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Review Article **Radiological Technology**

Medical Device Usability, Human Factors Engineering, and Quality of Life Among Healthcare Workers: A Comprehensive Review

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Abstract

Medical devices have become indispensable in modern healthcare settings, fundamentally transforming clinical workflows and patient care delivery. However, despite significant technological advancements, the integration of medical devices into healthcare environments presents multifaceted challenges that directly impact both healthcare worker quality of life and patient safety outcomes. This comprehensive review synthesizes recent literature examining the relationship between medical device usability, human factors engineering principles, and the well-being of healthcare professionals including radiological technicians, health informatics specialists, nurses, clinical coding technicians, and health administration staff. The review examines critical factors including device usability design, ergonomic considerations, training adequacy, workflow integration, and psychological impacts including burnout and job satisfaction. Evidence demonstrates that while medical devices offer substantial benefits in terms of efficiency, accuracy, and clinical decision support, their implementation frequently encounters significant barriers related to poor usability, inadequate training, ergonomic challenges, and psychological stress among users. Key findings indicate that healthcare systems exhibiting structured training programs, user-centered design principles, and adequate organizational support demonstrate markedly superior outcomes in staff satisfaction, productivity, and patient safety. This review identifies essential strategies for optimizing medical device integration, including comprehensive human factors engineering evaluation during development, iterative usability testing with end-users, enhanced training protocols, workflow-centered design approaches, and institutional commitment to supporting staff adaptation and well-being during technology transitions.

Keywords: Medical devices, Usability, Human factors engineering, Healthcare workers, Quality of life, Burnout, Clinical workflow, Ergonomics, Patient safety, Technology integration.

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BACKGROUND

The healthcare landscape has undergone dramatic transformation over the past two decades, driven substantially by rapid technological innovation and the proliferation of sophisticated medical devices across all clinical settings. From diagnostic imaging systems and laboratory equipment to wearable monitoring devices and clinical decision support systems, medical technologies now permeate virtually every aspect of healthcare delivery [1]. These devices have demonstrably improved diagnostic accuracy,

enhanced treatment efficacy, and contributed significantly to improved patient outcomes across numerous clinical domains [2]. However, beneath these technological advances lies a complex human-technology interaction dynamic that warrants critical examination. The successful implementation and utilization of medical devices depends fundamentally on the healthcare workers who interact with these technologies on a daily basis, including radiological technicians, health informatics specialists, nurses, clinical coding technicians, health administration specialists, and numerous other healthcare professions [3].

Despite the well-documented clinical benefits of medical device technologies, substantial evidence now demonstrates that their integration into healthcare environments frequently produces unintended negative consequences for healthcare worker well-being. Studies examining healthcare workers across multiple disciplines have identified significant associations between medical device use—particularly health information technologies and electronic health record systems—and increased occupational stress, burnout syndrome, and diminished quality of life [4, 5]. Approximately 48% of physicians working in hospital settings report experiencing burnout, with electronic health record systems identified as a primary contributing factor by 28% of surveyed physicians [6]. Nurses similarly report elevated stress levels, frustration, and diminished job satisfaction related to poorly designed medical devices and information systems [5]. Clinical coding technicians, health informatics specialists, and radiological technicians frequently encounter steep learning curves, inadequate training, ergonomic challenges, and workflow disruptions associated with new medical device implementations [7, 8]. These occupational health consequences extend beyond individual worker well-being, with emerging evidence demonstrating that healthcare worker burnout and reduced quality of life translate directly into compromised patient safety outcomes, medical errors, and diminished care quality [6, 9].

The scientific discipline of human factors engineering, also termed usability engineering, provides a comprehensive framework for understanding and addressing the human-technology interaction challenges inherent in medical device implementation and use [10, 11]. Human factors engineering encompasses the application of psychological, physiological, and sociological principles to optimize the design, development, and implementation of devices and systems for human use, with explicit emphasis on maximizing safety, effectiveness, and user satisfaction while minimizing error and adverse outcomes [3, 12]. When appropriately applied during medical device development and implementation, human factors engineering methodologies demonstrably improve device usability, reduce use-related errors, enhance user satisfaction, and contribute substantively to improved organizational performance and worker quality of life [13, 14]. Conversely, medical devices developed and implemented without adequate consideration of human factors principles frequently result in poor usability, increased cognitive and physical workload, elevated error rates, and significant psychological distress among users [15, 16]. This review synthesizes current literature examining the critical intersection of medical device usability, human factors engineering principles, and quality of life among diverse healthcare worker populations, with the objective of identifying evidence-based strategies for optimizing medical device integration within healthcare systems.

