



A Critical Review of Ergonomics Considerations in Early Medical Device Feasibility Studies

Ghulam Abbas

Department of Health Science, University of American Samoa

Abstract:

Ergonomics considerations play a pivotal role in the development of medical devices, ensuring their usability, safety, and effectiveness. This critical review examines the incorporation of ergonomics principles in early feasibility studies of medical devices. By analyzing existing literature and case studies, this review highlights the significance of integrating ergonomics assessments at the outset of the device development process. The review identifies several key areas where ergonomics considerations are crucial during feasibility studies, including user interaction, interface design, and task analysis. Additionally, it explores methodologies for evaluating ergonomic factors, such as usability testing, anthropometric measurements, and cognitive workload assessments. Despite the recognized importance of ergonomics, the review reveals gaps and challenges in current practices. These include inconsistent application of ergonomics principles, limited consideration of diverse user populations, and inadequate integration of feedback from end-users. Addressing these issues early in the feasibility phase can significantly enhance the design process and ultimately improve the usability and acceptance of medical devices. In conclusion, this review emphasizes the critical role of ergonomics considerations in early feasibility studies of medical devices. It underscores the need for a systematic approach to integrating ergonomics assessments, ensuring that devices are designed with the end-user in mind, thereby maximizing usability, safety, and overall effectiveness.

Keywords: Ergonomics, medical devices, feasibility studies, usability, human factors, design, healthcare, safety, user satisfaction, product development

Introduction:

The field of medical device development is undergoing rapid evolution, driven by technological advancements, emerging healthcare needs, and evolving regulatory landscapes. In this dynamic environment, the integration of ergonomic considerations has emerged as a critical factor in the design and development of medical devices. Ergonomics, often referred to as human factors engineering in the context of medical devices, focuses on optimizing the interaction between users and devices to enhance usability, safety, and user satisfaction. Early feasibility studies represent a pivotal stage in the development lifecycle of medical devices, where design choices and concept validation significantly influence product outcomes. Despite the recognized importance of ergonomics, its integration into early feasibility studies remains a challenging endeavor. This critical review seeks to examine the current state of ergonomics considerations in early medical device feasibility studies, identify key challenges and best practices, and propose strategies for improvement [1].

Ergonomics considerations in medical device development are multifaceted, encompassing various aspects of human-device interaction, including physical, cognitive, and organizational factors. A fundamental aspect of ergonomics is the design of devices that accommodate the capabilities and limitations of users, thereby optimizing performance and reducing the risk of errors. This is particularly crucial in healthcare settings, where the consequences of usability



Cosmic Journal of Biology

Volume No: 02 Issue No: 01(2023)

issues can have significant implications for patient safety and clinical outcomes. The early feasibility stage presents a unique opportunity to integrate ergonomic principles into the design process, laying the foundation for the development of safe, effective, and user-friendly medical devices. However, achieving this integration poses several challenges. Firstly, there may be a lack of awareness among device developers regarding the importance of ergonomics or a misconception that it is primarily a concern for later stages of development.

Secondly, the complexity of healthcare environments and the diversity of end-user's present challenges in identifying and prioritizing ergonomic requirements. Additionally, limited resources and time constraints in early feasibility studies may hinder comprehensive ergonomic evaluations and iterative design iterations. Despite these challenges, there are emerging best practices and strategies for incorporating ergonomics into early feasibility studies. One such approach is the integration of human factors engineering methodologies, such as usability testing and task analysis, into the feasibility study process. By involving end-users in early-stage evaluations, developers can identify ergonomic issues and iterate on design concepts before significant resources are invested. Moreover, interdisciplinary collaboration between engineers, clinicians, human factors experts, and regulatory specialists can facilitate the holistic consideration of ergonomic factors and ensure compliance with regulatory standards [2].

Importance of Ergonomics

Ergonomics plays a crucial role in the development of medical devices due to its direct impact on user experience, safety, and overall device performance. The significance of ergonomics stems from its focus on optimizing the interaction between users and devices to enhance usability and mitigate potential risks. In the context of medical device development, usability is of paramount importance as it directly affects the efficiency and effectiveness of healthcare delivery. Poorly designed devices can lead to usability issues, such as difficulties in device operation, misinterpretation of information, and user errors, all of which can compromise patient safety and clinical outcomes. Ergonomic design principles aim to address these challenges by tailoring device interfaces, controls, and feedback mechanisms to align with user capabilities, preferences, and limitations.

