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GLOBAL HEALTH 2025

Forward

The Fourteenth International Conference on Global Health Challenges (GLOBAL HEALTH 2025), held between September 28th, 2025, and October 2nd, 2025, in Lisbon, Portugal, continued a series of international events taking a global perspective on population health, from national to cross-country approaches, multiplatform technologies, from drug design to medicine accessibility, including everything under mobile, ubiquitous, and personalized characteristics of new age population.

Recent advances in technology and computational science have influenced a large spectrum of branches in approaching population health. Despite significant progress, many challenges exist, including health informatics, cross-country platforms interoperability, system and laws harmonization, protection of health data, practical solutions, accessibility to health services, and many others. Technological progress, personalized medicine, ambient assistance, and pervasive health, complement patient needs. A combination of classical and information-driven approaches is being developed, where diagnosis systems, data protection mechanisms, remote assistance and hospital processes are converging.

We take here the opportunity to warmly thank all the members of the GLOBAL HEALTH 2025 technical program committee, as well as all the reviewers. The creation of such a high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to GLOBAL HEALTH 2025. We truly believe that, thanks to all these efforts, the final conference program consisted of top-quality contributions. We also thank the members of the GLOBAL HEALTH 2025 organizing committee for their help in handling the logistics of this event.

We hope that GLOBAL HEALTH 2025 was a successful international forum for the exchange of ideas and results between academia and industry for the promotion of progress related to global health challenges.

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Towards Multi-Dimensional Collaborative Governance of Medical Research Integrity in China: A Stakeholder-Centric Strategy

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***Abstract*—Medical research integrity, fundamental to scientific advancement and public trust, confronts acute challenges posed by pervasive misconduct in China. Employing stakeholder theory, this study undertakes a qualitative synthesis to scrutinize the complex interplay of interests and strategic interactions among key actors—researchers, institutions, funders, publishers, and regulatory bodies—within the governance of research integrity, thereby uncovering inherent systemic deficiencies. We subsequently propose a multi-dimensional collaborative governance framework with role differentiation. This framework articulates distinct responsibilities for each stakeholder, designed to foster inter-stakeholder synergy and enforce mutual accountability. It aims to bolster the authenticity and credibility of research outcomes, optimize resource allocation, and ensure the sustainable advancement of medical research in China. The study offers critical theoretical insights and pragmatic strategies for enhancing the efficacy of China's medical research integrity governance system.**

Keywords-medical research; scientific research integrity; stakeholders; collaborative governance; multiple subjects.

I. INTRODUCTION

In recent years, with the rapid development of China's science and technology sector, significant achievements have been made in medical research. However, issues of research integrity have also become increasingly prominent. Research integrity is the cornerstone of scientific innovation and a critical factor in ensuring the healthy development of research activities. Yet, problems, such as data fabrication, plagiarism, and ghostwriting are all too common, severely impacting the international reputation of China's medical research and the healthy development of its research ecosystem. To address these issues, the state and relevant departments have successively issued a series of policy documents aimed at strengthening research integrity, standardizing research practices, and improving research quality. First, the national level places great emphasis on the construction of research integrity. In 2018, the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the "Several Opinions on Further Strengthening Research Integrity Construction," which clearly states the need to establish and improve a research integrity management system, strengthen research integrity education, and strictly investigate acts of research dishonesty. Given the special nature of medical research, relevant departments have also formulated specific policy documents [1]. In 2021, the National Health Commission, the Ministry of Science and Technology, and the National Administration of Traditional Chinese Medicine released the "Code of Conduct for Medical Research Integrity and Related Behaviors," which outlines the integrity requirements for medical researchers in areas, such as study design, data collection, and paper publication [2]. The implementation of these policies has provided strong institutional support for the construction of medical research integrity. While China has established a robust policy framework, the actual effectiveness and uniformity of implementation at the grassroots level still require further critical evaluation and optimization.

The development of medical research not only relies on support from funding, technology, and talent but also requires the improvement of a scientific integrity management system and the coordination of multiple stakeholders to optimize resource allocation, enhance the authenticity of results, and boost public trust. In the context of deepening reforms in the science and technology system, establishing a comprehensive management mechanism and a robust scientific integrity system has become a crucial issue for promoting high-quality development in medical science and technology. This study aims to analyze the multi-stakeholder dynamic in medical research integrity management based on stakeholder theory, and to construct a collaborative management approach to ensure the credibility and sustainable development of medical research in China. Stakeholder theory is particularly suitable for this analysis due to its focus on the diverse interests and influences of various groups, which often conflict. While institutional theory might focus more on formal rules and principal-agent models on contractual relationships, stakeholder theory provides a broader lens to understand the complex web of interactions and power dynamics.

The remainder of the paper is organized as follows: In Section II, we discuss the background and significance of research integrity in medical research. Section III presents the methodology used in this study. In Section IV, we analyze the multi-stakeholder game dynamics and propose a collaborative management approach. Finally, Section V concludes the paper and provides future research directions.

II. Theoretical Basis

A. Definition of medical research integrity

Medical research integrity is the core ethical principle in medical research activities, encompassing the authenticity, objectivity, and ethical compliance of research practices. The *Code of Ethics for Medical Research Integrity and Related Conduct* defines medical research behavior as involving all aspects of the process from project application, implementation, data reporting, publication of results, to evaluation and acceptance, across fields, such as basic medicine, clinical medicine, preventive medicine, pharmacy, and traditional Chinese medicine. The U.S. Federal Policy on Research Misconduct, enacted in 2000, defines "research misconduct" as: fabrication, falsification, or plagiarism in project planning, performance, or project review, or in the reporting of research results [3]. These unethical behaviors not only undermine the credibility of research outcomes but can also pose direct threats to patient health and public safety [4]. For example, the 2018 "heart stem cell research fraud incident," which led to data fabrication causing a halt in the field's research, highlighted the profound negative impact of integrity issues on medical progress. In recent years, the use of generative artificial intelligence in paper writing has become a new challenge to integrity. At the same time, the unique nature of the medical field further complicates research integrity: Firstly, the current research evaluation system's excessive reliance on the number of papers and impact factors (i.e., the "SCI supremacy" orientation) [4] can easily lead researchers to prioritize short-term results over rigor; Secondly, medical research directly involves human life and health, requiring strict adherence to ethical review and participant protection principles (such as informed consent and privacy confidentiality). However, the lack of transparency in experimental data and the difficulty in verifying reproducibility make it hard to promptly identify errors or biases [5]. Therefore, medical research integrity is not only an issue of academic standards but also an ethical responsibility concerning social trust and public health.

B. Stakeholder theory

Stakeholder Theory originated in the field of business management in the 1960s, emphasizing that organizational decisions must balance the demands and impacts of multiple stakeholders. This theory was later introduced into public health management and research integrity, becoming a systematic tool for analyzing complex social issues [6]. Globally, stakeholder theory has been applied to biomedical governance to understand and manage conflicts of interest, ethical concerns, and resource allocation in research. In medical research integrity management, the stakeholder analysis framework includes the following steps: identifying stakeholders, which involves defining individuals or groups directly or indirectly affected by research activities, such as researchers, research institutions, funders, journal publishers, regulatory bodies, and the public; analyzing influence and interests, assessing the power levels, interest claims, and potential conflicts of each party in research activities, for example, funders may influence the objectivity of research conclusions through funding [7]; categorizing management strategies, dividing stakeholders into supportive, marginal, mixed, or non-supportive based on their cooperation and threat levels, to develop differentiated coordination mechanisms; formulating participation strategies, promoting multi-party collaboration through institutional design, such as establishing joint regulatory committees or open science platforms, balancing academic freedom with social responsibility [8].

III. Research Status

In recent years, China has significantly improved its policy and legal framework for managing medical research integrity. The introduction of multiple regulations and guiding documents reflects the country's high regard for research ethics. In 2021, the National Health Commission, in conjunction with the Ministry of Science and Technology and the National Administration of Traditional Chinese Medicine, revised and released the *Code of Ethics and Related Conduct in Medical Research*, which outlines ethical requirements throughout the entire process of medical research, including project application, research implementation, data management, and publication of results. It downplays the role of paper quantity and impact factors in evaluations while emphasizing integrity education and professional training [2]. In the same year, the General Office of the State Council issued the *Guidance on Improving the Evaluation Mechanism for Scientific and Technological Achievements*, further proposing to establish a robust system for managing research integrity and improve the reward and punishment mechanism linking achievement evaluation to integrity, aiming to curb academic misconduct at its source [9]. Additionally, the *Several Opinions on Further Strengthening Research Integrity Construction* issued by the Central Committee of the Communist Party of China and the General Office of the State Council in 2018 provided top-level design for medical research integrity, requiring the establishment of research integrity files, the implementation of lifelong accountability, and clear joint disciplinary measures for research misconduct [1]. The *Handbook of Research Integrity Standards* released by the Ministry of Science and Technology in 2023 further detailed the behavioral guidelines for researchers, reviewers, and management institutions, covering aspects such as topic selection, project application, and data usage, providing practical guidance for managing research integrity [10]. The intensive introduction of these policies shows that China is building a medical research integrity management system through multi-level and multi-dimensional institutional design.

However, despite these comprehensive policy initiatives, critical analysis suggests that challenges persist in the effective implementation and enforcement of these regulations. There may be gaps between the aspirational policy goals and the realities of practice at the institutional and individual researcher levels. Factors, such as insufficient resources for oversight, varying interpretations of guidelines, and entrenched academic culture focused on output metrics, could impede full

compliance. Furthermore, the absence of publicly available empirical validation or comprehensive impact assessments of these policies limits the strength of conclusions regarding their overall effectiveness, highlighting a need for more data-driven evaluation.

The systematic exploration of medical research integrity management by the international community began at the end of the 20th century. Developed countries, represented by the United States and the European Union, established relatively comprehensive governance frameworks through policies, regulations, and institutional development. The National Institutes of Health (NIH) in the U.S. was the first to propose *Responsible Research Practices* in 1989 and further introduced the Data Management and Sharing Policy in 2020, which clearly outlines data management, conflict of interest disclosure, and procedures for investigating misconduct. Its Office of Research Integrity (ORI) significantly enhances the credibility of biomedical research through independent oversight and educational training mechanisms, mandating that researchers publicly disclose raw data and analytical methods, and reinforcing the reproducibility of research findings [11]. The EU promotes cross-border collaboration through standardized policies; the revised European Code of Conduct for Research Integrity in 2023 provides uniform ethical review standards for member states and emphasizes the role of open science (Open Science) in enhancing transparency, such as requiring clinical trial data to be registered on public platforms and made accessible [12]. Australia, through its Responsible Research Conduct Code published in 2018, clarifies the responsibilities of research institutions, requiring them to develop internal policies to address misconduct and stipulating that compliance with these norms is a prerequisite for securing funding from the National Health and Medical Research Commission (NHMRC) [13]. These policies and regulations not only regulate research behavior through legal and institutional constraints but also focus on enhancing researchers' integrity awareness through education and cultural development. However, with the deepening of international cooperation, the coordinated governance of transnational research misconduct still faces challenges of legal application and jurisdictional conflicts.

