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WEARABLE PHYSIOLOGICAL MONITORING IN TACTICAL EMERGENCY CARE: A NARRATIVE REVIEW OF ELECTRO-QUASISTATIC HUMAN BODY COMMUNICATION AND ITS IMPLICATIONS FOR CARE DELIVERY

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ABSTRACT

Most combat deaths occur before the casualty reaches a medical facility. A substantial proportion is caused by haemorrhage from sites beyond the reach of self-applied interventions, making rapid triage decisive. Continuous physiological monitoring may accelerate it. Military personnel are a distinct occupational group, and advances in their point-of-injury monitoring carry direct public-health relevance. Wireless Body Area Networks (WBANs) are a widely proposed approach for battlefield monitoring. However, they rely on active radiofrequency (RF) emission, producing an electromagnetic signature detectable by adversarial signals-intelligence systems. This places the clinical need to monitor in direct conflict with the operational need to remain undetected. This narrative review examines whether Electro-Quasistatic Human Body Communication (EQS-HBC), commercialised as Wi-R, resolves that conflict. Synthesising peer-reviewed literature, the review finds that EQS-HBC confines signal energy to the body's near field, enabling a continuous physiological record to be captured on-body and retrieved by touch without detectable RF emission. Because EQS-HBC does not radiate and operates below 1 MHz, conventional RF jamming cannot target it directly - though susceptibility to other forms of interference remains, and neither has been tested under real operational conditions. These advantages carry a clinical cost: the loss of remote, pre-contact triage awareness. Furthermore, the evidence base rests entirely on laboratory studies, and no peer-reviewed field trials exist in military medical settings. Military medicine has long been a source of innovation for civilian healthcare. Whether EQS-HBC follows that path remains to be seen - for now it is a promising platform awaiting field validation.

KEYWORDS

Wearable Health Technology, Digital Health, Population Health, Combat Casualty Care, Point-of-Injury Triage, Electro-Quasistatic Human Body Communication

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1. Introduction

Eastridge et al. (2012), reviewing 4,596 battlefield fatalities from Iraq and Afghanistan (2001–2011), found that 87.3% of injury mortality occurred before the casualty reached a medical treatment facility; 24.3% of these pre-facility deaths were potentially survivable, 90.9% of those were caused by haemorrhage. The most treatable component of it was extremity haemorrhage and it has already been substantially reduced by the implementation of limb tourniquets and corresponding Tactical Combat Casualty Care (TCCC) doctrine (Butler et al., 1996; Kotwal & Butler, 2017). The persistent burden lies elsewhere: most haemorrhage deaths were truncal (67.3%) or junctional (19.2%), namely sources self or buddy-applied tourniquets cannot control. Their control depends instead on rapid recognition of physiological deterioration and timely transport for surgical treatment (Eastridge et al., 2012). For this population, bleeding beyond the reach of immediate self-aid and deteriorating within minutes, rapid and accurate triage holds the greatest potential to alter outcome. That so many of these deaths remain potentially survivable makes this a public health concern as much as a tactical one - and continuous physiological monitoring a legitimate tool to influence both.

Triage, that is - systematic process of assessing, classifying and prioritising casualties (based on their injury severity, urgency of their specific need and availability of resources) especially useful in scenarios when medical need exceeds the available resources, allows the medic to identify those that are potentially survivable and at the same time require immediate, often surgical, intervention. By that means it carries a decisive weight particularly in a discussed mass casualty event. Because the dominant survivable death is internal haemorrhage, in which deterioration is rapid and initially occult, the speed and accuracy of recognising a casualty's true state may directly influence outcome, and continuous physiological monitoring is a technology that may accelerate it.

This argument requires a caveat. Initial battlefield triage under TCCC focuses less on numerical vital signs than on altered mental status (with absence of brain injury) and radial-pulse character (Committee on

Tactical Combat Casualty Care, 2024); continuous monitoring should not be perceived as a means of replacing current tactical triage or as a proven means of reducing mortality. On the other hand physiological data should not be trivialised. Even though static vital signs (which are scalar) are insensitive during compensated haemorrhage, where central blood volume can fall substantially before conventional values leave their normal range, there are certain physiological data that may be of particular interest for the medics. Namely - tracking the evolving trajectory of the vital signs and arterial-waveform-derived indices over time (including AI-based measures of compensatory reserve) which can detect deterioration earlier (Convertino & Cardin, 2022). This time-resolved signal, termed throughout this review the continuous physiological record - carries the earliest evidence of deterioration. EQS-HBC/Wi-R's potential value lies not in making triage vital-sign-driven but in providing an emission-free, body-coupled layer to carry and retrieve that record at the point of contact. Wi-R neither generates nor validates these indices; it would serve only as the transport medium an emitting link - such as the Bluetooth connection used by current decision-support tools presently provides.