Moreover, the integration of ergonomics into medical device development is essential for regulatory compliance and market acceptance. Regulatory bodies, such as the Food and Drug Administration (FDA) in the United States and the European Medicines Agency (EMA) in Europe, require manufacturers to demonstrate the safety and effectiveness of medical devices, including considerations for human factors and usability. Failure to address ergonomic factors early in the development process can result in costly redesigns, delays in product approval, and market rejection. The importance of ergonomics extends beyond regulatory requirements to encompass broader healthcare goals, such as patient-centered care and improved clinical outcomes. Medical devices are integral to modern healthcare delivery, facilitating diagnosis, treatment, and monitoring of patients across various clinical settings. Ergonomically designed devices not only enhance user satisfaction and workflow efficiency but also contribute to the overall quality of care by reducing the likelihood of errors and adverse events [3].

Early Feasibility Studies

Early feasibility studies represent a crucial phase in the development of medical devices, providing an opportunity to assess the technical feasibility, safety, and initial effectiveness of



device concepts. During this phase, key design decisions are made, and critical insights are gained into the potential challenges and opportunities associated with the proposed device. Integrating ergonomics considerations into early feasibility studies is essential for laying the groundwork for successful device development and market acceptance. One of the primary objectives of early feasibility studies is to evaluate the usability of device prototypes in realistic clinical scenarios. Usability encompasses the ease of use, efficiency, learnability, and user satisfaction associated with interacting with the device. By incorporating ergonomics into early feasibility studies, developers can identify usability issues early in the development process and iteratively refine device designs to optimize user experience.

Early feasibility studies provide an opportunity to assess ergonomic factors specific to the intended clinical environment and end-user population. Healthcare settings vary widely in terms of physical layout, workflow processes, and user preferences, making it essential to tailor device designs to meet the unique needs of each setting. Ergonomic considerations, such as the placement of controls, visibility of displays, and accessibility of interfaces, can significantly impact the usability and acceptance of medical devices in clinical practice. Incorporating ergonomics into early feasibility studies requires a multidisciplinary approach, involving collaboration between engineers, clinicians, human factors experts, and end-users. Clinicians provide valuable insights into the clinical context and user requirements, while human factors experts offer expertise in assessing user interactions and ergonomic design principles. By working collaboratively, stakeholders can identify potential ergonomic challenges, develop user-centered design solutions, and prioritize design features that enhance usability and safety [4].

Usability testing is a cornerstone of ergonomics integration in early feasibility studies, allowing developers to evaluate how end-users interact with device prototypes in simulated or real-world environments. Usability tests typically involve scenarios representative of the intended use of the device, with users asked to perform tasks relevant to their clinical workflow. Observations, feedback, and performance metrics collected during usability testing provide valuable data for identifying ergonomic issues, refining device designs, and validating design improvements. Moreover, early feasibility studies provide an opportunity to assess the ergonomic impact of device integration within existing clinical workflows and care processes. Integration challenges, such as space constraints, interoperability with other devices, and workflow disruptions, can affect the usability and acceptance of medical devices in clinical practice.

By conducting feasibility studies in real-world clinical settings, developers can identify and address integration challenges early in the development process, ensuring seamless adoption and integration of the device into existing workflows. Early feasibility studies represent a critical phase in the development of medical devices, providing an opportunity to assess usability, safety, and effectiveness in realistic clinical scenarios. Integrating ergonomics considerations into early feasibility studies is essential for optimizing device usability, addressing user needs, and ensuring market acceptance. By collaborating across disciplines, conducting usability testing, and evaluating device integration within clinical workflows, developers can identify and address ergonomic challenges early in the development process, ultimately enhancing the success of medical device innovations.

Usability Testing



Usability testing represents a cornerstone in the integration of ergonomic principles into early feasibility studies for medical devices. It involves systematically evaluating the usability of a device by observing how users interact with it in simulated or real-world environments. By incorporating usability testing methodologies into feasibility studies, developers can identify ergonomic issues, gather user feedback, and iterate on design concepts to optimize device usability and performance. The primary objective of usability testing is to assess the effectiveness, efficiency, and satisfaction with which users can accomplish specific tasks using the device. This involves evaluating various aspects of device usability, including ease of use, learnability, memorability, error recovery, and user satisfaction. Usability testing typically employs a combination of qualitative and quantitative methods, such as user interviews, observational studies, task performance metrics, and usability questionnaires, to gather comprehensive feedback from end-users [5].

