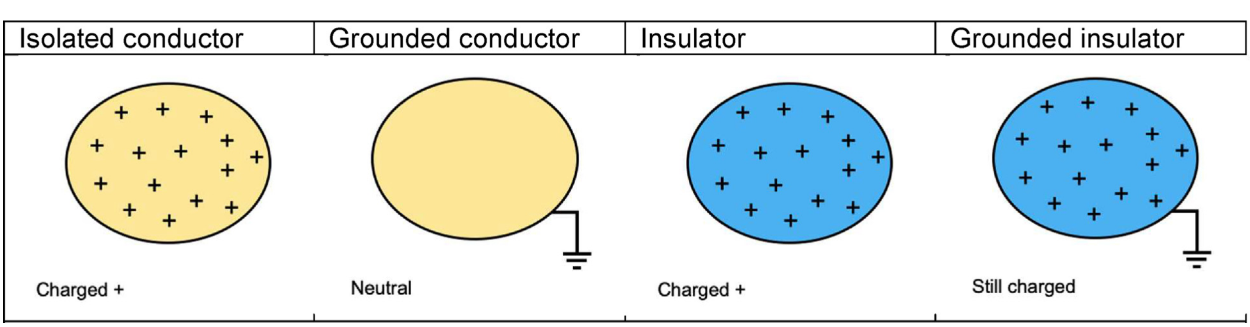

Fig. 2 Charge retention of conductors and insulators [38].

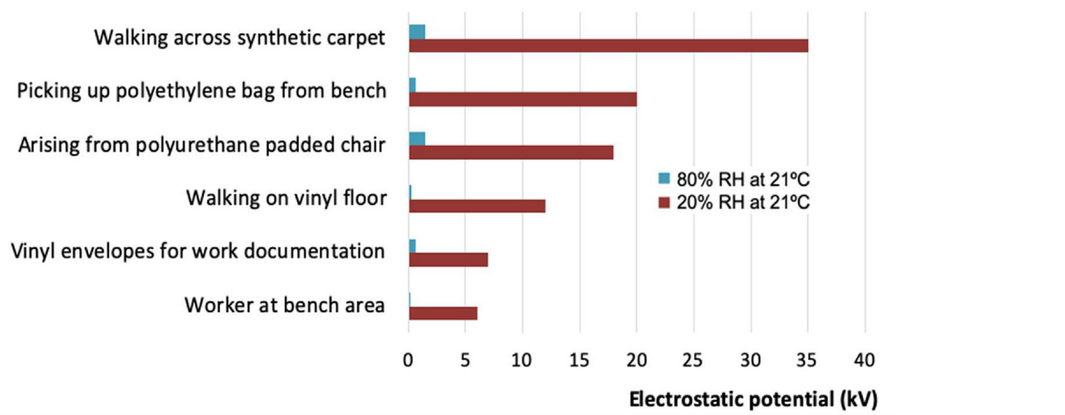

Fig. 3 Frictional charge generated through everyday actions at different humidities [62].

excess charge and the survival rates of microbes [38,63,64]. Optimizing RH can also help improve the conductivity of insulative materials and the skin.

Induced electric fields and grounding

There are further situations, as mentioned by Jonassen [65] that can compromise the possible effectiveness of biological grounding. These are discussed below.

Ungrounded conductor exposed to an electric field: A simplified situation is shown where a conductor (such as a human) experiences induced charge from a charged insulator (Fig. 4A). The field-lines from that source cause a bound-induced charge of negative polarity to be created on the side of the conductor facing it. That charge cannot be removed whilst the conductor is within the field created by the source. A corresponding positive charge of equal magnitude is created on the conductor's opposite side. Though the net charge of the conductor is zero, each side of the conductor possesses a different polarity of charge.

Grounded conductor exposed to an electric field: If under the same exposure conditions the conductor is grounded, its voltage will be zero. However, as it still possesses a bound induced charge through being close to the positively charged source, it will be a negatively charged conductor that possesses zero-voltage (Fig. 4B). This means that though it is grounded, part of it still carries an excess charge that will attract airborne contaminants towards it.