IV. Management Challenges from the Perspective of Stakeholders

A. Classification and role of stakeholders

Medical research integrity management involves multiple stakeholders, whose roles are complex and multidimensional. The roles and functions of these stakeholders vary significantly based on their depth of involvement and influence. According to their functional positioning in research activities, they can be categorized into core stakeholders, secondary stakeholders, and external stakeholders.

Core stakeholders include researchers, research institutions, and ethics committees. Researchers, as the direct executors of scientific activities, have professional ethics and data authenticity as the foundation of integrity management. However, under the evaluation orientation of "SCI supremacy," researchers may overlook research rigor, leading to data fabrication or plagiarism [4]. Research institutions bear the responsibility for institutional design and internal supervision, and must establish an integrity management system through formulating ethical guidelines, improving review mechanisms, and establishing reward and punishment systems. Ethics committees, as independent supervisory bodies, must ensure that research complies with ethical standards, especially in clinical trials involving human subjects, where strict scrutiny of informed consent procedures and privacy protection measures is crucial [14]. In China, ethics committees play a critical role similar to IRBs in the US, ensuring that human subject research is conducted ethically and responsibly.

Secondary stakeholders include funders and publishing institutions. Funders influence research direction through funding allocation, but their potential intervention in research outcomes can lead to conflicts of interest, such as selective data disclosure required by commercial interests for corporate-funded clinical trials [7]. Publishing institutions, as the core channels for disseminating scientific research, must maintain academic credibility through rigorous peer review and data transparency requirements. However, some journals may lower their standards for reviewing high-risk studies to boost impact [15].

External stakeholders include policymakers and the public and media. Policymakers establish institutional frameworks through laws and regulations, but insufficient cross-departmental collaboration can lead to regulatory fragmentation. The public and media promote research transparency through public opinion pressure, yet their excessive focus on "breakthrough results" may exacerbate a short-sighted research orientation [16]. Ambiguous boundaries of authority and lack of coordination mechanisms result in regulatory blind spots, such as formalistic ethical reviews and lagging cross-departmental data sharing, highlighting the urgency of categorized management and collaborative governance [14][17].

B. Stakeholder interest demands and interplay

In the management of medical research integrity, games usually occur among different stakeholders. These games are originated from the differences in roles, responsibilities and interests of all parties in scientific research activities. By analyzing these game relationships, we can better understand the contradictions in the management of scientific research integrity and put forward coordination strategies. Building trust in these interactions is crucial; it involves transparent communication, adherence to agreed-upon norms, and consistent demonstration of ethical conduct by all parties, whereas breaches of trust can severely erode collaboration and legitimacy.

1) The game between researchers and researchers: The game among researchers focuses on the distribution of academic contributions, authorship rights, and the use of research resources. In team studies, the attribution of the first author and corresponding author often becomes a point of contention. Some core contributors may feel they have not received their due recognition, leading to internal divisions within the team

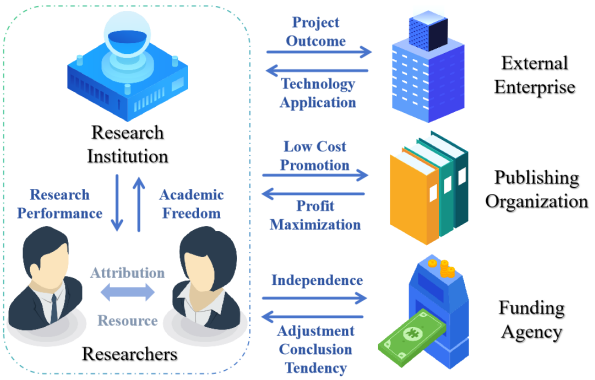

Figure 1. Game of stakeholders in "medical research integrity."

and even hindering research progress [4]. From a game theory perspective, this authorship conflict can be seen as a "zero-sum game," where one party's gain in terms of author order may mean a loss for the other.

2) The game between researchers and research institutions: The game between researchers and research institutions is also very significant. For example, researchers hope to maintain academic freedom and research independence, while research institutions focus more on overall research performance and the efficiency of resource allocation. Research institutions evaluate researchers based on the number of papers or funding indicators. This performance-oriented approach may lead researchers to prioritize short-term results at the expense of research integrity, such as data fabrication or exaggeration of research findings.

3) The game between researchers and funding agencies: Similarly, there is a game between researchers and funding agencies. Corporate or commercial sponsors may exert financial pressure, demanding that researchers selectively disclose data or adjust their conclusions to favor certain outcomes. For instance, if the results of clinical trials funded by pharmaceutical companies fall short of expectations, they might demand the concealment of negative data to protect business interests. Studies show that the policy orientation of funding agencies directly influences the design and implementation of research projects. For example, the National Natural Science Foundation constrains research misconduct through a reputation supervision mechanism, indirectly shaping the strategic choices of researchers. The optimization of this game relationship depends on communication and compromise in rule-making [18].

4) The game between scientific research institutions and publishing institutions: The game between research institutions and publishing houses is also reflected in the conflict between economic interests and scientific integrity. Research institutions strive to promote the widespread dissemination of their findings to enhance academic influence and social benefits, often preferring to place these results in the public domain or share them through low-cost channels. In contrast, publishing houses pursue maximum profit through strict copyright control and high subscription fees, treating academic achievements as tradable commodities. This difference in objectives leads to ongoing negotiations between the two parties on publishing models, fee structures, and accessibility of outcomes [19]. For example, the University of California engaged in a two-year negotiation with the publishing giant Elsevier over an open access agreement, which ultimately broke down due to conflicting interests [20].

5) Multi-party game: In the ecosystem of scientific research, complex interactions often occur among multiple parties including researchers, research institutions, funding agencies, and external partner companies. In cross-institutional research projects, researchers strive for personal academic achievements, research institutions focus on the overall impact of project outcomes, funding agencies emphasize the efficiency of fund utilization, while partner companies may prioritize economic returns from technology application. This multi-party dynamic relationship requires all parties to negotiate and compromise to form a balanced strategy, thereby maximizing overall benefits [16].

V. Conclusion

A. Government: Policy guidance and institutional guarantee

The government holds a central position in the top-level design and institutional supply of medical research integrity management. Through the formulation and enforcement of policies and regulations, it systematically standardizes research behavior and coordinates the responsibility boundaries of multiple stakeholders. In recent years, China has issued the "Several Opinions on Further Strengthening Research Integrity Construction" [1] and the "Code of Conduct for Medical Research Integrity and Related Behaviors" [2], establishing a system framework that includes penalties for dishonesty, data supervision, and ethical review. Specific measures include improving the legal system, establishing a tiered and categorized research integrity archive system, linking research misconduct to the social credit system, and strengthening joint punishment mechanisms, such as lifelong accountability for those responsible for data fabrication and plagiarism, and restrictions on their participation in project applications and evaluations; cross-departmental collaborative governance, integrating regulatory functions from the Ministry of Science and Technology, the National Health Commission, and the Ministry of Education, promoting data sharing and joint law enforcement to avoid fragmented regulation [17], while encouraging third-party independent institutions to participate in project assessments to enhance the objectivity of supervision [4]; reform of evaluation mechanisms, abandoning the "paper-only" orientation, and establishing evaluation standards centered on innovation quality, social value, and reproducibility, such as adding data traceability and repeated experimental validation steps in project acceptance to ensure the authenticity of results [7]; international cooperation and benchmarking, drawing on the research integrity policy framework of the National Institutes of Health (NIH) [11] and the EU's "European Code of Conduct for Research Integrity" [12], to improve the international standards of China's research integrity governance and enhance global academic discourse power.

B. Publishing institutions: Academic gatekeeping and transparency practices

Publishing institutions, as the core carriers of scientific research dissemination, need to maintain credibility through rigorous academic review and open science practices. This includes strengthening peer review mechanisms, implementing double-blind reviews, data transparency reviews, and dynamic peer evaluations to minimize conflicts of interest that could interfere with the fairness of the review process [15]. For example, requiring authors to submit raw data, experimental codes, and ethical review documents for experts to verify the reproducibility of their research; establishing early warning and correction systems to implement tiered alerts for journals with high rates of rejections or papers suspected of academic misconduct, and improving accountability mechanisms after rejections, promoting "post-publication peer review" (Post-Publication Peer Review), and encouraging continuous monitoring and revision of published results within the academic community [21]; advancing open science by supporting the widespread use of open access (Open Access), preprint platforms, and public databases (such as ClinicalTrials.gov), mandating the registration and publication of clinical trial data to avoid selective reporting risks; and standardizing AIGC usage by clearly defining the boundaries of AI-generated content in scientific writing, requiring authors to disclose the scope and specific functions of AIGC tools, and prohibiting their use to generate research conclusions, manipulate data, or fabricate experimental results [22].

C. Scientific research institutions: Internal governance and cultural ecology construction

Research institutions are the primary responsible entities for managing research integrity, and they need to build a sustainable integrity ecosystem through institutional constraints and ethical culture cultivation. Specific approaches include establishing an institutional management system, formulating detailed norms for research behavior, clarifying procedures for data management, authorship rights allocation, and conflict of interest disclosure, such as requiring researchers to sign integrity commitment letters during project initiation and regularly submitting original records of research progress; strengthening the ethics review mechanism, enhancing the independence and professionalism of ethics committees, involving external experts in high-risk research ethics reviews, and establishing a public disclosure mechanism for review results to prevent administrative interference [14]; strictly enforcing informed consent and privacy protection clauses for studies involving human subjects [5]; making education and training routine, integrating research integrity education into graduate student programs and continuing education systems for researchers, improving ethical awareness through case studies and simulated ethics reviews, for example, conducting specialized training on issues like data fabrication and improper image processing [23]; balancing incentives and penalties, incorporating integrity performance into core indicators for title promotion, funding allocation, and team excellence evaluations, providing resource support to rigorous scholars, while imposing internal notifications, project termination, and suspension of academic positions on those who violate trustworthiness.