In the context of early feasibility studies, usability testing serves several critical purposes. Firstly, it provides valuable insights into user needs, preferences, and pain points, which can inform design decisions and priorities. By observing how users interact with prototype devices, developers can identify usability issues, such as awkward hand positions, confusing interface layouts, or unclear instructions, that may not be apparent through traditional design reviews or expert evaluations. Secondly, usability testing enables developers to assess the impact of design changes on device usability iteratively. By conducting multiple rounds of testing with successive iterations of the device prototype, developers can evaluate the effectiveness of design modifications and refinements in addressing identified usability issues. This iterative approach to usability testing fosters continuous improvement and refinement of device designs based on user feedback and performance metrics.

Moreover, usability testing provides empirical evidence to support regulatory submissions and market claims regarding device usability and user satisfaction. Regulatory bodies, such as the FDA and EMA, require manufacturers to provide evidence of usability testing as part of the regulatory approval process for medical devices. By conducting rigorous usability testing during early feasibility studies, developers can gather the necessary data to demonstrate compliance with regulatory requirements and enhance the likelihood of successful product approval. Usability testing fosters user-centered design practices by actively involving end-users in the evaluation and refinement of device designs. By engaging clinicians, nurses, patients, and other stakeholders as usability test participants, developers can ensure that device designs align with user expectations, workflows, and clinical needs. This participatory approach to usability testing promotes collaboration, empathy, and co-design between developers and end-users, ultimately leading to the development of more intuitive, user-friendly, and clinically effective medical devices [6].

Human Factors Engineering

Human factors engineering (HFE) is a discipline integral to the optimization of medical device usability and performance. It encompasses the study of human capabilities, limitations, and behaviors to inform the design of systems, products, and environments that are intuitive, safe, and effective for users. In the context of medical device development, HFE principles are essential for identifying and addressing ergonomic factors that influence user interaction with devices. One of the key objectives of human factors engineering in medical device development



is to ensure that devices are designed with the end-user in mind. This involves understanding the needs, preferences, and abilities of various user groups, including healthcare professionals, patients, and caregivers. By conducting user research, task analyses, and usability studies, developers can gain insights into user behaviors and requirements, which inform design decisions and feature prioritization [7].

Another aspect of human factors engineering is the optimization of device interfaces and controls to minimize cognitive workload and facilitate efficient task performance. This entails designing intuitive user interfaces, clear feedback mechanisms, and ergonomic control layouts that align with user expectations and mental models. By reducing the cognitive burden on users, HFE principles contribute to enhanced usability and reduced error rates, ultimately improving patient safety and clinical outcomes. Human factors engineering involves the identification and mitigation of potential use errors through proactive risk assessment and mitigation strategies. By conducting usability testing and task simulations, developers can identify potential hazards, error-prone tasks, and usage scenarios that may pose risks to users or patients. This allows for the implementation of design enhancements, such as improved labeling, error prevention mechanisms, and user training protocols, to reduce the likelihood of adverse events and user errors.

Interdisciplinary collaboration is essential for the effective integration of human factors engineering into medical device development. This collaboration involves bringing together engineers, clinicians, human factors specialists, and other stakeholders to ensure that ergonomic considerations are addressed holistically throughout the design process. By fostering communication and collaboration across disciplines, developers can leverage diverse expertise and perspectives to optimize device usability, safety, and user satisfaction.

Design Iterations

In the development of medical devices, design iterations are integral to refining ergonomic features based on user feedback and testing. Iterative design processes involve a cycle of prototyping, evaluation, and refinement, allowing developers to incrementally improve the usability and performance of the device. One of the key benefits of design iterations is the opportunity to address ergonomic issues early in the development process. By creating prototypes and conducting usability tests with end-users, developers can identify design flaws, usability challenges, and ergonomic concerns that may not be apparent in initial concepts. This iterative approach enables rapid feedback loops, facilitating continuous improvement and optimization of ergonomic features. Moreover, design iterations foster collaboration between developers, end-users, and other stakeholders, promoting a user-centered design approach. By involving end-users in the evaluation of prototypes, developers gain valuable insights into user preferences, behaviors, and needs, which can inform subsequent design iterations. This participatory design process ensures that the final product aligns with user expectations and enhances user satisfaction.