Continuous physiological monitoring is typically delivered by a Wireless Body Area Network (WBAN): a set of body-worn sensors that continuously track traditional vital signs as well as other more complex physiological parameters and pass them to a small hub worn on the soldier. WBANs already support triage in civilian emergency medicine (Nino et al., 2020) and are increasingly proposed for tactical and combat casualty care (Alnuaimi, 2025; Friedl, 2018). When the sensor data is combined with an automated early-warning score and a defined medical response, the broader system is termed a Combat Medical Early Warning System (CMEWS) (Mathais et al., 2025). This review concerns only one part of that system - the link that carries the data. Additionally it asks whether EQS-HBC/Wi-R could provide it without the radio emission conventional links require.

That radio emission is the difficulty. To move data, a conventional WBAN emits radiofrequency (RF) electromagnetic waves over short-range. These produce wireless links such as Bluetooth Low Energy or Zigbee. It does so at two points that must be kept distinct: the on-body links carrying each sensor's data to the soldier's hub, and the onward link relaying the collected data to a medic's receiver. The first one, the sensor-to-hub link, transmitting continuously on every soldier throughout monitoring dominates the electromagnetic signature and is this review's principal concern. Because radio energy radiates outward into the surrounding space, these emissions can be detected, classified, and geolocated by an adversary's signals-intelligence systems (Watling & Sylvia, 2025). The technology meant to protect the soldier may therefore expose them.

This tension is not simply a harmful signal to remove. At one layer emission is also a clinical asset: a hub broadcasting outward lets a medic with a receiver know which casualty is deteriorating before reaching them, and whom to approach first. The remote prioritisation is an asset only an outward-radiating link can provide. But that same radiation is what an adversary detects and its heaviest, most involuntary source is the always-on sensor-to-hub link. Eliminating emission to defeat the targeting signature therefore acts primarily on this continuous on-body link between the sensors and the hub, but should also foreclose the broadcast from the hub to the medic/military command on which their remote awareness depends. This review treats this tradeoff as central.

Electro-Quasistatic Human Body Communication (EQS-HBC) sits within this tradeoff. First demonstrated by Das et al. (2019), it transmits data between wearable devices through the body's conductive properties, confining the signal to the near field rather than radiating it; Wi-R is its current commercial implementation (Sen et al., 2020). By practically eliminating RF emission EQS-HBC removes the detectability threat, but by the same mechanism forgoes the remote telemetry, that emitting systems provide. This review examines that exchange from a clinical perspective.

Two research questions follow:

1. Can EQS-HBC enable continuous physiological monitoring and point-of-contact data retrieval without the RF emissions inherent to conventional WBANs, and what is gained and lost in doing so?

2. Beyond avoiding detection, does the body-coupled monitoring link offer better resistance to electronic-warfare jamming than the radio links it would replace?

2. Methodology

This narrative review synthesises evidence on EQS-HBC from a combined clinical and technical perspective, evaluating the technology both as a candidate approach to casualty monitoring and against the engineering and physical principles that underlie its claimed advantages. A structured literature search of PubMed/MEDLINE, IEEE Xplore, and Google Scholar combined terms including electro-quasistatic human body communication, human body communication, Wi-R, wireless body area network, near-field communication, wearable biosensors in tactical medicine, and combat casualty care triage. The search emphasised peer-reviewed literature published from 2014 onwards, while foundational work on intrabody and human body communication, together with relevant international standards and electromagnetic-safety guidelines, was included irrespective of publication date. Peer-reviewed journal articles and conference proceedings formed the primary evidence base; technical reports and grey literature, including manufacturer documentation, were consulted only for commercial-development context and are distinguished from peer-reviewed evidence throughout. Sources were integrated through a narrative thematic synthesis organised around the review's research questions and the comparison of EQS-HBC with alternative monitoring architectures. Scope is limited to tactical and prehospital triage in contested environments; in-hospital monitoring lies outside it.

3. Background

3.1 The Dual Nature of Electromagnetic Emission in Tactical Monitoring

Conventional continuous monitoring near the point of injury depends on active radiofrequency transmission: Bluetooth (2.4 GHz) and Zigbee (sub-GHz and 2.4 GHz ISM bands), which radiate continuously from every wearer and is therefore open to detection, the operational threat developed in Section 4. The same emission, however, is what makes a casualty's data remotely available to a medic before contact, a clinical asset examined in Section 6.1. EQS-HBC must be evaluated against this same tradeoff: emission as simultaneous liability and asset.