AC electric fields can also create induced fields on humans and objects. Grounding conductive objects reduces the induced AC fields they can carry and should ideally be carried out as standard. It has however been demonstrated that grounding the human body can increase RF radiation absorption [66] further indicating why biological grounding should ideally be undertaken in areas with good electromagnetic hygiene.

Health conditions, particulates, pathogens and electromagnetic hygiene

As noted by Professor Bernard Watson [67] and Bach [68], the excess charge created by clothing, bedding, and furniture can be a significant contributory factor to incidents of asthma, emphysema, and other respiratory problems. The mitigative measures they had patients take greatly reduced such episodes. These included wearing cotton clothing instead of synthetics (as cottons generate less charge) and applying anti-static finishes to materials and surfaces. Reducing excess charge reduces the concentrations of charged airborne particles around individuals and the number of airborne contaminants retained from inhalation [60].

Reducing exposure to air pollution is the most effective way to preclude the onset and progression of respiratory diseases [69], and reduces risk of neurodegenerative disease and all-cause mortality [70]. Improved electromagnetic hygiene measures can help reduce the incidence of diseases [11,12,38], including SARS-CoV-2 [10,60].

Particulate matter, pathogens and excess charge

Particulate matter can act as a carrier for pathogens and enable them to remain airborne for prolonged periods [71]. Pathogens can be carried on respiratory droplets, droplet nuclei, and larger sized contaminants, including dust and skin flakes [72,73]. Infective dose varies between pathogens. With regard to viruses, Ward et al. [74] noted that the infective dose for rotavirus might be $\leq$ 10 infected particles, whilst Caul [75] observed that for Norwalk-like viruses it could be $\geq$ 10–100 infected particles. Karimzadeh et al. [76] suggest that the infectious dose for COVID-19 could be $\geq$ 100 infected particles. In contrast to many non-biological particles, airborne microorganisms can carry very high charge [77].

Typically, over 90% of airborne particles found indoors are less than 1 μm (<1 μm) in size [78], a size range for which electric fields can often act as a major transport and removal mechanism [79]. The electrostatic force of highly-charged particles can be thousands of times larger than the force of gravity [80]. The degree to which the level of charge a particle carries can affect its deposition in human airways is shown (Fig. 5A) [81] alongside an indication of the types of particles that can be found within that size range (Fig. 5B) [60]. It appears that excess charge can increase COVID-19 risk [60].

High particle charge can significantly increase the deposition of particles ≤20 μm in human airways [81].

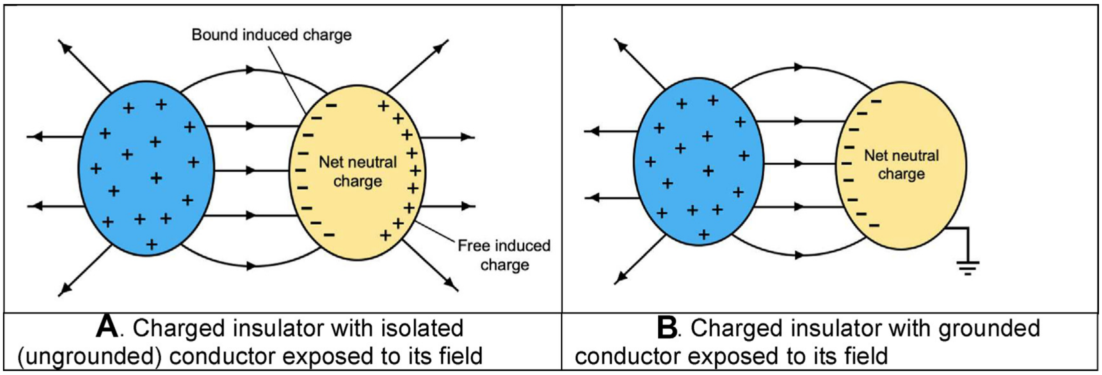

Fig. 4 Charged insulator with isolated (ungrounded) conductor exposed to its field. Adapted from Jonassen [65]. B. Charged insulator with grounded conductor exposed to its field.

The presence of raised electric fields can increase localized concentrations of charged particles within individuals' personal breathing zones [38,39,59]. Additionally, they can greatly increase the pathogen deposition surfaces receive, with significant increases arising at higher surface potentials [82–84]. Both DC and AC electric fields can increase particle deposition [82,83,85].