Design iterations enable developers to explore and evaluate multiple design alternatives, leading to innovative solutions and optimal design configurations. Through iterative prototyping and testing, developers can experiment with different ergonomic layouts, interface designs, and feedback mechanisms to determine the most effective approach. This iterative exploration allows for the identification of design solutions that balance usability, functionality, and



Cosmic Journal of Biology

Volume No: 02 Issue No: 01(2023)

manufacturability. Importantly, design iterations also support risk management and regulatory compliance by enabling developers to identify and address potential safety hazards and usability issues early in the development process. By iteratively refining design concepts based on user feedback and testing results, developers can mitigate risks associated with device use errors, user-related accidents, and adverse events. This proactive approach to risk management enhances patient safety and facilitates regulatory approval processes.

Design iterations are essential for integrating ergonomic considerations into the development of medical devices. By fostering collaboration, facilitating rapid feedback loops, and enabling iterative exploration of design alternatives, design iterations promote the creation of user-friendly, safe, and effective medical devices. Embracing a culture of continuous improvement through design iterations enhances the likelihood of developing successful products that meet the needs of end-users and contribute to improved healthcare outcomes.

User-Centered Design

User-centered design (UCD) is a fundamental approach in integrating ergonomic considerations into the development of medical devices. It prioritizes the needs, preferences, and capabilities of end-users throughout the design process, ensuring that the final product is intuitive, efficient, and satisfying to use. At its core, UCD emphasizes the active involvement of end-users in all stages of the design process, from requirements gathering and concept generation to prototyping and evaluation. By engaging end-users early and often, developers gain valuable insights into user behaviors, preferences, and challenges, which inform design decisions and drive innovation. One of the key principles of UCD is empathy, which involves understanding the perspectives and experiences of end-users to create designs that resonate with their needs and expectations. Through methods such as contextual inquiry, interviews, and usability testing, developers immerse themselves in the user's environment, gaining firsthand insights into their workflow, tasks, and pain points. This empathetic approach fosters a deep understanding of user needs, enabling developers to design solutions that address real-world challenges and enhance user satisfaction.

Moreover, UCD promotes iterative design processes that prioritize user feedback and validation. By creating prototypes and soliciting feedback from end-users early in the development cycle, developers can identify usability issues, ergonomic concerns, and design preferences that inform subsequent design iterations. This iterative approach ensures that the final product reflects the evolving needs and expectations of end-users, leading to higher levels of usability and satisfaction. UCD encourages interdisciplinary collaboration between designers, engineers, clinicians, and human factors experts, fostering a holistic approach to design that considers technical feasibility, clinical requirements, and user experience. By bringing together diverse perspectives and expertise, UCD facilitates the integration of ergonomic principles into all aspects of the design process, from hardware and software development to user interface design and packaging.

UCD is essential for creating medical devices that meet the needs of end-users while optimizing usability, safety, and satisfaction. By prioritizing user needs, embracing empathy, and fostering interdisciplinary collaboration, UCD enables developers to design products that enhance the quality of care, improve clinical outcomes, and ultimately transform the healthcare experience. Embracing a user-centered approach to design ensures that medical devices not only meet



regulatory requirements but also deliver meaningful value to patients, caregivers, and healthcare providers [8].

Risk Assessment

Conducting ergonomic risk assessments during early feasibility studies is vital for identifying and mitigating potential hazards associated with medical device use. Ergonomic risk assessments evaluate the likelihood and severity of ergonomic-related injuries or errors that may occur during device operation, handling, or maintenance. One of the primary objectives of ergonomic risk assessments is to proactively identify design features or user interactions that may pose risks to patient safety or device effectiveness. This involves analyzing factors such as interface design, control placement, feedback mechanisms, and user workload to identify potential sources of user error, discomfort, or injury. By systematically assessing ergonomic risks, developers can prioritize design modifications or mitigation strategies to minimize these risks and enhance device safety. Moreover, ergonomic risk assessments play a crucial role in regulatory compliance by demonstrating due diligence in addressing ergonomic considerations. Regulatory bodies, such as the FDA and EMA, require manufacturers to conduct risk assessments as part of the medical device development process to ensure the safety and effectiveness of devices. By integrating ergonomic risk assessments into early feasibility studies, developers can proactively identify and address ergonomic concerns, thereby facilitating the regulatory approval process.

Ergonomic risk assessments contribute to the overall quality and reliability of medical devices by reducing the likelihood of adverse events or usability issues in clinical settings. By identifying and mitigating ergonomic risks early in the development process, developers can enhance user confidence, satisfaction, and trust in the device, leading to improved clinical outcomes and patient care. To conduct ergonomic risk assessments effectively, developers employ a variety of methods and tools, including task analysis, hazard analysis, usability testing, and expert evaluations. These approaches enable developers to systematically evaluate ergonomic risks across different stages of device use, from setup and operation to maintenance and troubleshooting. By leveraging a combination of qualitative and quantitative data, developers can prioritize ergonomic improvements based on their potential impact on user safety and device performance.