3.2 Human Body Communication: From Concept to Wi-R

Zimmerman (1996) first proposed the human body as a transmission medium, showing its electrical properties could support a personal-area-network channel without conventional RF emission. Human body communication (HBC) later became standardised: IEEE Std 802.15.6-2012, the first global WBAN standard, defines a dedicated HBC physical layer centred near 21 MHz (bandwidth ~5.25 MHz). At these frequencies the body behaves like an antenna - Kibret et al. (2015) showed, it resonates between approximately 40 and 60 MHz with radiation efficiency up to 70%, therefore radiating a substantial fraction of signal energy outward. This was the fundamental limitation of MHz-range of HBC: the mechanism conducting data has also made the body a broadcasting antenna producing a detectable signature.

EQS-HBC, developed by Sen and colleagues at Purdue University has resolved this by operating below 1 MHz, where the wavelength greatly exceeds body dimensions and thanks to that - the body does not radiate efficiently. In this electro-quasistatic regime the system behaves not as a radiating antenna but as a closed circuit: the body is the forward conduction path, while the return path closes through parasitic capacitive coupling between the device's ground plane and the earth (Nath et al., 2021). The body becomes a wire, and the circuit closes invisibly through the environment rather than a second conductor. Signal energy is thus confined to the near field rather than broadcasted (Das et al., 2019). This is the capacitive mode of HBC; the alternative, galvanic coupling, injects current directly between skin-contact electrodes and is not what Wi-R uses (Zhao et al., 2017).

Because the capacitive channel completes its circuit through the environment and depends on the electrode-skin interface, link quality is sensitive to body grounding, skin condition, and ambient electromagnetic conditions (Sections 5.1 and 6.4).

The confinement implied by this near-field operation has also been bounded quantitatively. Theoretical analysis by Nath et al. (2021) showed that the electric field 30 metres from an EQS-HBC transmitter was approximately 20,000 times below the FCC limit for unintentional radiators. Experimentally, a standard RF antenna could not intercept the signal beyond about 1 cm from the body surface or 15 cm from the device. The same authors identified a subtler limit - an inter-body coupling pathway letting an adversary in near-direct bodily proximity coupled to the signal. However it was successfully reduced by signal-level optimization to within roughly 10 cm of the user.

In practice, an EQS-HBC equipped soldier-monitoring system would comprise of several sensors for e.g. ECG electrodes, a photoplethysmographic oxygen-saturation sensor, a respiratory sensor, a skin-temperature sensor - each reaching a central hub through the body-coupled channel rather than via RF. The hub stores data locally and presents it on contact. Transfer occurs through touch alone, with no pairing, or configuration steps needed (Maity et al., 2020a). A terminological point follows from this design. The record is continuous only in that the on-body sensors acquire and store it without interruption; in a purely electromagnetically silent mode the medic receives nothing until the moment of contact and holds no physiological picture of the casualty before then. Throughout this review, continuous therefore denotes uninterrupted on-body acquisition from the soldier's perspective, not continuous availability to the medic. The architecture and durability of such a system remain significant engineering challenges, untested in combat conditions (Section 6).

Wi-R, the current commercial implementation, is developed by Ixana, a Purdue spin-out co-founded by Sen. Peer-reviewed findings must be separated from manufacturer claims. The literature establishes signal confinement, low interception risk, high energy efficiency, and touch-initiated transfer under controlled laboratory conditions (Das et al., 2019; Maity et al., 2019; Maity et al., 2020a; Nath et al., 2021). Ixana's documentation further asserts energy consumption roughly 100 times lower than Bluetooth and reports evaluation in defence-adjacent contexts; absent from peer-reviewed sources, these are noted only as context, not evidence.

4. Operational Security: Electromagnetically Silent Monitoring at the Point of Injury

4.1 Defining "Electromagnetically Silent" Monitoring

Military medicine has long recognised that providing care can itself generate risk: from light discipline at night to radio silence during sensitive manoeuvres, tactical medicine is partly a history of making clinical capability less detectable. Wearable physiological monitoring adds a dimension - the electromagnetic signature of the monitoring system itself.

This review analyses electromagnetically silent monitoring: an architecture that continuously acquires, stores, and makes physiological data available to the medic while generating no detectable RF emission across acquisition, storage, and retrieval. That silent property belongs mainly to the monitoring layer. A second part of the process - conveying the stored record onward to the medic - can, depending on circumstances, operate in a 'loud' or 'silent' mode, with or without detectable RF emission. This review focuses on the silent case, in which the record is transferred to a receiver in direct physical contact (Section 6.1).