D. Scientific research personnel: Professional self-discipline and responsibility practice

Researchers, as the direct implementers of scientific activities, have professional ethics and ethical awareness that form the foundation of integrity management. The implementation path includes strictly adhering to academic norms, following ethical guidelines throughout the research process from design, data collection to paper writing, and preventing data manipulation, plagiarism, and multiple submissions [4]. Using Electronic Laboratory Notebook (ELN) systems to record the entire research process ensures data integrity and traceability; proactively disclosing conflicts of interest, fully disclosing economic relationships with funding sources and enterprises during paper submission, project application, and technology transfer to avoid biased research conclusions [7], such as requiring corresponding authors to declare whether they serve as corporate advisors or hold relevant patents; socially responsible research, prioritizing social value and safety alongside academic output, for example, strictly adhering to the principles of the Declaration of Helsinki in clinical trials to protect participants' rights [5]; participating in the co-construction of an integrity ecosystem, actively reporting academic misconduct, supporting open data sharing and international cooperation, and promoting a "bottom-up" network of scientific integrity supervision.

This study utilized stakeholder theory to analyze the complex interactions within China's medical research integrity ecosystem and proposed a multi-dimensional collaborative governance framework. The framework aims to enhance accountability, foster synergy among stakeholders, and improve the credibility and sustainability of medical research by clearly articulating the roles and responsibilities of the government, publishing institutions, research institutions, and individual researchers. While the proposed framework offers a normative guide for improving research integrity, its effectiveness relies on robust implementation, continuous evaluation, and the ability to adapt to evolving challenges. Future research should focus on empirical studies to validate the framework's components, assess policy implementation gaps, and develop concrete tools for resolving conflicts of interest and building trust among stakeholders. Further quantitative evidence on misconduct prevalence and the impact of existing policies in China would provide invaluable insights for refining these strategies.

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Comparative Healthcare Delivery Models: Insights from the United States and Ghana

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***Abstract*— Comparing healthcare delivery systems across countries provides opportunities to identify best practices, highlight systemic challenges, and promote cross-national learning. This study evaluates healthcare delivery in Ghana and the United States through a mixed-methods comparative framework. We assess infrastructure capacity, financing mechanisms, accessibility, and health outcomes. Findings demonstrate similarities in shared health goals and reliance on mixed public-private systems, yet reveal profound differences in resource allocation, disease burden, and care affordability. Lessons learned provide actionable pathways for strengthening equity, efficiency, and resilience in both settings.**

Keywords- healthcare delivery; Ghana; United States; comparative analysis; health systems.

I. INTRODUCTION

Healthcare systems globally face mounting pressure to deliver equitable, affordable, and high-quality care [1]. Comparative studies of different systems shed light on effective strategies while identifying areas for reform [2]. Ghana and the United States, despite differences in socioeconomic context and resource levels, share the overarching goals of improving population health and reducing disparities. Ghana's healthcare model reflects ongoing transitions from managing infectious diseases to addressing an increasing burden of Non-Communicable Diseases (NCDs) [3]. Meanwhile, the United States grapples with high expenditures and persistent inequities despite advanced infrastructure and technology [4]. This paper builds on a U.S.–Ghana institutional collaboration to examine structural, financial, and health outcome differences between the two countries.

The rest of the paper is structured as follows. Section II presents the methods used while Section III described the findings. In Section IV, we discuss the implications of the findings, and conclude the work in Section V.

II. METHODS

This study employed a rigorous mixed-methods approach to capture the complexity of healthcare systems in Ghana and the United States, recognizing that both quantitative metrics and contextual insights are essential for meaningful cross-national comparisons. Quantitative analyses utilized secondary data from authoritative sources such as the World Bank [5], the World Health Organization [6], and national health system reports to examine key indicators, including physician density, healthcare expenditure as a percentage of GDP, insurance coverage rates, life expectancy, disease prevalence, and system financing models [7][8][9]. These measures provided objective benchmarks to compare resource allocation, population health outcomes, and system performance across countries. To complement this, a qualitative review of peer-reviewed literature explored healthcare access, workforce distribution, and health equity, offering a deeper understanding of structural, social, and cultural factors that influence care delivery but are not easily captured by numerical data. Additionally, semi-structured interviews with key stakeholders from the University of Houston College of Medicine and the University of Ghana Medical School provided real-world perspectives on operational challenges, policy priorities, and opportunities for adaptation of best practices. By integrating quantitative and qualitative evidence, this mixed-methods approach allowed for a nuanced synthesis of converging trends and critical divergences, highlighting how systemic, economic, and sociocultural factors interact to shape healthcare delivery and outcomes in each context. The combination of data-driven analysis and stakeholder insights strengthens the validity of the findings, providing a robust foundation for actionable recommendations in both countries.

III. FINDINGS

Both Ghana and the U.S. rely on hybrid systems blending public and private healthcare provision and insurance-based financing. However, critical differences emerged, as shown in Table I.

TABLE I. COMPARISON OF GHANIAN AND AMERICAN HEALTHCARE METRICS

Indicator	*Ghana*	*United States*	*Notes/Implications*
Healthcare Expenditure [% of GDP]	3.5%	17.8%	U.S. spends ~5x more of GDP on healthcare; Ghana faces resource constraints.
Per Capita Healthcare Spending	~$140	>$12,000	Huge gap in affordability and access to advanced technology.
Physician Density [per 1,000 people]	0.18	2.6	Severe shortage of healthcare professionals in Ghana.

Indicator	*Ghana*	*United States*	*Notes/Implications*
Insurance Coverage	~40% National Health Insurance Scheme (NHIS)	~90.4% covered [9.6% uninsured]	Many Ghanaians lack financial protection for care.
Life Expectancy	64 years	77 years	Reflects differences in disease burden and healthcare access.
Infant Mortality Rate	35 per 1,000 live births	5.4 per 1,000 live births	Indicates maternal and child health disparities.
Disease Burden	Infectious + rising NCDs [40% deaths]	Predominantly chronic diseases: heart disease [695k deaths], cancer [609k deaths], obesity [42.4%]	Double burden in Ghana; U.S. faces lifestyle-related NCDs.
Hospital Beds [per 1,000 people]	0.9	2.8	Limited inpatient capacity in Ghana.
Physician-to-Nurse Ratio	1:3	1:4	Slightly lower nursing capacity in Ghana.
Access to Essential Medicines	Limited	High	Affordability and supply chain challenges in Ghana.
Healthcare Infrastructure	Urban concen-tration, rural gaps	Widespread, advanced	Rural areas in Ghana underserved; U.S. has advanced tech broadly.

IV. DISCUSSION

This comparative study highlights how context-specific challenges shape healthcare delivery and offers important lessons for both Ghana and the United States. In Ghana, the dual burden of infectious diseases and rising NCDs creates complex demands on an already resource-constrained health system [3]. Lessons from the U.S., a high-resource setting with extensive experience in chronic disease management, can guide Ghana in developing strategies for prevention, early screening, and effective long-term management of NCDs. Adapting these strategies to local contexts—such as integrating community health workers, leveraging mobile health technologies, and implementing population-level screening programs—can help mitigate the rising burden of chronic diseases [10]. Additionally, expanding medical and allied health training programs, creating structured workforce pipelines, and incentivizing practice in underserved regions are essential for addressing the country's severe physician and nurse shortages.

Conversely, the U.S. can benefit from Ghana's emphasis on community-based, cost-effective approaches to healthcare delivery. Programs like Ghana's National Health Insurance Scheme [NHIS] demonstrate progress toward universal health coverage, particularly in providing financial protection to populations that might otherwise face catastrophic health expenditures. Such models illustrate how high-resource systems can incorporate grassroots-level strategies to improve affordability, equity, and accessibility, especially for vulnerable populations who may encounter barriers to care despite technological and infrastructural advantages. Furthermore, Ghana's focus on preventive care and primary health interventions offers insights into reducing healthcare costs while improving population health outcomes—lessons that could be applied to U.S. efforts in value-based care and health equity initiatives [11].

Despite differences in resources, infrastructure, and epidemiological profiles, both healthcare systems face shared challenges. Inequitable distribution of care between rural and urban regions persists in both countries, contributing to disparities in health outcomes [12][13]. Rising rates of NCDs, coupled with the need to maintain sustainable financing mechanisms, further complicate the delivery of effective healthcare. By examining these commonalities and divergences, this comparative analysis underscores the potential for cross-country learning, where lessons from one system can inform innovations and reforms in the other. Ultimately, a nuanced understanding of context-specific challenges paired with adaptive strategies can enhance the capacity of both Ghana and the U.S. to provide equitable, efficient, and high-quality care for their populations.

V. CONCLUSION

To translate these insights into practice, both countries can consider targeted policy and implementation strategies. In Ghana, this could include scaling up community health worker programs, integrating chronic disease management into primary care, and investing in workforce development initiatives to address provider shortages. In the U.S., adopting more community-centered, cost-conscious interventions—such as expanding preventive care outreach and exploring innovative insurance models inspired by Ghana's NHIS—could improve equity and reduce unnecessary expenditures. Collaborative exchanges, research partnerships, and cross-country learning initiatives can further strengthen both systems, fostering adaptable solutions that respond to local needs while addressing shared healthcare challenges.

Cross-national learning between Ghana and the United States underscores the importance of adaptable, resilient, and people-centered healthcare models. While differences in resource allocation remain stark, opportunities exist for both countries to strengthen care delivery by adopting innovative practices from each other. International collaborations between medical institutions play a critical role in advancing shared learning and improving global health outcomes.

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Global Surgery Course

Evaluation of Course Outcomes and Future Course Planning

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Abstract — **Having enough trained surgical personnel to perform emergency surgeries in rural areas continues to remain a significant problem for low- and middle-income countries in Asia. Hence, we designed and conducted a cross disciplinary global surgery course in November 2024 with the aim of training surgical trainees and surgeons operating in rural areas to gain confidence in performing emergency essential surgical procedures. Through our pre and post course questionnaire, we have found that the course helped increased participant confidence levels in performing various emergency surgical procedures covered during the course and all participants felt that they would recommend the course to their colleagues. Although there are challenges in defining the scope of a global surgery course and implementing appropriate assessment measures to evaluate participants, this course shows promise as means to train and upskill surgeons operating in rural areas in the region.**

Keywords- Global surgery; Rural surgery; Surgical training in Asia.

I. INTRODUCTION

Access to healthcare, and in particular surgical care, remains a significant problem in Low- and Middle-Income Countries (LMICs) and rural areas in Asia. While the reasons for inequity to essential surgical care are multifactorial, one of the major issues identified in the Lancet commission for Global Surgery 2030 was the insufficient number of surgically trained personnel and their concentration in urban areas [1][2]. The other issues that were identified included the lack of continuous training and supervision in peripheral surgical units, the need for cross-specialty knowledge, and working with limited resources [1].