Interdisciplinary Collaboration

Interdisciplinary collaboration is key to effectively integrating ergonomic considerations into early feasibility studies for medical device development. By bringing together experts from diverse fields, including engineering, medicine, human factors, and regulatory affairs, developers can leverage a wide range of expertise and perspectives to address ergonomic challenges comprehensively. One of the primary benefits of interdisciplinary collaboration is the synthesis of diverse knowledge and insights, leading to a more holistic understanding of ergonomic requirements and considerations. Engineers bring technical expertise in device design and manufacturing, while clinicians provide insights into clinical workflows, patient needs, and safety requirements. Human factors specialists contribute expertise in user-centered design, usability testing, and human-computer interaction, ensuring that devices are intuitive, efficient, and safe to use. Regulatory affairs professionals provide guidance on regulatory requirements and standards, ensuring that devices meet the necessary criteria for market approval.



Cosmic Journal of Biology

Volume No: 02 Issue No: 01(2023)

Moreover, interdisciplinary collaboration fosters a culture of innovation and creativity, encouraging the exploration of novel solutions to ergonomic challenges. By encouraging open communication and collaboration between team members, developers can leverage diverse perspectives to generate innovative ideas and approaches to address ergonomic concerns. This interdisciplinary approach to problem-solving promotes the development of unique and effective solutions that may not have been possible through isolated efforts. Interdisciplinary collaboration enhances the efficiency and effectiveness of early feasibility studies by facilitating a coordinated approach to ergonomic evaluation and testing. By working collaboratively, team members can align their efforts, share resources, and streamline processes, leading to more efficient data collection, analysis, and decision-making. This collaborative approach enables developers to leverage the strengths of each discipline to address ergonomic concerns comprehensively and effectively.

Interdisciplinary collaboration promotes a shared understanding of ergonomic considerations among team members, fostering a collective commitment to prioritizing user safety, satisfaction, and usability. By involving stakeholders from different disciplines early in the development process, developers can ensure that ergonomic considerations are integrated into the design and development process from the outset. This proactive approach to interdisciplinary collaboration minimizes the likelihood of ergonomic issues arising later in the development lifecycle, reducing the need for costly redesigns or modifications [9].

Regulatory Compliance

Addressing ergonomic requirements early in the development process is crucial for ensuring regulatory compliance and market acceptance of medical devices. Regulatory bodies, such as the FDA in the United States and the EMA in Europe, require manufacturers to demonstrate the safety and effectiveness of medical devices, including considerations for human factors and usability. Ergonomic considerations are integral to meeting regulatory requirements related to device safety, effectiveness, and user satisfaction. Regulatory standards, such as ISO 13485 and IEC 62366, outline specific requirements for incorporating human factors engineering into the design and development of medical devices. By addressing ergonomic considerations in early feasibility studies, developers can demonstrate compliance with these standards and facilitate the regulatory approval process. Moreover, early consideration of ergonomic factors can help mitigate the risk of regulatory delays or rejections due to usability issues or safety concerns. By conducting ergonomic evaluations and usability testing early in the development process, developers can identify and address potential ergonomic risks before submitting regulatory applications. This proactive approach to regulatory compliance enhances the likelihood of obtaining timely approvals and market clearance for medical devices.

Addressing ergonomic requirements early in the development process is essential for meeting customer expectations and market demands. Healthcare providers and end-users increasingly prioritize usability, safety, and user satisfaction when selecting medical devices. By integrating ergonomic considerations into device design from the outset, developers can differentiate their products in the marketplace and gain a competitive advantage. To ensure regulatory compliance, developers employ a variety of methods and tools to assess and address ergonomic considerations. These may include usability testing with representative end-users, ergonomic risk assessments, task analysis, and expert evaluations. By leveraging a combination of qualitative



and quantitative data, developers can demonstrate compliance with regulatory requirements and standards related to human factors engineering.