This contrasts with the prevailing active-emission paradigm, in which transmitting physiological data is inseparable from broadcasting a detectable signal. DSS-MEDEVAC, for example - a proposed military system integrating uniform-embedded sensors, continuous monitoring, and automated triage - requires periodic RF transmission to its inference subsystem and therefore, its developers note, cannot operate during radio silence (Lubkowski et al., 2023). To remain undetectable, the data must travel not through the air but through physical contact between medic and soldier. What appears to be a downgrade - the loss of remote communication - is, under the right conditions, an important upgrade. The technical details of such an implementation are discussed in Section 6.

4.2 The Evidence Base and a Comparison of Alternatives

The claim that EQS-HBC is electromagnetically silent rests on specific peer-reviewed engineering evidence, which must be examined before clinical arguments are built on it.

Das et al. (2019) showed EQS-HBC produces a covert channel - one an adversary is unlikely to detect or intercept - by geometric confinement rather than encryption: the signal is localised to the near field, simply absent from the space an adversary would need to occupy. This is physical-layer security in its most direct form: not a barrier between adversary and signal, but the absence of signal in the adversary's environment. Its quantitative boundaries, from Nath et al. (2021), are set out in Section 3.2.

Versus Bluetooth and Zigbee WBANs — the principal advantage.

In a conventional architecture the sensor-to-hub links are themselves continuous RF emissions, active on every wearer throughout monitoring — whether or not a medic is present, and whether or not the soldier needs care. Conventional WBANs thus generate background emission from every sensor-to-hub link, on every soldier, at all times. EQS-HBC replaces these links with body-coupled transmission, eliminating the emission at its source, to the soldier's continuous benefit.

Versus near-field communication (NFC) — a modest and honest advantage.

NFC operates at 13.56 MHz and emits a weak signal at the moment of transfer - where EQS-HBC emits practically nothing detectable - and requires precise alignment within a few centimetres, where EQS-HBC transfers through general body contact. Under gloved hands, body armour, darkness, and time pressure, that ergonomic difference - any point of contact versus precise alignment - can be operationally significant. The deeper distinction is architectural: NFC is a data-handoff protocol, not a continuous channel, and cannot serve as the live sensor-to-hub link. An NFC design must reach the hub by other means: wires or conductive textile (the silent baseline of Section 6.3), or RF such as Bluetooth, which reintroduces emission at the sensor layer. EQS-HBC provides that layer wirelessly yet without emission - a combination neither NFC nor a wired harness offers.

5. Jamming Resistance and Comparative Assessment

5.1 Resistance to Electronic-Warfare Jamming

A contested environment poses a second question: not whether the adversary can detect the link but whether they can deny it. Jamming - the deliberate transmission of electromagnetic energy on a target's operating frequency at a power level high enough to drown out its intended signal - has decentralised in modern peer conflict. It has moved from being a specialist capability fielded by dedicated electronic-warfare (EW) units to being distributed across ground units down to company echelon (Watling & Sylvia, 2025). Any device emitting RF on the battlefield is therefore exposed not only to detection (Section 4) but also to active disruption. Conventional WBANs predominantly operate in the 2.4 GHz (industrial, scientific and medical) band, which is also the conventional operating frequency for commercial unmanned aerial vehicles (Zulkifley et al., 2021), which have become a principal target of contemporary battlefield electronic attack (Watling & Sylvia, 2025). Whether the non-radiating physics that keeps EQS-HBC silent also makes its link harder to jam than the broadcast links it would replace is the question this section addresses.

Two factors suggest that EQS-HBC may be more resistant to jamming than conventional radiating WBANs, but both have important limits. The first is physical. EQS-HBC operates below 1 MHz, where the body and electrodes do not radiate efficiently into free space, and signal energy remains confined to the wearer's near field (Section 3.2). The same near-field coupling that limits adversary interception to within roughly 10 cm of the wearer (Nath et al., 2021) should, by the underlying physics, also impede deliberate interference injected from a distance, although this has not been directly tested. The second is engineering. The BodyWire transceiver (Maity et al., 2019) demonstrates that signal recovery is possible even when the interfering signal is approximately 1,000 times stronger than the legitimate one; this robustness, however, was demonstrated against ambient laboratory electromagnetic noise rather than against an adversarial jammer.

The limits of this evidence base should be stated plainly. No peer-reviewed study has tested EQS-HBC under the kind of deliberate, frequency-tuned, high-power jamming that constitutes electronic attack in modern combat. Two distinct concerns are worth distinguishing. Ambient body-antenna pickup - the body's reception of incidental electromagnetic noise from nearby electronics and mains wiring - is a documented reliability problem in the broader human body communication literature and is what the BodyWire interference rejection addresses. Deliberate adversarial jamming, by contrast, would involve a hostile emitter potentially tuned specifically to the sub-MHz band EQS-HBC uses; whether such a jammer could couple sufficient energy to the body-coupled receiver to disrupt the link, and at what range, remains untested.