While training a surgical workforce and building healthcare systems capacity requires interventions at different levels, there was a strong focus on education and training in the World Health Organisation (WHO) Global strategy on Human Health Resources: Workforce 2030 [3]. The idea of having a short course to equip surgeons with skills required in the rural environment is not new but it is rarely conducted as a structured regular course with the frequency and intensity required to sufficiently train rural surgeons in LMICs. From literature, these are often organized by High Income Countries (HICs) for LMICs. Training competencies are often decided by HICs with limited input from LMICs [4]. In addition, there was a paucity of data on programs in Asia.

Hence, our aim is to develop a multidisciplinary global surgery course that would help surgeons operating in rural areas in Asia to gain confidence in performing essential emergency surgical procedures. The secondary aim is to collaborate with participants and gradually refine and adapt the course for countries in the region. After several cycles of the course to solidify the course structure and teaching methods, our long-term goal is to be able to train surgeons in LMICs to replicate and conduct the course themselves in their home countries. This would help ensure sustainability of the course and benefit more participants by increasing access to the teachings.

We organised and conducted the first "Surgery In Rural and Austere Environments Course" (SIRAEC) over 4 days in November 2024 in the Singapore General Hospital Academia (which has a wet skills lab) for 54 participants from neighbouring countries as well as local Singaporean participants.

The focus of the course was on building up cross disciplinary surgical knowledge and providing a hands-on cadaveric practical session to develop participants' surgical skills. Apart from the knowledge component of the course, we also recognised that experiential knowledge can be equally valuable, and time was dedicated for sharing of experiences such as the structure of surgical training programs in the region and challenges that participants faced in their own communities. Guest speakers also shared their own experiences on humanitarian missions with inspiring and humbling stories as well as solutions to shortages in manpower and equipment.

Given the significant costs of training programs including travel, accommodation and course fees, we sponsored participants from LMICs attending the course to reduce barriers to access and improve participation from regional surgeons. Funding was sourced from private donations.

The rest of this paper is organized as follows. Section II describes the course design and evaluation. Section III addresses the analysis of the course evaluation. Section IV discusses some of the limitations of the course design and evaluation. Section V gives a brief conclusion and mentions future work that we are doing. The acknowledgement section closes the article.

II. METHOD - COURSE DESIGN AND EVALUATION

The initial core course design was based upon the three Bellwether procedures – emergency caesarean section, emergency laparotomy, and management of long bone

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fractures [1]. Consultant doctors from various specialties in Singapore including general surgery, obstetrics and gynaecology, urology, orthopaedic surgery, plastic surgery, paediatric surgery, and anaesthesia were invited to volunteer to teach in the course. Additional procedures relevant to each subspeciality were then added after a literature search to review other similar emergency rural surgical courses and discussions with team leads from each speciality. Each speciality team also designed their own course material on core conditions and procedures relevant to a rural environment.

We started each speciality training module with didactic lectures followed by a practical session. We utilised simulation models for some of the teachings such as the anaesthesia segment (e.g. intubation, spinal anaesthesia, emergency cricothyroidotomy). The hands-on practical sessions for the surgical specialities (e.g. cholecystectomy, bowel repair/resection, perforated ulcer repair, hysterectomy, etc.) were conducted as cadaveric dissection supervised by consultant specialist volunteers both from Singapore and the region.

Prior to the start of the course, participants were given a pre course questionnaire to determine their level of experience in performing common procedures that were to be taught during the course. This questionnaire was then repeated after the course to evaluate the impact of the course in improving confidence levels with performing various procedures. Participants were also surveyed after the course on their level of satisfaction with the course using open ended questions in the questionnaire to assess the strengths and weaknesses of the course. Finally, participants were also asked about procedures that they would like to have covered or felt were unnecessary to determine how we could refine the course curriculum. The results of the pre and post questionnaires are compared in the next section.

III. RESULTS – ANALYSIS OF COURSE EVALUATION

A. Course demographics

54 participants responded to the questionnaire (described in the previous section) that was administered just before the start of the first lectures and after the entire course had ended. Of these 54 participants, 73% worked in tertiary referral centres, 17% worked in secondary centres, 6% worked in primary healthcare settings and 4% worked in remote medical posts.

48% were specialists or board-certified surgeons, 33% were surgical trainees, 19% were not from the above two categories, and consisted of anaesthesiologists, emergency medicine physicians, obstetrics and gynaecology trainees.

Participants had varying familiarity with the procedures taught. The only procedures which more than half of respondents indicated they performed regularly were soft tissue debridement, vacuum dressing application, chest drain insertion, inguinal hernia repair, and cholecystectomy.

B. Course satisfaction

Participants reported high satisfaction with the SIRAEC with all participants indicating that they "Agree" or "Strongly agree" that they would recommend the course to their colleagues. There was broad satisfaction for the course resources, instructors' knowledge, course organisation and support equipment as well.

C. Procedure confidence

There was a universal increase in percentages of participants indicating they "Strongly agree" or "Agree" that they were more confident in performing the procedures post course. Notably, for procedures which more than half of participants indicated that they performed regularly, there was also an increase in confidence performing them. For instance, the proportion of "Strongly agree" and "Agree" respondents increased from 62% to 83% for soft tissue debridement, 52% to 79% for vacuum assisted dressing, 63% to 88% for chest drain insertion and 57% to 83% for hernia repair.

D. Strengths and weaknesses

When surveyed on the strengths of the course, a large proportion of participants (n = 18) reported the importance of hands-on training contributing to their satisfaction of the course. Having knowledgeable instructors was widely seen as a strength (n = 11). Other themes include good organisation (n = 9), good quality information transfer (n = 8), the collaborative nature of the course i.e. interdisciplinary, multi-national (n = 4), and opportunities for networking (n = 3). Some participants also responded with praise of specific topics, notably component separation (n = 3).

When surveyed on the weakness of the course, there were considerable opinions reported pertaining to the course length and time allocation (n = 11), with seven respondents indicating they would prefer longer practical sessions, four respondents indicating they would prefer shorter theory sessions, three respondents indicating they would prefer the course duration to be longer and one respondent indicating he/she would prefer the course duration to be shorter. Four participants responded that the sessions were too packed, resulting in difficulty focusing.

Some participants also provided feedback pertaining to the theory sessions (n = 3) with one respondent suggesting it should be more practical, one suggesting it should be more focused, and one suggesting it should be more discussion based. Three participants also suggested a greater focus on austere techniques and how they could be practiced in the rural environment. With regards to the learning material, one participant suggested sharing the resources via online platforms beforehand to allow better learning. Seven participants also gave comments with regards to weaknesses in specific skills taught, such as the lack of coverage of pericardial window, obstructed hernias and laparoscopic surgery. Five participants reported no weaknesses.

E. Procedures to be covered

When surveyed on which procedures that were not covered that participants would like to have covered, there

was a spectrum of procedures listed. Categorising these responses into broad categories, we identified the following key areas to include or develop further for future courses: procedures for urinary diversion and managing ureteric/bladder injuries (n=12), commonly performed gynaecological procedures and obstetric complications (n=12), trauma surgery (n=9) and bowel resection/repair and stool diversion (n=8).

IV. DISCUSSION AND LIMITATIONS

The training background of participants from different LMICs in Asia is not uniform, so developing a single course for surgeons / surgical trainees from various countries is challenging. For example, the training needs for a participant from Nepal are quite different from that of a participant from Malaysia or even between different parts the same country depending on how often they are involved in rural surgical practice. This may explain the varied feedback regarding the course curriculum.

What we as organisers from an urban country perceive as important may not always match what participants wish to learn. It is important then that we seriously take into consideration the feedback given by our participants to build a course that is relevant to their needs [4][5][6]. However, given limited resources, we need to find a common curriculum within a single course that can address the majority of our participants' diverse training needs.

Additionally, as the course did not incorporate an observed evaluation component, it was difficult to guarantee each participant's degree of competency. The questionnaire focused on self-assessment of competency and satisfaction with the course. However, we were unable to assess their knowledge, learning and behaviours due to the limited time, training materials and manpower.

There were also limitations in the number of course participants and materials as the course funding was external through donations and insufficient to support a larger group.

V. CONCLUSION AND FUTURE WORK

It is only recently that the term global surgery has emerged together with the acknowledgement that surgery is an important part of global health and its scope is still being defined [7]. Additionally, with only about 4.1% of global health research being related to surgery [6] there is a lack of literature and guidance on designing a global surgery training program curriculum. Determining the depth and breadth of content, method of teaching, mode of training assessment and evaluation continues to remain a challenge and will require time (years) to properly develop [5][6].

Although we have managed to achieve our initial aim of conducting a multidisciplinary global surgery course that would help surgeons operating in rural areas in Asia to gain confidence in performing essential emergency surgical procedures, we still have much to do in terms of refining the curriculum, introducing assessment and scaling up.

We are currently in the process of organising our second course and one of the major changes we are making based on the course feedback is that we are shifting a lot of the didactic teaching to online pre-reading material to give more time for hands-on practical during the in-person 4-day course. We also plan to include a short quiz in the pre and post questionnaire as a form of competency assessment.

Additionally, recognising the differences in healthcare systems between countries, we need to conduct an assessment of the surgical training needs of individual countries if we are to eventually adapt the course design and decentralise the teaching. This would help to build a more sustainable training model and also form long-term partnerships with other countries in the region [4][5][6].

Over time, we hope to scale up the course to be conducted more frequently and have other countries in the region host the course to gradually transfer stewardship and ownership of the course to the home countries of participants. However, a large part of this depends on funding, infrastructure and acceptance of the course by countries in the region.

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Impact of the COVID-19 Pandemic on Emergency Care for Severe Non-COVID Patients: A Nationwide Retrospective Analysis by Phase

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***Abstract*—Korea was internationally recognized for its successful infection control strategies and healthcare policies during the COVID-19 pandemic. While these efforts helped limit virus transmission, their indirect impact on emergency care for non-COVID critically ill patients remains uncertain. This study aimed to assess how emergency care delivery for severe non-COVID patients changed across different phases of the pandemic using nationwide data. Among COVID-19 patients, the time from symptom onset to Emergency Department (ED) visit steadily decreased from 46.1 hours in the early phase to 25.1 hours in later waves. In contrast, this interval increased for non-COVID critically ill patients, from 18.4 hours pre-pandemic to 20.2 hours during the fourth wave. ED mortality for COVID-19 patients remained low at approximately 0.1%, whereas it increased for non-COVID severe patients from 5.4% pre-pandemic to 6.6–7.6% across the waves. Intensive Care Unit (ICU) admission for COVID-19 patients peaked at 5.8% during the fourth wave, while it declined to 25.8% among non-COVID severe patients in the same period. Despite Korea's effective pandemic response, emergency care for non-COVID critical patients was negatively affected. The prioritization of resources toward COVID-19 care may have contributed to delays and worse outcomes for other high-acuity patients. Future preparedness strategies must ensure balanced resource allocation to maintain essential emergency services for all patients.**

***Keywords-Emergency Care; Resource Allocation; Severe Non-COVID Patients; COVID-19 Pandemic; Health System Impact*.**

I. INTRODUCTION

Korea was internationally recognized for its effective infection control strategies and health system responsiveness during the COVID-19 pandemic. High testing rates, contact tracing, and centralized coordination helped limit virus transmission and sustain healthcare capacity. Despite a relatively high hospital bed availability—12.8 beds per 1,000 population, well above the Organisation for Economic Co-operation and Development (OECD) average of 4.3 [1]—the healthcare system faced resource strain during peak outbreak periods [2].