Human skin and excess charge

Skin surface voltage tends to increase when RH is reduced [86]. Additionally, exposure to raised electrostatic potentials increases the deposition velocities of contaminants onto the skin of grounded human subjects [87]. The same is true for ungrounded individuals. Wedberg [88,89] found the deposition of particulate matter >0.07 μm in size onto human skin was ≈100 particles/mm^2/hr at 0 kV conditions, ≈1000 particles/mm^2/hr for body potentials of ±5–6 kV, and >10,000 particles/mm^2/hr under larger fields. The body potentials assessed can easily arise in real life unless suitable precautions are undertaken.

Skin flakes form the greatest source of particulate matter within people's personal breathing zones and can gain high charge. Around 6000–50,000 skin flakes of between 5 and 50 μm in size can enter the nasal passages per liter of air inhaled [90]. Approximately between 5 and 10% of all skin scales shed from the human body can harbor bacteria [91]. It is proposed by the present author that pathogen counts can be even higher in situations where humans gain high charge and they are nearby infected individuals. Reducing skin flake production reduces the likelihood of infection from their inhalation or deposition onto open wounds. This can be achieved by moisturizing the skin [92]. Skin lotions/moisturizers can additionally reduce frictional charging between clothing and skin [60] and aid grounding.

Technical issues that can affect grounding and electromagnetic hygiene initiatives

Many of those selling biological grounding items suggest grounding be undertaken through the ground port of electric power outlets or through ground rod electrodes inserted into the soil. Similar methods are used in many biological grounding studies. It is important to be aware of technical issues that can arise with these methods and how they can be addressed.

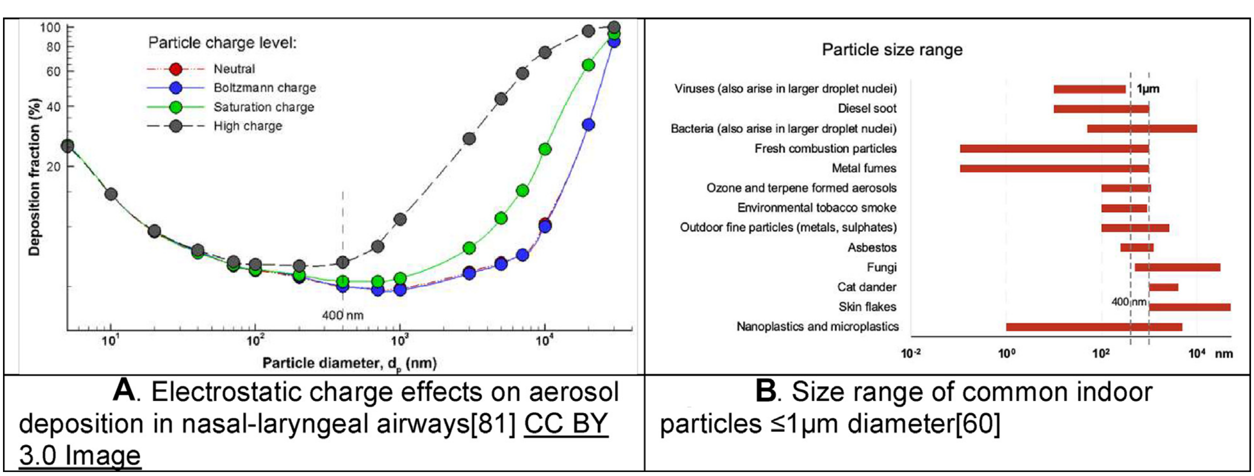

Fig. 5 Electrostatic charge effects on aerosol deposition in nasal-laryngeal airways [81] CC BY 3.0 Image. B. Size range of common indoor particles ≤1 μm diameter [60].

Electrical power outlets used for grounding

A number of studies ground test-subjects using grounding cords connected to power outlet grounds [53,57,93]. Some suggest a ground checker be used to verify that electrical grounding systems are working properly. This appears to be because many buildings have either very poor electrical mains ground connections, or no electrical mains ground connections, even when they have three-pin sockets. Such situations are observed in many countries, including the United States and the United Kingdom [94,95], and will determine grounding effectiveness.