For combat soldier monitoring, the practical implication is mixed but worth stating directly. The available evidence is consistent with EQS-HBC being harder to jam at a distance than a 2.4 GHz wireless link, by the same physics that keeps it covert. This expectation, however, is grounded in physical inference and laboratory engineering rather than in any field test under real electronic-warfare conditions. The reasonable position is to treat it as a plausible operational advantage requiring validation rather than as an established performance characteristic - and not to rely on it as a reason to deploy EQS-HBC in highly contested environments without parallel testing.

5.2 Comparative Summary

Table 1 summarises the technologies. Two framing points are essential. First, it separates two layers easily conflated: the on-body sensor-to-hub layer, by which sensors reach the soldier's hub, and the hub-to-medic egress layer, by which stored data later reaches the medic. The first of the mentioned layers includes not only Bluetooth/Zigbee WBANs and near-field communication (NFC) but also the simplest non-radiating baseline — a wired or textile-integrated sensor-to-hub harness with local storage. As stated in Section 6.3, EQS-HBC is not the only architecture that can make the sensor-to-hub layer electromagnetically silent.

Table 1. Comparison of a Bluetooth/Zigbee WBAN, a wired or textile-integrated sensor-to-hub harness, NFC, and EQS-HBC (Wi-R), separating the on-body sensor-to-hub layer from the hub-to-medic egress layer. Non-radiating entries denote the absence of active RF transmission at the layer named; passive conductors and their electronics may still produce limited unintentional emission, or be susceptible to interference, depending on shielding, signal levels, and cable geometry, so no architecture should be treated as perfectly electromagnetically invisible.

Dimension	Bluetooth / Zigbee WBAN	Wired / textile sensor-to-hub	NFC + local memory	EQS-HBC (Wi-R)
RF emission (sensor-to-hub layer)	Continuous	None (passive conductors)*	None (wired sensors)*	None (body-coupled)
RF emission (hub-to-medic egress)	Continuous / on-demand	Optional (none if wired)	Weak (during contact)	None detectable (touch)
Continuous sensor-to-hub networking	Yes (via RF)	Yes (wired)	Yes (wired)	Yes (body-coupled)
Remote pre-contact awareness	Yes	No (unless RF egress added)	No (unless RF egress added)	No (unless RF egress added)
Resistance to standoff jamming (sensor-to-hub)	Low (2.4 GHz, targeted EW)	High (wired link)	High (wired link)	High (theoretical, not tested on EW)
Retrieval by general body contact	No (remote)	No (connector / egress)	No (precise alignment)	Yes (any point of the casualty's body)
Speed of data transfer to the medic	Moderate (~1–3 Mb/s)	High (wired egress)	Low (≤424 kb/s)	High (~30 Mb/s)
Mechanical vulnerability (cabling, connectors, snagging)	Low	Moderate	Moderate	Low
Maturity / confirmed reliability	High	High	Medium	Low
Cost	Low	Low	Low	High (experimental)
Field validation in combat settings	Partial	Partial	None published	None published

The table makes two things explicit: no single technology dominates, and silence at the sensor-to-hub layer is not unique to EQS-HBC. Conventional Bluetooth/Zigbee monitoring alone offers remote pre-contact awareness, but only by emitting continuously at both layers - precisely what exposes it to detection and jamming. A wired or textile harness removes sensor-to-hub emission with no new technology, at the cost of cabling, connectors, and mechanical fragility. NFC avoids continuous emission but reintroduces a weak signal at each retrieval and requires precise alignment. EQS-HBC's distinctive position is narrow but real: the only option combining a cable-free silent sensor-to-hub layer with retrieval by general body contact. Whether that justifies its immaturity against a ruggedised wired baseline is taken up in Section 6.3.

6. Challenges and Limitations

The preceding chapters argued that EQS-HBC's principal advantage is generating no detectable emission during continuous on-body monitoring, and that the same non-radiating physics may give its link some resistance to electronic-warfare jamming. Both claims rest on laboratory evidence obtained under benign interference; neither has been validated in the field or against deliberate electronic warfare. This chapter maps what separates that evidence base from operational deployment - an account of the unknowns as clinically important as the affirmative case.

6.1 The Pre-Contact Awareness Tradeoff: The Central Clinical Cost

The most significant limitation of any non-emitting architecture is not technical but clinical, and deserves treatment as such rather than burial among engineering concerns.

Conventional Bluetooth- and Zigbee-based WBANs emit continuously, and that emission - the signature of Section 4 - simultaneously makes physiological data remotely available to friendly receivers. A medic with a compatible receiver can, in principle, see multiple casualties states before reaching any, and in a mass-casualty event prioritise the deteriorating from a distance, planning movement on objective data rather than visual assessment alone.