To meet growing demand, the Korean government designated COVID-19 hospitals, expanded hospital-level autonomy, and provided substantial financial support. While these measures strengthened the pandemic response, they may have unintentionally burdened Emergency Departments (EDs) responsible for treating both COVID-19 and non-COVID critically ill patients.

Particularly for non-COVID patients requiring urgent care, concerns arose over delayed treatment and adverse outcomes due to resource reallocation. In emergency medicine, timely intervention within the "golden hour" is essential for improving survival and recovery [3][4]. Overwhelmed EDs may have compromised care delivery for non-COVID high-acuity cases.

This study aims to evaluate the impact of the COVID-19 pandemic on emergency care for non-COVID critically ill patients in Korea. Using nationwide retrospective data, we assess clinical indicators across pandemic phases to inform future strategies for maintaining balanced emergency care during public health crises.

The remainder of this paper is organized as follows: Section II details the data sources and methodology; Section III presents the results by pandemic phase; Section IV discusses the policy and clinical implications; and Section V concludes with key findings and recommendations.

II. METHODS

This retrospective study included COVID-19 and severe non-COVID patients who visited Level 1 and 2 EDs in Korea from January 2019 to August 2022, using data from the Korean National Emergency Department Information System (NEDIS).

COVID-19 patients were identified as those diagnosed with COVID-19 in the ED or upon hospital discharge. Severe non-COVID patients were defined as individuals

triaged as Level 1 or 2 according to the Korean Triage and Acuity Scale (KTAS).

We compared three clinical indicators: time from symptom onset to ED arrival, Intensive Care Unit (ICU) admission rate, and ED mortality across six COVID-19 pandemic phases [5]: (1) initial outbreak and regional spread (Jan 2020), (2) August 15 Seoul rally surge (Aug 2020), (3) nationwide variant spread (Nov 2020), (4) Delta wave (Jul 2021), (5) Omicron wave (Jan 2022), and (6) Omicron subvariant spread (Jun-Aug 2022).

Chi-square tests analyzed categorical variables, such as ICU admission and mortality rates, while the Kruskal-Wallis test compared continuous variables, including onset-to-ED arrival time. Statistical significance was defined as $p < 0.05$. This approach allowed assessment of temporal changes in emergency care delivery during different stages of the pandemic.

III. Results

A total of 176,650 COVID-19 patients and 1,317,624 severe non-COVID patients were included in the analysis.

Among COVID-19 patients, the time from symptom onset to ED arrival decreased steadily ($p < 0.0001$), from 46.1 hours during the first wave to 25.1 hours by the sixth wave. In contrast, severe non-COVID patients experienced increased delays in ED arrival, with onset-to-arrival time rising from 18.4 hours in the pre-pandemic period to a peak of 20.2 hours during the fourth wave and remaining elevated at 19.2 hours in the sixth wave ($p < 0.0001$).

ED mortality among COVID-19 patients remained consistently low at approximately 0.1% across all phases of the pandemic. However, for severe non-COVID patients, ED mortality increased significantly—from 5.4% in the pre-pandemic period to a range of 6.6% to 7.6% during the pandemic waves ($p < 0.0001$).

Regarding ICU admissions, the rate among COVID-19 patients peaked at 5.8% during the Delta wave (Wave 4). In contrast, ICU admission rates for severe non-COVID patients declined over time, reaching 25.8% during the same wave.

IV. Discussion

This study revealed a divergent trend in emergency care accessibility during the COVID-19 pandemic: while the time from symptom onset to ED arrival decreased for COVID-19 patients, it increased for severe non-COVID patients, accompanied by a rise in ED mortality. These findings suggest that the pandemic placed a substantial burden on the emergency care system, which may have compromised timely treatment for non-COVID critically ill patients.

The observed decline in ICU admission rates among severe non-COVID patients—coinciding with peaks in ICU admissions for COVID-19 patients—indicates that limited critical care resources may have been disproportionately allocated to COVID-19 cases. This resource concentration will likely reduce access for other high-acuity patients requiring intensive care.

Despite efforts to support emergency care, including limiting non-urgent ED visits and funding dedicated personnel, the majority of governmental policies were still predominantly directed toward managing infectious diseases.

Policies including enhanced health insurance reimbursement for COVID-19 care, infrastructure support for isolation units, and the expansion of telemedicine may have inadvertently contributed to delays in ED visits for non-COVID patients.

Previous studies have demonstrated that delays in emergency care are associated with increased mortality among critically ill patients [6][7][8].

Our findings raise concerns about healthcare equity during pandemics, highlighting the need for a more balanced approach in future emergency preparedness planning. Ensuring equitable access to time-sensitive care for all critically ill patients—regardless of infectious status—should be a key priority in designing resilient health systems.

V. Conclusion

While Korea's COVID-19 response was widely recognized internationally, the concentrated focus on pandemic-related care produced unintended consequences for non-COVID critically ill emergency patients. These included increased emergency department mortality, prolonged arrival times, and reduced intensive care unit admissions. To safeguard all emergency patients during future health crises, policies must ensure balanced resource allocation across patient groups. Further research is warranted to clarify the long-term impacts on emergency care delivery and patient outcomes.

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TABLE 1 CHARACTERISTICS AND EMERGENCY DEPARTMENT OUTCOMES OF COVID-19 AND SEVERE NON-COVID PATIENTS ACROSS PANDEMIC WAVES

		2019yr	Wave						
			First	Second	Third	Fourth	Fifth	Sixth	p-value
COVID-19 patients	Total		9,838 (100.0)	5,794 (100.0)	14,942 (100.0)	18,044 (100.0)	71,310 (100.0)	56,722 (100.0)	
	Sex								<.0001
	Male		5,101 (51.8)	2,877 (49.7)	7,656 (51.2)	9,116 (50.5)	35,297 (49.5)	26,374 (46.5)	
	Female		4,737 (48.2)	2,917 (50.3)	7,286 (48.8)	8,928 (49.5)	36,013 (50.5)	30,348 (53.5)	
	Age, years		48.1±24.6	51.5±23.9	52.7±23.8	51.2±25.1	45.6±29.9	44.9±28.1	<.0001
	Age Groups								<.0001
	0-1		120 (1.2)	68 (1.2)	143 (1.0)	194 (1.1)	2,102 (2.9)	1,544 (2.7)	
	1-14		802 (8.2)	395 (6.8)	1,000 (6.7)	1,685 (9.3)	15,574 (21.8)	10,038 (17.7)	
	15-64		5,921 (60.2)	3,256 (56.2)	8,207 (54.9)	9,489 (52.6)	28,775 (40.4)	27,741 (48.9)	
	65-		2,995 (30.4)	2,075 (35.8)	5,592 (37.4)	6,676 (37.0)	24,859 (34.9)	17,399 (30.7)	
	Onset-to-ED arrival time, hours		46.1±55.3	44.9±54.9	43.1±54.0	43.5±53.4	31.3±44.0	25.1±34.3	<.0001
	ED LOS, hours		7.7±10.8	7.8±10.6	8.3±10.9	9.2±13.1	6.7±10.2	3.9±6.0	<.0001
	ED death		11 (0.1)	6 (0.1)	12 (0.1)	20 (0.1)	67 (0.1)	14 (0.0)	<.0001
	ICD Admission		766 (7.8)	440 (7.6)	676 (4.5)	1,040 (5.8)	2,857 (4.0)	1,351 (2.4)	<.0001
Severe non-COVID patients	Total	390,102 (100.0)	182,383 (100.0)	86,083 (100.0)	234,699 (100.0)	217,099 (100.0)	139,005 (100.0)	68,253 (100.0)	
	Sex								<.0001
	Male	228,721 (58.6)	107,730 (59.1)	51,075 (59.3)	136,305 (58.1)	124,868 (57.5)	80,424 (57.9)	39,640 (58.1)	
	Female	161,381 (41.4)	74,653 (40.9)	35,008 (40.7)	98,394 (41.9)	92,231 (42.5)	58,581 (42.1)	28,613 (41.9)	
	Age, years	57.1±24.9	59.6±22.9	60.0±22.6	59.9±22.8	58.7±23.7	59.8±23.6	59.1±23.9	<.0001
	Age Groups								<.0001
	0-1	17,212 (4.4)	5,682 (3.1)	2,341 (2.7)	6,162 (2.6)	6,236 (2.9)	4,198 (3.0)	2,073 (3.0)	
	1-14	21,217 (5.4)	5,879 (3.2)	2,684 (3.1)	7,911 (3.4)	8,669 (4.0)	5,538 (4.0)	3,197 (4.7)	
	15-64	172,724 (44.3)	82,519 (45.2)	38,722 (45.0)	104,500 (44.5)	98,551 (45.4)	59,228 (42.6)	29,464 (43.2)	
	65-	178,949 (45.9)	88,303 (48.4)	42,336 (49.2)	116,126 (49.5)	103,643 (47.7)	70,041 (50.4)	33,519 (49.1)	
	Onset-to-ED arrival time, hours	18.4±39.0	18.1±38.8	18.4±38.9	19.4±40.1	20.2±40.6	19.3±40.0	19.2±39.7	<.0001
	ED LOS, hours	6.2±8.8	6.4±8.2	6.3±7.8	6.9±8.6	7.2±9.5	8.2±11.1	7.0±9.2	<.0001
	ED death	21,211 (5.4)	12,338 (6.8)	5,978 (6.9)	15,891 (6.8)	14,391 (6.6)	10,628 (7.6)	4,014 (5.9)	<.0001
	ICD Admission	101,084 (25.9)	51,308 (28.1)	24,654 (28.6)	65,539 (27.9)	55,983 (25.8)	35,144 (25.3)	17,998 (26.4)	<.0001