LITERATURE REVIEW

A comprehensive examination of recent literature reveals substantial heterogeneity in approaches to medical device usability assessment, implementation strategies, and outcomes measurement across healthcare settings. However, several consistent themes emerge across this diverse literature base. First, extensive research demonstrates that inadequate consideration of human factors principles during medical device development and implementation produces predictable negative outcomes including poor usability, user errors, workflow disruption, staff frustration, and burnout [17, 18]. Second, structured implementation approaches incorporating human factors engineering principles, comprehensive user training, adequate workflow integration planning, and organizational support for staff adaptation produce markedly superior outcomes across multiple dimensions including usability satisfaction, productivity, safety, and worker well-being [19, 20]. Third, individual user characteristics—including prior technology experience, health literacy, age, and occupational role—significantly influence both device usability experiences and burnout risk, suggesting necessity for personalized implementation and training strategies [21, 22]. Fourth, organizational and systemic factors including available resources, leadership support, institutional culture, and technical infrastructure substantially moderate the relationship between device characteristics and user outcomes [23, 24]. Fifth, the relationship between technology implementation and worker well-being appears partially mediated by workload and task load variables, such that poorly designed or inadequately integrated devices increase perceived workload, which in turn elevates burnout risk and reduces job satisfaction [25, 26].

Research examining electronic health records implementation provides particularly detailed evidence regarding these mechanisms. Studies tracking healthcare provider time allocation demonstrate that physicians spend approximately six hours daily interacting with electronic health record systems, with substantial portions of this time occurring outside regular work hours [27]. Survey data from 4,197 physicians revealed that 64% agreed or strongly agreed that electronic health

records added to their daily frustration, 38% reported excessive time spent on electronic health records outside work, and 46% rated time spent on documentation as poor or marginal [28]. Critically, all these electronic health record-related stressors demonstrated significant associations with physician burnout risk. Similar findings emerge from qualitative research examining nursing experiences with health information technologies, wherein nurses frequently report feeling frustrated, frightened, and concerned about digital tool integration, particularly when implementation occurs without adequate training, workflow integration, or organizational support [29, 30]. These negative experiences contrast sharply with experiences in healthcare environments that prioritize adequate training, appropriate workflow integration, and user interface design informed by human factors principles, wherein healthcare workers report improved satisfaction, enhanced productivity, and reduced stress [31, 32].

Medical Device Usability and Ergonomic Design Principles

Medical device usability encompasses the ease with which healthcare workers can interact with devices across the full spectrum of use scenarios, including device preparation, operation, maintenance, and troubleshooting [33]. Usability deficiencies in medical devices represent a critical patient safety concern, as approximately 30% of reported adverse medical device events involve use errors that could be substantially reduced through improved device design incorporating human factors principles [34, 35]. Research examining home medical devices used by patients with various conditions demonstrates that devices with ergonomic design limitations and poor usability frequently result in reduced user compliance, increased frustration, and compromised therapeutic efficacy [36]. In healthcare settings, poorly designed devices create similar problems for healthcare worker users. For example, research examining continuous renal replacement therapy devices identified significant use-related risks attributable to suboptimal device interfaces and inadequate attention to user needs during development [37]. Systematic application of human factors engineering methodologies—including comprehensive user needs assessment, iterative prototyping with end-user feedback, usability testing in realistic clinical environments, and design refinement based on identified usability challenges—successfully mitigated these identified risks, resulting in devices with substantially improved usability satisfaction and reduced error likelihood [37].