Pre-contact awareness matters for what it allows before reaching the casualty. In civilian trauma systems, pre-arrival notification readies the receiving team, allows them to preassign roles and anticipate specific interventions. Battlefield is not a trauma bay, but the principle holds - earlier physiological data permits earlier preparation and more deliberate sequencing of actions across casualty scenes with better medical resources management. This is consistent with vital-sign trends rather than isolated readings carrying the early signal of haemorrhagic deterioration: a casualty whose oxygen saturation has fallen from 99% to 91% over four minutes may warrant closer attention than one presenting with a stable 91%, and saturation in particular may remain near-normal until haemorrhage is advanced (Convertino & Cardin, 2022). But direct evidence from combat as opposed to simulation exercises - that remote telemetry improves triage accuracy or survival does not yet exist; the benefit is best called clinically plausible and operationally reasonable but not yet proven in this particular setting.

EQS-HBC, confining its signal to the near field, forfeits this entirely. The medic gains data only on contact, and only from the casualty touched; between contacts there is no objective information about any other casualty. With multiple simultaneous casualties, approach-priority decisions rest on visual observation, reported symptoms, or mechanism of injury alone. That leads to creating conditions under which triage errors are more likely.

This is not a reason to reject EQS-HBC but to be precise about where it offers net benefit. The calculus when it favours the use of being electromagnetically silent over the ability to communicate remotely is out of scope of this manuscript. No study has quantified this tradeoff empirically, doing so could be very beneficial.

Two qualifications temper the stealth argument. First, eliminating the monitoring emission does not make a soldier electromagnetically invisible: combat forces routinely carry emitting combat-net radios - SINCGARS in US service, Bowman in UK service whose transmissions are themselves detectable. A body-coupled layer removes not all emission but one continuous, involuntary source: the always-on sensor-to-hub link that emits on every wearer regardless of situation, including an unconscious casualty. Second, the technology if implemented into a hybrid system could restore control over emission rather than guarantee its absence. For e.g. tactical radios operate under emission discipline. A hybrid architecture combining wearable biosensors with Wi-R and RF technology could in principle extend that discipline to physiological data monitoring, by decoupling continuous monitoring (which proceeds silently on the body), from the act of transmission, which subsequently becomes more controlled and discretionary.

6.2 NFC as a Mature Incumbent

NFC shares one of the EQS-HBC's claimed advantages: namely it allows short-range, low-detectability transfer simultaneously offering practical advantages EQS-HBC cannot yet match. It is already standardised and globally deployed at 13.56 MHz with a transfer range of approximately 4 cm (ISO/IEC 18092, 2013), inexpensive, available in ruggedised form for harsh environments. As a casualty-monitoring architecture, the realistic NFC configuration would consist of body-worn sensors connected to a central hub by uniform-integrated wired links. The hub would store the continuous physiological record and present it via NFC on contact. This keeps the sensor-to-hub layer free of continuous RF networking but depends on the physical integrity of the wiring, itself vulnerable to damage by the extreme environmental conditions present in a war scene.

As established in Section 4.2, EQS-HBC's advantages over NFC at the retrieval layer are real: no detectable emission during transfer, and retrieval through general body contact rather than precise alignment. A third difference is quantitative. EQS-HBC links have been demonstrated at tens of megabits per second (Maity et al., 2019), about two orders of magnitude above NFC's 424 kb/s standard ceiling. For the indices most relevant to occult haemorrhage detection at point of injury, this margin is not decisive: a device such as the CipherOx CRI monitor analyses waveform morphology on board and outputs a single value (Convertino & Cardin, 2022), which any low-bandwidth channel including NFC can carry. The bandwidth difference becomes practically meaningful for a different use: transferring the underlying raw multi-channel waveforms accumulated over hours of mission duration. At realistic sensor data rates, several hours of stored raw waveforms amount to roughly tens to hundreds of megabytes, which EQS-HBC can transfer through a touch interaction in seconds whereas NFC would require many minutes. The distinctive contribution of EQS-HBC over NFC at the retrieval layer is therefore not the ability to carry currently used indices, which NFC can match, but the practical feasibility of transferring the underlying raw record itself within a clinically acceptable time. Such information may be relevant for post hoc clinical review as well as for multi-algorithm analysis, and future indices not yet developed.

6.3 Wired and Textile-Integrated Architectures: The Strongest Non-Radiating Comparator

The comparison most consequential for EQS-HBC’s claim to novelty is not with Bluetooth or Zigbee but with the simplest architecture that also avoids active RF emission at the on-body layer. A wearable bio sensor-to-hub harness that uses cables or other garment-integrated conductors to feed the hub with local storage and an optional egress to the medic (either by wire or by wire + RF option if needed). It removes the necessity of continuous RF emission from the sensor-to-hub layer with no new communication technology, making it a non-radiating comparator to EQS-HBC.