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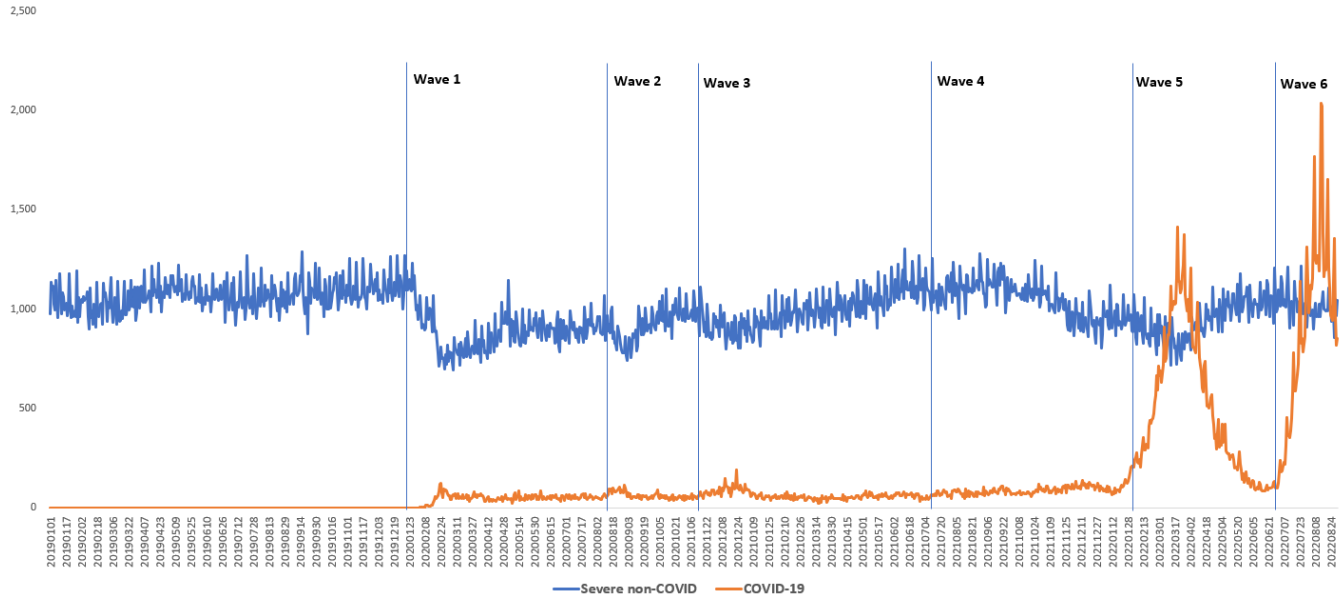

Figure 1 Daily Volume of Emergency Department Visits by COVID-19 Wave Phase (Jan 2019–Aug 2022)

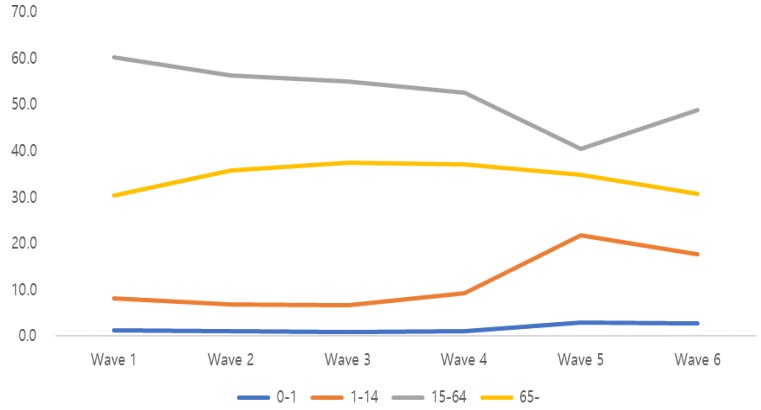

Figure 2 Age Distribution of COVID-19 Patients Acress Pandemic Waves

Segmented Gait Analysis Using Pressure-Sensing Insoles in a Hemiparetic Patient: A Case Study

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***Abstract*—Recent technological advancements in wearable devices equipped with a wide range of sensors have enabled the collection of detailed biomechanical data, offering new possibilities for assessing and supporting rehabilitation in both clinical and everyday settings. However, individuals with unstable health conditions or limited physical activity may find it difficult to directly apply analytical methods developed for healthy individuals. This study investigated gait analysis using smart insoles embedded with pressure sensors in four regions of each sole, totaling eight regions, in an individual undergoing rehabilitation for post-stroke hemiparesis. The patient's gait exhibited distinct characteristics compared to that of healthy individuals. Notable features included fluctuating and inconsistent peak and trough values, irregular peak shapes, variable stride times, marked left–right asymmetry, and the absence of distinct peaks during presumed turning phases. Given these differences, conventional analytical methods were not directly applicable; thus, a new analytical approach was developed. Due to the wide variability in peak amplitudes, applying a uniform threshold for peak detection across the entire dataset was not feasible. Additionally, gait involves steady straight walking and variable-speed phases, such as turning, stepping over obstacles, stopping, and swaying—phases that are particularly challenging for individuals with gait impairments. Analyzing the entire walking period under uniform conditions may obscure important gait characteristics. Based on 1.1 times the mode of the stride time, smart insole data were segmented to distinguish between straight and irregular walking phases, followed by the calculation of mean, peak, and post-peak decline values. This approach enabled an objective evaluation of the effectiveness of a gait-assist robot used in rehabilitation, highlighting the clinical potential of smart insole–based gait analysis.**

Keywords- smart insole; rehabilitation; hemiparesis; gait analysis.

I. INTRODUCTION

Basic movements—such as walking and transitioning between positions, including standing up and sitting down—are essential components of the Activities of Daily Living (ADL). The soles of the feet, being the only body parts in contact with the ground while standing, play a critical role in maintaining posture and balance. Furthermore, owing to their distance from the heart, the feet are prone to poor blood circulation during prolonged periods of sitting or standing. Walking is considered fundamental to health that it is sometimes referred to as the “sixth vital sign” [1]. Therefore, evaluating plantar conditions and mobility is significant both from a functional mobility standpoint and a health monitoring perspective. Gait assessments have been conducted across diverse populations, including older adults [2]–[4]; individuals with central nervous system disorders such as stroke, Parkinson’s disease, and multiple sclerosis [5]–[9]; those with cardiovascular or respiratory diseases [10][11]; those with musculoskeletal conditions such as low back pain [12]; and individuals with cognitive impairments [13]. In recent years, advances in digital technologies have enabled gait assessment using wearable devices [14]–[16], including the development of smart insoles designed to evaluate age- and disease-related changes and support fall prevention [17]–[20]. As insoles are integrated with footwear, smart insoles embedded with pressure sensors allow continuous gait monitoring over time. If wearable devices such as smart insoles become widely available for evaluating ADL such as walking, objective assessments could be conducted in clinical settings during therapist-led rehabilitation as well as in home environments. However, when gait disturbances are severe, applying gait analysis methods developed for healthy individuals may be inappropriate. In this study, we propose a novel gait analysis approach using pressure sensor-embedded smart insoles in a single patient undergoing inpatient rehabilitation following stroke. This case study aimed to

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demonstrate the feasibility and utility of this approach in a clinical setting.

This study was approved by the Ethics Committee on Research with Humans as Subjects of the Teikyo University of Science. The participant was an individual receiving medical rehabilitation services and was fully informed of the potential benefits and risks of participating in the study. Written informed consent was obtained by occupational therapists from patients undergoing rehabilitation who participated in the study. Section II describes the experimental method, Section III presents the results, Section IV provides a discussion, and Section V concludes the study and outlines future work.

II. EXPERIMENTAL METHOD

A single participant undergoing gait rehabilitation was assessed under three conditions: before, during, and after the use of a gait-assistive robot. The resulting data were analyzed to establish a gait evaluation framework.

A. Devices and Software

A wireless pressure-sensing smart insole, FEELSOLE® (Toyoda Gosei Co., Ltd.), was used in this study. The device was equipped with four pressure sensors positioned at the toe, heel, inside, and outside, enabling measurements at a total of eight points across both feet. Calibration was performed prior to use and consisted of four steps: (1) no pressure applied without inserting the foot into the shoe, (2) standing with both feet, (3) standing on the left foot only, and (4) standing on the right foot only. The insole sampling frequency was 50 Hz. The insole was connected via Bluetooth to an iOS application, ORPHE TRACK® (ORPHE Inc.), which automatically uploaded the data to the cloud. The recorded data were subsequently downloaded in CSV format using the ORPHE ANALYTICS system for further analysis.

Figure 1. Appearance of smart insoles.

For gait rehabilitation, the Orthobot® (FINGGAL LINK Inc.) was used. This device is attached to a Knee–Ankle–Foot Orthosis (KAFO) and helps guide the lower limb toward a desirable movement pattern during walking.

B. Participant and Measurement Method

Gait measurements were conducted on a single male participant in his 70s who was hospitalized and undergoing rehabilitation following a stroke. With the cooperation of the hospital's physical and occupational therapists, gait was assessed under three conditions: before using the gait-assistive robot, during its use, and after its removal. The participant had left hemiparesis and higher brain dysfunction due to a stroke, along with a medical history of traumatic brain injury and left femoral neck fracture. Motor impairments resulting from prior traumatic brain injury were suspected to affect not only the left upper and lower limbs but also the right limbs.

Rehabilitation, including physical, occupational, and speech-language therapies, began the day after stroke onset. Each therapy was provided five times per week, with each session lasting 40 min. Physical therapy included gait training. On day 16 after stroke onset, gait assessment was conducted using a smart insole and gait-assisted robot. Since the participant was unable to walk independently, a physical therapist provided support from behind during the measurement. The gait-assisted robot was attached to the participant's left lower limb. The gait task included straight walking and a U-turn.

C. Gait Characteristics and Analysis Method

For analysis, we excluded the first and last 100 data points recorded at the beginning and end of the measurement period. The raw heel data are shown as the blue line in Figure 2. Our previous study on healthy adults investigated a method for gait assessment using pressure sensor-equipped insoles, and suggested the utility of both peak values and post-peak decline rates at the four insole regions during each step [21]. In the present investigation, the participant's gait was compared with that of healthy controls, and the following distinguishing features were observed: (i) peak and trough values fluctuated and lacked consistency; (ii) peak shapes were irregular, occasionally presenting two successive peaks that produced an "M-shaped" waveform; (iii) the interval between successive heel peaks—that is, the stride time—was inconsistent; (iv) inside and outside pressures on the right foot were reduced; (v) pronounced left–right asymmetry was evident; and (vi) no distinct peaks appeared during periods presumed to correspond to irregular gait while turning.