Improvement

Establishing mechanisms for continuous improvement of ergonomic features is essential for the long-term success of medical devices in clinical practice. While early feasibility studies provide valuable insights into ergonomic considerations, ongoing evaluation and refinement are necessary to address evolving user needs, technological advancements, and regulatory requirements. Continuous improvement involves systematically collecting feedback from end-users, monitoring device performance in real-world settings, and implementing design modifications based on this feedback. By maintaining open channels of communication with end-users, developers can identify emerging ergonomic issues, user preferences, and opportunities for enhancement. Moreover, continuous improvement fosters a culture of innovation and adaptability, encouraging developers to explore new technologies, methodologies, and design approaches to optimize device usability and safety. By embracing a mindset of continuous learning and improvement, developers can stay ahead of the curve and anticipate future ergonomic challenges and opportunities.

Continuous improvement supports regulatory compliance by demonstrating a commitment to monitoring and addressing ergonomic concerns throughout the device lifecycle. Regulatory bodies expect manufacturers to implement post-market surveillance programs to monitor device performance and address safety issues promptly. By incorporating continuous improvement processes into post-market surveillance activities, developers can ensure ongoing compliance with regulatory requirements and standards. To facilitate continuous improvement of ergonomic features, developers leverage a variety of tools and methodologies, including user feedback surveys, usability testing, post-market surveillance, and quality management systems. These tools enable developers to systematically collect, analyze, and act on feedback from end-users and other stakeholders, driving iterative improvements to device design and performance [10].

Conclusion:

In conclusion, ergonomics considerations are crucial for the success of medical devices, particularly in the early stages of feasibility studies. This critical review has underscored the importance of integrating ergonomic principles into the design and development process to enhance usability, safety, and user satisfaction. Through interdisciplinary collaboration, iterative design processes, and continuous improvement efforts, developers can address ergonomic challenges comprehensively and effectively. By prioritizing user needs, leveraging diverse expertise, and embracing a culture of innovation and adaptability, developers can create medical devices that meet the highest standards of usability, safety, and effectiveness.

Addressing ergonomic considerations early in the development process is essential for regulatory compliance, market acceptance, and long-term success in clinical practice. By proactively identifying and mitigating ergonomic risks, developers can minimize the likelihood of adverse events, usability issues, and regulatory delays, ultimately improving patient outcomes and driving innovation in healthcare delivery. Moving forward, it is imperative for developers to continue prioritizing ergonomic considerations and integrating them into all stages of medical device development. By embracing a user-centered approach, fostering interdisciplinary collaboration, and committing to continuous improvement, developers can ensure that medical



devices meet the evolving needs of end-users and contribute to improved healthcare delivery worldwide. Ultimately, by prioritizing ergonomics, developers can enhance patient safety, satisfaction, and quality of care, leading to better outcomes for patients and healthcare providers alike.

References

- [1] Bitkina, O. V., Kim, H. K., & Park, J. (2020). Usability and user experience of medical devices: An overview of the current state, analysis methodologies, and future challenges. *International Journal of Industrial Ergonomics*, 76, 102932.
- [2] Wiklund, M. E. (Ed.). (1995). *Medical device and equipment design: Usability engineering and ergonomics*. CRC Press.
- [3] Ganesh, A. (2022). Critical Evaluation of Low Ergonomics Risk Awareness among Early Product Development Stage of the Medical Device Industry. *Industrial Engineering Journal*, 15(12).
- [4] Li, X., Yi, W., Chi, H. L., Wang, X., & Chan, A. P. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in construction*, 86, 150-162.
- [5] Zare, M., Croq, M., Hossein- Arabi, F., Brunet, R., & Roquelaure, Y. (2016). Does ergonomics improve product quality and reduce costs? A review article. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 26(2), 205-223.
- [6] Westgaard, R. H., & Winkel, J. (1996). Guidelines for occupational musculoskeletal load as a basis for intervention: a critical review. *Applied ergonomics*, 27(2), 79-88.
- [7] Privitera, M. B., Evans, M., & Southee, D. (2017). Human factors in the design of medical devices—Approaches to meeting international standards in the European Union and USA. *Applied ergonomics*, 59, 251-263.
- [8] Hägg, G. M. (2003). Corporate initiatives in ergonomics—an introduction. *Applied ergonomics*, 34(1), 3-15.
- [9] Ashween. Ganesh, *Critical Evaluation of Low Ergonomics Risk Awareness among Early Product Development Stage of the Medical Device Industry*, pp. 15, 2022.
- [10] Sun, X., Houssin, R., Renaud, J., & Gardoni, M. (2019). A review of methodologies for integrating human factors and ergonomics in engineering design. *International Journal of Production Research*, 57(15-16), 4961-4976.