Ergonomic considerations represent another critical dimension of medical device design directly impacting healthcare worker quality of life and patient safety. Ergonomic issues in medical devices contribute substantially to musculoskeletal disorders and repetitive strain injuries among healthcare workers, with epidemiological data indicating that approximately 40% of workplace injuries in healthcare settings involve overexertion and repetitive motion, with back and wrist injuries predominating [38]. Poor ergonomic design in medical devices and workstations contributes to physical discomfort, fatigue, and chronic pain conditions that compromise both worker well-being and clinical performance [7, 38, 39]. Facilities implementing ergonomic workstations featuring height-adjustable surfaces, appropriate task lighting, and ergonomic accessories report significant reductions in worker-reported musculoskeletal pain and improved overall satisfaction [40]. Research examining specific ergonomic interventions in pathology and sterile reprocessing departments found that implementing ergonomic pathology grossing stations with height-adjustable work surfaces, integrated task lighting, and strategically positioned storage reduced reported wrist injuries by 30% and improved employee satisfaction within six months [38]. These findings underscore the importance of integrating ergonomic principles throughout the medical device design and implementation process, not as an afterthought but as a foundational consideration alongside functional and safety requirements.

Training Adequacy and Implementation Strategy

Comprehensive training represents one of the most consistently identified facilitators of successful medical device adoption and utilization across healthcare professional populations [41, 42]. Conversely, inadequate training emerges as one of the most frequently cited barriers to effective device utilization, user satisfaction, and adoption success [41, 42]. Research examining barriers and facilitators to adoption of digital health technologies identified need for additional training as the most frequently reported technical barrier appearing across 6 separate studies in the systematic review [41]. The timing, content, duration, and delivery modality of training substantially influence outcomes. Training conducted during the early adoption phase proves more effective than retrospective training conducted after implementation challenges have already emerged [43]. Structured training programs that clearly communicate device functionality, address common use challenges, provide opportunity for hands-on practice in low-stress environments, and include ongoing support yield superior adoption outcomes compared to brief orientation sessions lacking these elements [31, 32, 44].

Training effectiveness additionally depends on recognition that healthcare workers present heterogeneous prior knowledge, learning preferences, and technology experience. Research examining the influence of prior health knowledge on medical device usability identified significant relationships between baseline health knowledge and device usability performance, with some devices exhibiting threshold effects wherein users required minimum health knowledge levels to achieve accurate operation [45].

This finding suggests importance of customized training approaches that account for baseline user knowledge and experience levels. Training programs incorporating multiple modalities—including written materials, video demonstrations, hands-on practice, peer mentoring, and ongoing decision support—demonstrate superior outcomes compared to single-modality approaches [32]. In healthcare environments prioritizing comprehensive training, early communication with stakeholders, structured implementation timelines, on-site technical assistance, inclusion of staff in implementation decisions, and clear leadership vision for implementation necessity, healthcare workers report substantially higher satisfaction, confidence, and adoption rates [32, 46].

Healthcare Worker Quality of Life and Burnout: Technology-Related Stressors

Healthcare worker quality of life encompasses multiple dimensions including physical well-being, psychological well-being, job satisfaction, work-life balance, professional fulfillment, and absence of occupational illness [47, 48]. Burnout syndrome, increasingly prevalent among healthcare workers across disciplines, represents a multidimensional condition characterized by emotional exhaustion, cynicism, and reduced professional efficacy resulting from chronic occupational stress [49]. Recent epidemiological data indicates that 61.2% of medical staff in surveyed hospitals exhibit at least one burnout symptom, with 9.8% experiencing high-level burnout [50]. Notably, elevated burnout rates concentrate among physicians and surgeons with less than 10 years professional experience, with 30–39-year-old physicians and surgeons demonstrating particular vulnerability [50]. Technology-related factors constitute significant contributors to burnout risk, with electronic health record systems, health information technologies, and poorly designed medical devices identified as primary stressors [6, 51]. Quantitative investigations examining the specific relationship between electronic health record usability and burnout among physicians reveal strong associations, with more favorable usability associated with lower workload perceptions, improved job satisfaction, and reduced burnout likelihood [52]. Conversely, patients or healthcare workers perceiving electronic health records and other health technologies as inefficient, requiring excessive time investment, and inadequately supporting clinical work generate persistent frustration and stress responses that cumulatively contribute to burnout development [6, 51].