Due to the wide variation in peak amplitudes, establishing a single threshold for peak detection throughout the entire recording was impractical. Accordingly, the dataset was segmented to exclude intervals with prolonged stride durations, which were assumed to reflect irregular gait. Analysis was focused on periods assumed to represent straight walking. The methods used for data segmentation, peak extraction, and calculation of the post-peak decay rate are described in Section 2) below.

1) Calculation of Stride Time: Since peak values occasionally appeared in rapid succession and irregular forms, a moving average was applied to smooth the data and calculate stride times. The signal was smoothed using a moving average with a window size of 11. Stride time was defined as the interval between two successive heel peaks on the same side (either left or right).

2) Method for Segmenting Insole Data: The mode of stride times was determined based on the values calculated from the smoothed data. Periods with stride times exceeding 1.1 times the modal duration were considered to involve irregular gait events, such as turning or interruptions, and were excluded from the analysis as nonstraight walking. The segmentation procedure involved the following steps:

- Calculation of Modal Stride Time.
  Stride duration was calculated from the smoothed data obtained using a moving average with a window size of 11. Stride duration was defined as the interval between a peak value x and the subsequent peak x+1. Peak values were defined as time points corresponding to the maximum force recorded by the insole sensor at each instance of foot-ground contact. Peaks were detected using the find_peaks function in the SciPy Python Library. Equation (1) defines the threshold used to detect peaks in the smoothed data.

$$thresh\_peak = Min + (Max - Min) \times 0.25 \quad (1)$$

  Subsequently, time bins were created in 0.2-second increments up to the maximum stride duration. Among these bins, the one containing the highest number of stride durations for the right heel—assumed to represent the better-functioning side—was identified, and its upper limit was defined as the modal stride time.
- Exclusion of irregular gait periods.
  Time intervals exceeding 1.1 times the modal stride duration were regarded as irregular gait, such as during turning or interruptions, and were excluded from the analysis to isolate segments representing straight walking. To ensure that the start and end times of the straight walking segments did not overlap with any peak values, a buffer equal to one-fourth of the median stride time of the right heel (calculated after smoothing) was added to both ends of each segment. For analysis, the longest of the identified straight walking segments was used for further examination.

3) Calculation of Mean Values: The mean values for each insole region were calculated using both nonsegmented and segmented raw data.

4) Mean of Peak Values: For nonsegmented and segmented data, the peak values were defined as the maximum force detected at the heel, toe, inside, and outside regions of the insole during each instance of foot-ground contact.

5) Calculation of Decline Rate: The decline rate reflects the decrease in pressure values following each peak. In this study, it was calculated by measuring the difference in weighted averages between adjacent data points. Specifically, the decline rate was defined as the difference between the weighted averages at point x and point x+1. The weighted average was calculated using five consecutive data points: the target point, two preceding points, and two succeeding points. To emphasize the influence of the central value, weights were assigned as follows: 40% to the target point, 20% to the points immediately before and after, and 10% to the secondary points before and after. Among the calculated decline rates, the largest value within each foot-ground contact was defined as the maximum decline rate. These maximum values were extracted for each instance, and their mean was then computed.

III. RESULTS

In this section, the results of the analysis of gait characteristics before, during, and after robot-assisted walking are presented. We compare segmented and nonsegmented data to examine changes in stride time, mean and peak insole values, and decline rates.

A. Data Segmentation

Among the walking periods with irregular time segments excluded, the longest and second longest durations were identified. Figure 2 shows the walking data recorded before the robot was worn and after its removal. The green lines indicate the start times of the extracted segments estimated to represent straight walking, and the yellow lines indicate the corresponding end times.

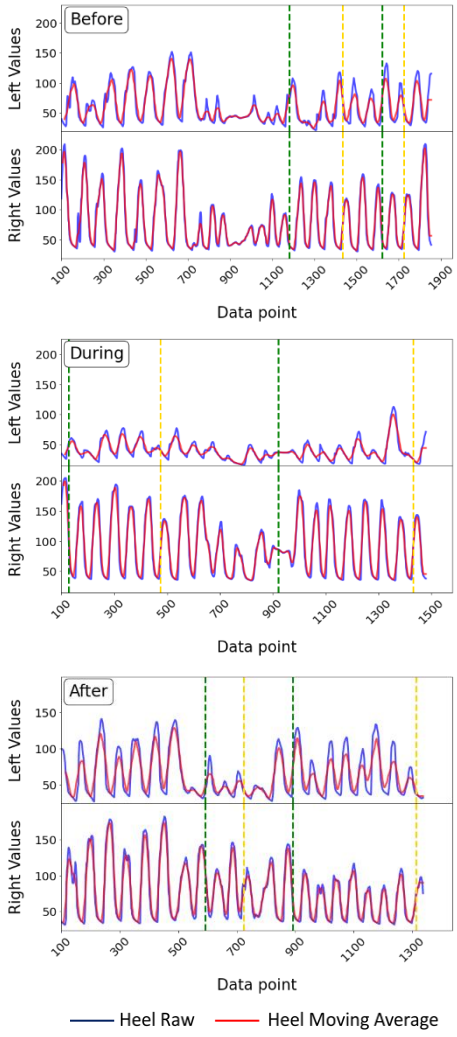

Figure 2. Irregular walking exclusion time.

Irregular gait periods were excluded from the data recorded before the robot was worn. However, in the data recorded after the robot was removed, some segments presumed to represent an irregular gait were included and misclassified as straight walking. Additionally, in the data recorded while the robot was worn, a small portion of the irregular gait was included among the extracted segments.

B. Stride Time

The average stride times were calculated using the timings of heel peaks on the left and right sides during walking—before wearing the robot, while wearing it, and after its removal. These results, based on both segmented and nonsegmented data (referred to as "split" and "non-split" data), are presented in Figure 3.

Stride time on the left side tended to be longer on the right side, which was considered the better-functioning side. The left stride time was defined as the interval between one left heel contact and the next. After removal of the robot, the overall stride times decreased, and in the split data, the differences in stride times between the left and right sides were reduced. A particularly large difference was observed between the split and non-split data for the left heel.

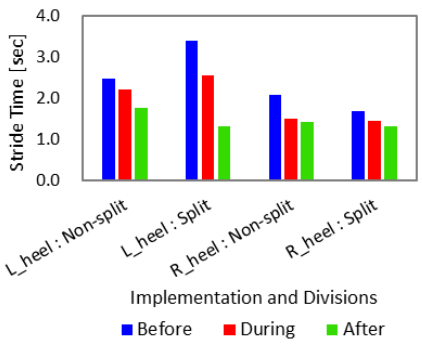

Figure 3. Average stride time from split and non-split data.

Regarding asymmetry, the difference in stride time between the left and right sides was particularly pronounced before robot use, with greater asymmetry observed in the split data compared to the non-split data. As illustrated in the raw data graphs in Figure 2, left–right stride time asymmetry was evident even during walking segments presumed to be straight walking, before and during robot use. This pattern is consistent with the trend shown in Figure 3. However, as shown in Figure 2, the number of foot contacts detected in the split dataset was limited. For instance, prior to robot use, the left stride time could only be calculated over one or two steps. Therefore, although these values indicate a tendency toward left–right differences, they were insufficient to definitively characterize the participant's gait.

C. Mean Values

The mean values of the split and non-split raw data are shown in Figure 4. While the overall trends were similar between the two types, some differences were observed. Specifically, the mean value for the right heel after robot removal was lower in the split data compared to the non-split data, and left–right asymmetry was reduced. Additionally, the mean value of the right toe increased following robot removal. These changes were not apparent in the non-split data; however, the split data revealed that robot use reduced heel asymmetry and increased toe loading.

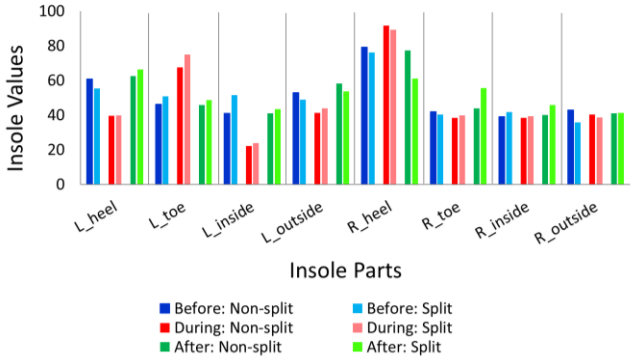

Figure 4. Mean values of insole regions from split and non-split data.

D. Mean Peak Values

The mean peak values for each part of the insole are shown in Figure 5. These results show trends similar to those observed in Figure 4, which displays the mean values for the entire raw dataset. After wearing the robot, the peak values increased at the heel and outside region of the left side—the side on which the robot was worn—compared to before use. On the right side, which was not equipped with the robot, the heel peak values decreased, resulting in a reduced asymmetry between the sides. In addition, the toe peak values on the right side increased.

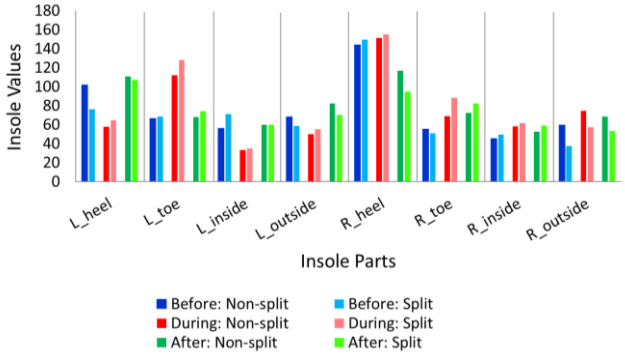

Figure 5. Mean peak values of insole regions in split and non-split data.

E. Decline Rate

The decay rates for each part of the insole are shown in Figure 6. When comparing the average values before and after the removal of the robot, overall decay rates tended to be higher after removal. On the left side, although a slight decrease was observed in the inside region for the split data,

increases were observed in the other regions. Notably, a pronounced change in the decay rate was observed at the left heel in the split data. On the right side, a decrease was observed at the heel, whereas other parts showed increased decay rates, with the most prominent increase occurring at the toe. These findings suggest that robot-assisted walking led to a higher rate of change per unit time, particularly on the side where the robot was worn. The differences between the split and non-split data were particularly noticeable at the left heel before robot use and at the right toe during robot use.