Ground rod electrodes

Many ground rod electrodes used for biological grounding are only 30.48 cm in length [50,96,97]. In contrast, White [98], who pioneered biologically grounding individuals indoors, advocated that a rod of around 1.22 m in length be used. If rods are not driven deep enough into the soil, their grounding effectiveness can be compromised, especially during cold spells. Ideally, they should be long enough to be driven below the frost line in order to help maintain low electrical resistivity all year round [1]. There is additionally the possibility of the grounding wire picking up unwanted RF signals. Being in direct physical contact with the ground in areas with good electromagnetic hygiene is a better way to ground the body.

Soil moisture levels and grounding effectiveness

Seasonal variations in soil resistivity can be a confounding factor in grounding effectiveness and measures should be taken to help ensure good grounding conditions at all times of year. Conditions are normally best during the spring and autumn, as the weather is usually reasonably warm and humid [1]. Just [8], who advocated walking barefoot and sleeping on the ground as part of his patient treatment routines, often achieved his most impressive patient recoveries during those seasons. Reduced soil resistivity creates better grounding conditions. Chemical treatment of the soil area where ground rods are to be located can greatly lower electrical resistance [1]. Alternatively, biochar can be used. As an example, its use reduced the electrical resistance of a ground electrode in clay sandy soil during the dry season from 242.0 ohm (Ω) to 26.27 Ω on average and to 2.1 Ω in the rainy season [99]. Biochar can also be added into the soil of areas where individuals undertake barefoot walking to improve soil conductivity and moisture levels throughout the year (personal observation). Furthermore, occasionally watering grounding rods' locations, and/or where individuals undertake barefoot walking, can further help improve grounding efficiency. This measure should particularly be considered in areas where there are low levels of rainfall or drought conditions, and just prior to going barefoot outdoors.

Use of resistors when indirectly biologically grounding individuals

Some devices for biological grounding now contain a 100,000-Ω resistor, or one with even higher resistivity, to help protect against electric shock risks. This restricts the flow of current, which is helpful as a safety measure if there is a faulty electrical appliance, but also impedes the flow of electrons to and from the body. This could be a contributory factor to Chevalier et al. [93] reporting a statistically significant reduction in individuals' temperatures instead of their predicted increase when biologically grounded.

Electromagnetic pollution

The vast majority of peer-reviewed studies indicate that exposure to electromagnetic pollution at intensities well below those permitted in many guidelines can pose health risks [11]. A substantial opportunity exists to create healthier electromagnetic environments and technologies that aid performance, biological functioning, and patient recovery.

If individuals wish to be grounded when indoors, this should be ideally undertaken in areas where low field levels exist and where appropriate grounding connections have been established. Additionally, actions should be taken to help biologically optimize the electromagnetic characteristics of locations where people spend prolonged periods of time, whether they themselves are grounded or ungrounded. These include grounding other conductive objects, including electrical equipment; using hardwired connections instead of wireless ones; re-organizing room layouts and seating layouts to reduce pollutant exposures; taking measures to reduce frictional charging; and switching off and unplugging electrical devices when not in use. More advanced measures can also be applied [38,60,100].

Conclusion

When looking at biological grounding, and other bioelectromagnetic health initiatives, it is necessary to understand that there are a wide variety of confounding factors and variables that can influence results. Identifying and assessing possible synergies between these could enable multilevel interventions to increase their efficacy and viability. Their adoption could also benefit other bioelectromagnetic-based and conventional therapies, and infection control operations.

Where possible, "Gold Standard" randomized double-blind placebo-control intervention-based studies should be undertaken to help assess the efficacy of approaches. In particular, the combined effects of different factors should be considered more, as it appears they can create enhanced results beyond those achieved by individual measures.

The opportunity now exists for multi-disciplinary research to develop healthier next-generation electronic devices, electromagnetic environments and bioelectromagnetic treatments that aid biological functioning in clinical settings and everyday life. Correctly undertaken, biological grounding can be an important component of such innovative proactive measures.

Conflicts of interest

None.

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