Its limitations are mostly mechanical and ergonomic but not only. Cabling and conductive textiles are subject to, abrasion, flexion fatigue, and the routing constraints of body armour. Moreover the connectors are points of contamination by blood, mud, and water and like any on-body system its wires and connections are vulnerable to mechanical trauma. Due to their widespread location they are probably more prone to damage and loss of function then a minimalist wireless construction (in the setting of combat). These are some genuine engineering burdens. Nevertheless the overall construction seem to be a viable option as wired and textile-integrated wearables already exist and have seen field use (Friedl, 2018).

This reframes EQS-HBC’s contribution more honestly than comparison against emitting WBANs alone. Its distinctive claim is not that it uniquely enables electromagnetically silent local monitoring - a wired or textile harness does that too - but that it may provide a cable-free silent sensor-to-hub layer, removing the mechanical and ergonomic costs of conductors and connectors, and may add what a wired harness cannot: retrieval through general body contact, with no connector to locate, align, or keep clean. Whether those advantages outweigh EQS-HBC’s immaturity, unproven ruggedness, and absent combat validation, against an already-available hardened wired baseline, is precisely what future evaluation must determine.

One caveat avoids overclaiming on either side: a wired architecture is best described as avoiding active RF transmission at the sensor-to-hub layer, not as perfectly electromagnetically invisible. Conductors and their electronics can still produce an unintentional emission. That’s why even then they can produce an unintentional electromagnetic leakage that sometimes can be detected and geolocated by adversarial forces.

6.4 System Architecture and Redundancy in Combat Conditions

A soldier-worn system - multiple sensors, a hub, local storage, and a body-coupled channel has several points of failure that combat can degrade or destroy: ballistic or blast trauma to sensor-bearing tissue; contamination by blood, mud, water, or chemicals; a sensor–skin interface disrupted by dressings, burns, or oedema; shifts in body bioimpedance as haemorrhagic shock and dehydration alter blood volume and skin properties (Anakmeteeprugsa et al., 2024; Lee, 2024; Björklund et al., 2013); and, for capacitive coupling specifically, diversion of the return path by nearby large conductors, metal, water, or wiring (Zhao et al., 2017). None of the peer-reviewed EQS-HBC studies was conducted under these conditions, so the channel’s behaviour in them is untested. Distributing sensors across body sites would add redundancy, and because the body conducts the signal as a whole, critical parameters such as oxygen saturation or heart rate can be retrieved through any intact skin surface rather than a specific, possibly wounded site. These are engineering questions, not fatal objections, but each requires dedicated bench and field validation by biomedical-engineering specialists before clinical reliance.

6.5 Patient Safety and Regulatory Framework

Any technology passing electrical signals through or around the body raises an immediate question: is it safe for the patient? The question carries added weight in the tactical context, where the casualty's physiology may already be severely deranged by haemorrhagic shock, electrolyte imbalance, and compromised skin integrity - the last of which could in principle also affect how the body responds to electrical current.

At the sub-1 MHz frequencies EQS-HBC uses, the relevant limit is not Specific Absorption Rate (the thermal metric for RF exposure) but current density and internal electric field, which govern the risk of peripheral-nerve or central-nervous-system stimulation (ICNIRP, 2010, 2020; Maity et al., 2020b). For capacitive operation, where the signal is conducted through the body's natural electrical properties without direct current injection, simulation places induced current densities orders of magnitude below ICNIRP limits across the operating range, and an experimental study of continuous monitoring in seven healthy subjects over one month found no significant change in any monitored parameter - preliminary in-vivo evidence of safety (Maity et al., 2020b).

Three secondary points can be stated briefly. Cardiac stimulation requires current densities well above this capacitive, sub-threshold regime and is correspondingly remote (ICNIRP, 2010); galvanic, direct-electrode implementations can instead approach exposure limits at the electrode and would need a separate safety evaluation (Maity et al., 2020b); and because the device's field falls far below the FCC limit for unintentional radiators at operationally relevant distances (Nath et al., 2021), it falls under FCC Part 15 with no dedicated RF-emission certification. Each warrants device-specific confirmation - particularly for casualties with myocardial injury, electrolyte derangement, or an implanted cardiac device - within any field-validation protocol.

7. Conclusions

This review examined, from a clinical perspective, whether Electro-Quasistatic Human Body Communication offers a defensible solution to a specific, demanding problem in tactical medicine: monitoring a casualty's physiological state continuously, at the point of injury, without the electromagnetic signature conventional wireless monitoring entails. The evidence permits a measured answer to each research question.