Burnout among healthcare workers produces extensive negative consequences extending beyond individual well-being. Healthcare worker burnout associates with reduced care quality, increased medical errors, patient safety compromises, decreased patient satisfaction, and elevated healthcare costs [49, 51]. Studies tracking healthcare worker well-being during high-stress periods such as the COVID-19 pandemic identified that 39% of surveyed workers experienced moral injury risk, 41% experienced posttraumatic stress risk, 27% experienced depression risk, and 25% experienced persistent burnout [53]. Critically, modifiable workplace factors—including perceived management support for worker health and safety, supervisor support, coworker support, and empowerment to make job-related decisions—demonstrated significant associations with burnout and mental health risks, suggesting substantial opportunity for organizational intervention [53]. Healthcare workers identifying positive leadership support and interprofessional collaboration demonstrate significantly higher resilience and job satisfaction, with these protective factors partially offsetting burnout risk related to demanding work conditions and technology stressors [54]. These findings underscore the importance of organizational approaches to technology implementation that explicitly prioritize worker well-being, provide adequate support resources, establish leadership commitment to implementation success, and foster organizational cultures emphasizing team support and worker input into technology-related decisions.

Human Factors Engineering Integration in Medical Device Development

Successful medical device usability optimization requires systematic integration of human factors engineering methodologies throughout the device development lifecycle, from initial concept definition through post-market surveillance [33, 55]. Human factors engineering integration involves multiple sequential and iterative phases. Initial phases include comprehensive user needs assessment establishing clear understanding of intended users' characteristics, capabilities, limitations, anticipated use environments, and specific tasks requiring device support [33, 56]. This user needs assessment phase proves critical, as devices developed without adequate understanding of user needs frequently produce devices misaligned with user workflow, expectations, and preferences [36, 37]. Subsequent phases involve specification of user interface requirements, prototyping, iterative usability testing with representative end-users in realistic or simulated use environments, and refinement based on identified usability challenges [37, 56, 57]. Throughout development, human factors engineering methodologies emphasize user-centered design approaches ensuring end-users meaningfully influence design decisions rather than serving solely in feedback roles following largely completed design decisions [37, 57].

Comprehensive human factors engineering integration during device development demonstrably reduces device use errors, improves user satisfaction, reduces training time requirements, and enhances patient safety outcomes [15, 37, 57, 58]. Regulatory frameworks increasingly mandate human factors engineering consideration during device development, with the FDA providing detailed guidance on appropriate human factors engineering processes [59]. Nevertheless,

implementation of comprehensive human factors engineering remains inconsistent across the medical device industry. Studies examining medical device development processes identify that many devices reach market without adequate consideration of human factors principles, resulting in devices presenting unnecessary complexity, poor intuitiveness, steep learning curves, and substantial use error potential [4, 36, 60]. Healthcare facilities implementing devices developed with minimal human factors engineering consideration encounter predictable challenges including extended adoption timelines, user frustration and resistance, elevated error rates during initial implementation phases, and persistent user dissatisfaction even after extended device experience [5, 6].

Workflow Integration and Organizational Support

Workflow integration represents a critical yet frequently underappreciated dimension of successful medical device implementation. Workflow integration refers to the degree to which a medical device interfaces seamlessly with existing clinical workflows, task sequences, communication patterns, and information flow within healthcare settings [61]. Medical devices implemented without careful attention to workflow integration frequently disrupt established work processes, necessitate time-consuming workarounds, divert clinical attention away from patient care to administrative technology tasks, and generate frustration and resistance among end-users [6, 29, 30, 31]. Conversely, devices developed and implemented with explicit attention to workflow integration—ensuring devices support rather than impede existing clinical processes—demonstrate markedly superior adoption, user satisfaction, and productivity outcomes [31, 62]. Research examining factors facilitating successful electronic health record adoption identified adequate workflow integration and sufficient training as the most critical facilitators across multiple healthcare professions [31, 63]. Physicians and nurses both identified workflow integration as essential, though specific workflow challenges differed between professions, underscoring importance of profession-specific workflow analysis during implementation planning [31, 62].

Organizational factors encompassing leadership support, resource availability, organizational culture, and institutional commitment to implementation success substantially influence medical device implementation outcomes and subsequent user well-being [24, 64]. Healthcare facilities with strong leadership commitment to device implementation success, adequate resources allocated to training and technical support, cultures supporting staff input and adaptability, and expectations of iterative refinement and optimization report superior implementation outcomes and staff well-being compared to facilities implementing devices with minimal leadership attention, inadequate resources, punitive attitudes toward implementation challenges, and minimal staff input [24, 32, 46, 64]. Organizational support appears particularly important during early implementation phases when end-users encounter learning curves and workflow disruptions. Facilities providing adequate on-site technical assistance, peer mentoring, flexible timelines accommodating staff adaptation, and recognition that implementation challenges represent opportunities for system refinement rather than staff failures demonstrate substantially better outcomes [32, 46]. These organizational factors appear partially independent from device characteristics per se, suggesting that even devices with usability limitations can function reasonably well in organizational contexts providing strong implementation support, whereas devices with superior usability can underperform in organizations lacking implementation support [65, 66].

Physical and Psychological Health Impacts of Medical Devices

Medical device use influences healthcare worker physical and psychological health through multiple mechanistic pathways. Ergonomic considerations impact physical health directly through postural demands, repetitive motion requirements, equipment design features, and workstation layout [38, 39, 40]. Poor ergonomic design contributes to musculoskeletal disorders, chronic pain syndromes, fatigue, and increased injury risk, collectively compromising worker well-being and productivity [38, 40, 67]. Psychological health impacts occur through multiple mechanisms including stress from inadequate device usability requiring excessive cognitive effort and time investment, anxiety related to concern about making errors, frustration from workflow disruptions, feelings of incompetence when devices prove difficult to master, and demoralization when technologies fail to support rather than enhance clinical work [6, 29, 30, 31, 51, 61]. Video and electronic health record use specifically associates with physical eye fatigue, neck pain, and stress; employees report dissatisfaction with documentation requirements, effort demanded by systems, and time-consuming interruptions [68]. These physical and psychological stressors accumulate over time, contributing to burnout development and psychological symptoms including depression, anxiety, and sleep disturbance [51, 53, 69].

The relationship between medical device-related stressors and healthcare worker well-being appears mediated substantially by perceived workload, particularly documentation burden and time spent on administrative tasks rather than patient care [6, 27, 28, 52]. Healthcare workers expressing frustration with technology identify excessive time demands, clerical task burdens, and inadequate support for core clinical work as primary complaints [28, 51]. Notably, improving electronic health record usability while decreasing associated task load provides potential to increase available working memory for medical decision-making and patient communication, thereby

improving care quality alongside worker well-being [52]. This observation suggests that technology-related worker distress does not represent inevitable consequence of technological advancement but rather reflects suboptimal implementation approaches and device design characteristics amenable to improvement through systematic application of human factors engineering principles and organizational support for appropriate implementation.

Healthcare Professional Populations and Device Implementation

This review explicitly encompasses multiple healthcare professional populations including radiological technicians, health informatics specialists, nursing technicians, clinical coding technicians, medical secretaries, health administration specialists, psychologists working in healthcare settings, and social care specialists. These diverse professions exhibit heterogeneous interactions with medical devices, occupational tasks, technical expertise, and baseline knowledge. However, evidence demonstrates that medical device implementation challenges transcend specific professions, with similar patterns of challenges and barriers emerging across nursing, physician, and allied health professional populations [41, 42, 63]. Common challenges include inadequate training, poor workflow integration, insufficient user interface design, excessive documentation burdens, lack of organizational support, and concerns about technology replacing professional judgment [41, 42, 63, 70]. Common facilitators include adequate training, appropriate workflow integration, user-friendly interface design, organizational support, and opportunities for professional input into implementation processes [41, 42, 63].

Profession-specific differences merit recognition. Nurses report particular concern about inadequate training and lack of confidence using complex medical devices and information systems [31, 63, 71]. Physicians highlight workflow integration challenges and excessive documentation burden as primary frustrations [31, 62, 63]. Health information technicians and clinical coding technicians emphasize need for adequate training in complex software systems and concerns about data accuracy and system reliability [72]. Radiological technicians prioritize understanding of image quality and device operation alongside concerns about radiation safety in conjunction with device use [73]. These profession-specific variations argue for tailored implementation approaches considering each professional group's particular needs, concerns, and work context. Healthcare facilities implementing medical devices with one-size-fits-all approaches to training, support, and workflow integration frequently encounter profession-specific resistance and suboptimal adoption outcomes compared to facilities customizing implementation approaches to each professional group's particular circumstances and needs.