On the first, whether EQS-HBC can capture a continuous physiological record and retrieve it on contact without the RF emissions inherent to conventional WBANs, the peer-reviewed evidence supports a qualified affirmative under laboratory conditions. EQS-HBC confines signal energy to the near field, producing no RF emission detectable at operationally relevant distances under standard conditions (Das et al., 2019; Nath et al., 2021). Its strongest advantage is at the continuous monitoring layer: it can replace the Bluetooth sensor-to-hub links that otherwise emit on every wearer with a body-coupled channel that emits nothing detectable. Its advantage over the low-emission alternatives is narrower and must be stated precisely: a wired or textile-integrated harness can silence the sensor-to-hub layer with no new technology, and NFC can provide low-emission retrieval, whereas EQS-HBC alone offers a sensor-to-hub layer that is silent and cable-free together with retrieval by general body contact. Whether that combination justifies its immaturity against a ruggedised wired baseline is the central unresolved comparison. The security gain carries a clinical cost: eliminating emission forfeits the remote, pre-contact triage awareness emitting systems provide - a genuine loss in multi-casualty scenarios that bounds where the technology offers net benefit, greatest in high-threat, low-casualty-density point-of-injury care and least in permissive environments where the detectability risk is acceptable.

On the second, whether the body-coupled link resists electronic-warfare jamming better than the radio links it would replace, the evidence does not yet support a definite answer either way. The same near-field confinement that keeps EQS-HBC covert should, by physical inference, also make deliberate interference harder to inject from a distance than into a 2.4 GHz link (Nath et al., 2021), but this expectation has not been field tested against an military grade jammer. The BodyWire transceiver's demonstrated robustness to strong interference (Maity et al., 2019) was established against ambient laboratory noise, not deliberate electronic attack, and capacitive body channels are themselves susceptible to ambient and mains interference in their own right (Kang et al., 2016; Zhao et al., 2017); Jamming resistance is therefore a plausible consequence of EQS-HBC's physics, not a demonstrated property, and should inform research priorities rather than deployment decisions in contested environments.

The most important conclusion concerns not what the evidence shows but what it does not. Across the peer-reviewed literature on EQS-HBC there is no field trial in a military medical setting, and no study of performance under the conditions that define the point of injury: trauma to sensor-bearing tissue, contamination, mechanical stress, and the altered physiology of haemorrhagic shock. The safety evidence, though encouraging for capacitive operation, derives from healthy subjects under controlled conditions (Maity et al., 2020b). The affirmative case therefore rests entirely on translating laboratory findings to an operational environment where they have not been tested - the central gap, and the priority for future research. The single most valuable study would be a head-to-head field comparison, under representative tactical conditions, of an EQS-HBC architecture against conventional emitting WBANs, a ruggedised wired or textile-integrated harness, and an NFC-plus-local-memory alternative, assessing emission, durability, jamming resistance, and triage accuracy together rather than in isolation.

What can be confidently stated is narrower than the surrounding enthusiasm suggests, but not trivial: EQS-HBC is a physically sound approach to a real, well-defined problem - the conflict between the imperative to monitor and the imperative to remain electromagnetically silent at the point of injury - and the laboratory evidence for its core claim is credible and consistent. The clinical case for point-of-injury triage is coherent, provided its costs are acknowledged as openly as its benefits and the absence of field validation is treated as the decisive limitation it is.

On the laboratory findings alone, EQS-HBC could serve as a reasonable supplement to the soldier's equipment. The capability is distinctive and addresses real point-of-injury problems, but it is not a universal tool for battlefield triage: in many situations its disadvantages, used alone, outweigh its advantages, and it should not be relied on as the only communication channel - least of all for the hub-to-medic link - because the price of remaining electromagnetically silent is sometimes too high. Against that, the opportunity it offers - to fall silent on command yet still transfer physiological data to the medic by direct contact - may be valuable in specific scenarios, and a system able to operate in both modes could let a soldier adapt to the tactical context. The logic of which mode is preferable when it is itself complex and lies outside this article's scope. Nevertheless, on the strength of these promising laboratory findings, field-validation research is warranted.

For the present, EQS-HBC is best understood not as a deployable capability but as a promising laboratory platform whose clinical value remains to be demonstrated. Whether it becomes a standard component of tactical medical monitoring will depend less on the elegance of its physics than on whether future field research can show that its theoretical advantages survive contact with the operational environment they are meant to serve.

The trajectory of military medical innovation has often led into civilian care, and the problem EQS-HBC addresses - capturing reliable physiological data under adverse conditions - is not unique to combat. If field validation confirms its laboratory promise, the technology may find relevance in civilian emergency settings as readily as military ones. That broader potential, however, rests on the same unproven foundation: it must first survive contact with the operational environment.

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