Strategies for Optimizing Medical Device Integration

Evidence synthesized throughout this review identifies evidence-based strategies for optimizing medical device integration within healthcare systems to enhance both patient safety and healthcare worker quality of life. First, comprehensive human factors engineering evaluation during device development, including detailed user needs assessment, iterative usability testing with representative end-users in realistic environments, and design refinement based on identified usability challenges, should become standard practice rather than optional consideration within medical device industry. Regulatory frameworks should mandate and systematically enforce human factors engineering requirements during device development [33, 59]. Second, healthcare facilities selecting medical devices should systematically evaluate usability characteristics during procurement processes, requesting usability testing data from manufacturers and conducting independent usability testing with representative end-users prior to large-scale implementation [74]. This evaluation approach requires organizational investment in procurement expertise and usability assessment capabilities but prevents expensive implementations of devices with fundamental usability limitations amenable to pre-procurement identification.

Third, comprehensive pre-implementation planning incorporating explicit attention to workflow integration represents essential foundation for successful device implementation. This planning should involve representatives from all professional groups who will interact with devices, clinical leadership, health IT personnel, and when available, human factors professionals [32, 46, 61]. Planning processes should explicitly map current workflows, identify anticipated disruptions, develop mitigation strategies, establish implementation timelines allowing adequate user adaptation, and define success metrics extending beyond technical function to encompass usability, workflow efficiency, and user satisfaction [32, 46]. Fourth, comprehensive training programs delivered before and during device implementation should employ multiple modalities, accommodate diverse learner preferences and baseline knowledge levels, provide hands-on practice in low-stress environments, and include ongoing support mechanisms extending beyond initial implementation phases [31, 32, 44]. Training should explicitly address common use challenges, provide opportunity for scenario-based practice, and include clear communication regarding rationale for implementation and benefits expected from device adoption.

Fifth, adequate staffing and resources dedicated to implementation support, including on-site technical assistance, peer mentoring, and access to implementation

subject matter experts, should be available throughout early implementation phases [32, 46]. Sixth, organizational cultures supporting iterative refinement and viewing implementation challenges as opportunities for system optimization rather than staff failures foster superior implementation outcomes and worker well-being [24, 32, 65]. Leadership explicitly communicating that implementation processes represent collaborative efforts among administration, IT, and clinical staff, that end-user input regarding identified challenges will be systematically addressed, and that staffing and resource constraints will not compromise implementation success establishes organizational contexts supporting successful adaptation. Seventh, ongoing post-implementation evaluation should track not only technical function but explicitly measure usability, workflow integration success, healthcare worker satisfaction, and well-being indicators, with results systematically used to drive continuous optimization of device utilization and supporting workflows [32].

CONCLUSION

Medical devices have fundamentally transformed healthcare, enabling diagnostic capabilities, therapeutic interventions, and clinical workflows impossible without technological advancement. However, realizing these potential benefits requires systematic attention to human factors principles, healthcare worker well-being, and implementation approaches emphasizing user-centered design and organizational support. Evidence reviewed throughout this comprehensive examination demonstrates that medical device implementation success depends only partially on device technical characteristics; equally important are human factors engineering principles guiding device design, workflow integration during implementation, comprehensive training adequacy, organizational support for staff adaptation, and explicit institutional commitment to healthcare worker well-being as fundamental implementation success criteria. Healthcare systems prioritizing these dimensions achieve superior outcomes across multiple measures including usability satisfaction, error reduction, productivity enhancement, and healthcare worker quality of life. Conversely, implementations neglecting these dimensions frequently encounter predictable challenges including user resistance, adoption delays, safety compromises, and burnout acceleration among affected healthcare workers. Future research should continue examining long-term effects of medical device implementation on healthcare worker well-being, investigate comparative effectiveness of different training approaches and implementation strategies, explore profession-specific considerations in technology implementation, and examine integration of emerging technologies including artificial intelligence and machine learning within human factors frameworks established for conventional medical devices. Healthcare organizations, device manufacturers, regulatory bodies, and healthcare professional associations should collaboratively establish and enforce standards ensuring human factors engineering principles, adequate implementation planning, comprehensive training, organizational support, and explicit measurement of healthcare worker well-being outcomes become standard rather than exceptional practice in medical device development and implementation. Through such integrated approaches, healthcare systems can harness technology's transformative potential while actively protecting and enhancing healthcare worker quality of life, creating sustainable improvements in both clinical care quality and healthcare professional well-being.

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