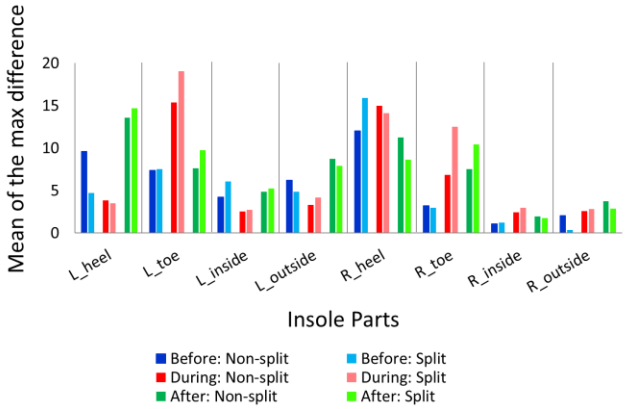

Figure 6. Decrease rates of insole regions in split and non-split data.

IV. DISCUSSION

In participants with gait impairments, the peak and valley values were inconsistent compared with healthy individuals, and M-shaped patterns—characterized by two successive peaks—were observed during periods presumed to correspond to irregular walking, such as U-turns. Therefore, the analysis was conducted using segmented data, excluding these irregular periods. The use of segmented data enables the detection of gait-assisted robot effects. To avoid distortion caused by extremely long or short stride durations, the mode, rather than the mean, was adopted as a representative stride time. Durations exceeding 1.1 times the mode were considered indicative of irregular walking, such as turning or interruptions, and were distinguished from straight walking periods. A lower threshold ensures stricter exclusion of irregular intervals, but risks omitting valid straight walking data. Conversely, a higher threshold allows the inclusion of straighter walking data, but may fail to exclude some irregular periods. These settings should be adjusted by considering the primary focus of the analysis: walking speed and balance ability.

In the segmented dataset, irregular periods were successfully excluded under pre-robot conditions. However, in the post-removal condition, some data from irregular walking phases were not excluded and were instead classified as straight walking. Furthermore, even under robot-wearing conditions, a small amount of irregular data were included. One possible explanation is that the gait-assistive robot improved walking ability, leading to more regular patterns in the better-functioning right limb, even during turning. This trend was also observed in the raw data graph (Figure 2), which showed more consistent insole readings on the right side after robot use. Our previous investigations in healthy adults have also revealed that gait patterns during U-turn phases can resemble those observed during straight walking. This suggests that individuals with a certain level of walking ability may exhibit regular gait patterns, even during turning. Conversely, in the post-removal condition, the right limb (which retained better function) maintained regular patterns even during irregular walking, whereas the left limb (which had worn the robot and had lower functional capacity) exhibited irregular data, highlighting a clear asymmetry in gait regularity. Future studies should consider segmentation based not only on the better-functioning limb, but also on incorporating data from the left and right limbs. The results differed between the segmented and nonsegmented data. However, the number of detected foot contacts in the segmented data was limited. Although these values suggested left–right asymmetry, they were insufficient to clearly characterize the participant's gait. To enhance the reliability of gait characterization, future analyses may need to include the longest segment along with other usable segments to increase the amount of available data.

In the present analysis, the focus was on straight walking, and the longest segment from the divided data was used for evaluation. Irregular walking phases were not analyzed as straight walking. However, Leach et al. demonstrated the importance of assessing fall risk during turning movements [22]. This suggests that future analyses focusing on irregular gait phases could offer valuable insights into mobility assessment. Refining data-segmentation methods and applications remains an important future direction.

Changes were observed in both the peak values and rates of decline in the insole data following robot-assisted walking. Particularly, the segmented data showed a marked increase in the rate of decline of the left heel (on the robot-wearing side) and right toe (on the nonwearing side). These results indicate that robot-assisted walking leads to increased pressure and quicker movement at the left heel and right toe. Additionally, the findings suggest the potential usefulness of segmented data for capturing such changes.

V. CONCLUSIONS AND FUTURE WORK

Walking includes steady-paced straight walking and variable-speed phases, such as turning, stepping over obstacles, stopping, and swaying. Therefore, analyzing the entire walking duration under uniform conditions may obscure critical gait characteristics. This is particularly relevant in individuals with gait impairments, for whom the evaluation of variable-speed phases presents additional challenges. This study focuses on measurements, data analysis, and method development. Notably, using the mode of stride time—rather than the mean—helped minimize the influence of extreme stride time values and enabled effective data segmentation. This approach enabled the evaluation of the gait improvement effects resulting from the use of a gait-assist robot in a rehabilitation setting. Moreover, the practical utility of smart insoles depends on their digital functions and structural design, which play a crucial role in physical comfort

and psychological usability, especially in everyday settings outside controlled clinical environments. As this was a single-case study, the generalizability of the results is limited. Future studies should include a larger sample size and further investigate the measurement data, analysis methods, and insole design.

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Postural-Change Detection Before and After Hemodialysis Using MediaPipe

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Abstract— **This study aimed to evaluate changes in physical condition before and after hemodialysis using estimated joint angles in hemodialysis patients. The flexion angles of the elbow, knee, and hip joints were analyzed from captured images to assess potential changes in posture and motor control. The results indicated that the flexion angles increased or decreased depending on the subject, suggesting that hemodialysis may influence balance and muscle tone. However, limitations were noted in the accuracy of angle estimation due to the static posture during measurement and oblique camera positioning. Despite these constraints, the proposed method offers a simple approach for detecting physical changes associated with hemodialysis, indicating its potential for fall-risk assessment and real-time monitoring during hemodialysis sessions.**

Keywords: hemodialysis; postural-change detection; MediaPipe; joint-angle estimation, computer vision; fall-risk assessment; lightweight measurement method.

I. INTRODUCTION

Hemodialysis is the primary treatment for end-stage renal disease, and many patients worldwide undergo hemodialysis several times per week. After hemodialysis, patients often experience symptoms such as orthostatic hypotension and impaired balance due to rapid fluid shifts and reduced blood pressure. These symptoms frequently lead to post-dialysis unsteadiness [1]-[4], which is closely associated with an increased risk of falls. This is particularly concerning among elderly hemodialysis patients, as the incidence of falls in this population is significantly higher than that in non-dialysis older adults. Falls in hemodialysis patients may result in fractures, hospitalization, and an even worse long-term prognosis.

Given this background, early detection and assessment of post-dialysis unsteadiness are crucial for ensuring patient safety and improving quality of life. However, conventional methods for assessing unsteadiness often rely on subjective clinical observations or simple balance tests (e.g., the timed up-and-go test) [5][6], which may lack objectivity and reproducibility.

Our research group conducted a series of studies on the clinical application of gait analysis using MediaPipe [7]. For example, we demonstrated that the use of walking aids improved the gait trajectory and that this effect persisted for a certain duration even after the aid was removed [8]. Other studies explored technical considerations and error sources in pose estimation [9], quantitatively analyzed gait changes in patients with hemiparesis [10], and attempted to evaluate mobility during rehabilitation using MicroElectronic Mechanical System (MEMS) sensors [11]. These efforts contribute to the advancement of quantitative motion analysis using computer vision and highlight the clinical potential of machine-learning-based pose estimation.

Building on these findings, the present study focused on the postural behavior exhibited when stepping onto a weighing scale before and after hemodialysis. We developed a method using MediaPipe—a real-time pose-estimation

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library developed by Google that is capable of accurately extracting skeletal landmarks from video footage—to quantitatively assess the presence and degree of post-hemodialysis unsteadiness.

Stepping on a weighing scale requires maintaining balance over a small surface area, which can accentuate subtle changes in postural control. Therefore, assessing the trunk sway, body instability, and center-of-gravity shifts during this motion may be effective in detecting postural unsteadiness.

In the present study, we aimed to establish a new method for quantitatively evaluating post-dialysis unsteadiness by analyzing video-captured motion during weight measurement. This paper presents a preliminary examination of key body parts and motion patterns of interest, along with relevant quantitative indicators, and discusses future directions for clinical applications.

The remainder of this paper is organized as follows: Section II presents the experimental conditions. In Section III, we present the results of the calculation of posture indices and joint angles, which are the evaluation points. Section IV discusses the obtained results. Section V concludes the paper.

II. EXPERIMENTS

A. Participants

Details regarding the participants are presented in Table I. The selection criteria for participants in this study were based on blood pressure fluctuations after dialysis, visual dizziness. This study was approved by the Ethics Committee of the Katori Omigawa Medical Center, Katori, Japan (No. 2024-3). Written informed consent was obtained from all participants prior to data collection. Here, of ESRD stands for End Stage Renal Disease, ABI stands for Ankle-Brachial Index, ΔDW stands for the change from the ideal Dry Weight when the body has an appropriate level of hydration, CG stands for Chronic Glomerulonephritis, and DM stands for Diabetes Mellitus.

TABLE I. PARTICIPANT INFORMATION.

Subject	Age	Sex	Case of ESRD	ΔDW	ABI R	ABI L	Note
A	54	F	CG	4.2	1.10	1.17	BP reduced
B	62	M	Unknown	4.8	1.18	1.21	BP stable
C	78	M	DM	5.3	0.98	1.46	BP stable
D	51	M	DM	6.0	1.15	1.23	BP stable

B. Experimental Setup and Recording Conditions

As shown in Figure 1, the participants were recorded while standing still or shifting their posture on a body-weight scale. A consumer-grade video camera was placed approximately 2 m in front of the participants to capture their motion. Owing to spatial constraints in the clinical environment, the camera was positioned slightly above and to the left of each participant.

Figure 1. Experimental setup.

C. Data Acquisition and Skeletal Landmark Extraction

Video data were processed using the Pose module of MediaPipe. The analysis was conducted on a Jupyter Notebook using Python. MediaPipe extracted 3D skeletal landmarks (x, y, and z coordinates) for 33 body points. These coordinates, along with the overlaid visualization of the skeletal estimation, were saved in Comma-Separated Value (CSV) format for further analysis.

D. Postural Indices and Joint-Angle Computation

To evaluate changes in posture before and after hemodialysis, we defined a set of approximated joint angles (referred to as “approximated angles”), as illustrated in Figure 2. The following six metrics were used.

(1) The approximated Trunk Forward Tilt Angle (TFTA) was defined as the angle formed between the trunk axis (midpoints of the shoulders and hips) and lower-limb axis (midpoints of the hips and knees).

(2) The approximated Cervical Flexion Angle (CFA) was defined as the angle between the line connecting both shoulders and the nose and the line connecting the midpoint of both hips to the midpoint of the shoulders.

(3) The approximated Shoulder Abduction Angle (SAA_L of SAA_R) was calculated using the shoulder and elbow positions.

(4) Approximated Elbow Flexion Angle (EFA) was calculated as the angle formed by the wrist, elbow, and shoulder.

(5) The approximated Knee Flexion Angle (KFA) was calculated as the joint angle formed by the hip, knee, and ankle.

(6) The approximated Hip Flexion Angle (HFA) was defined as the angle between the extended trunk and lower-limb axis.

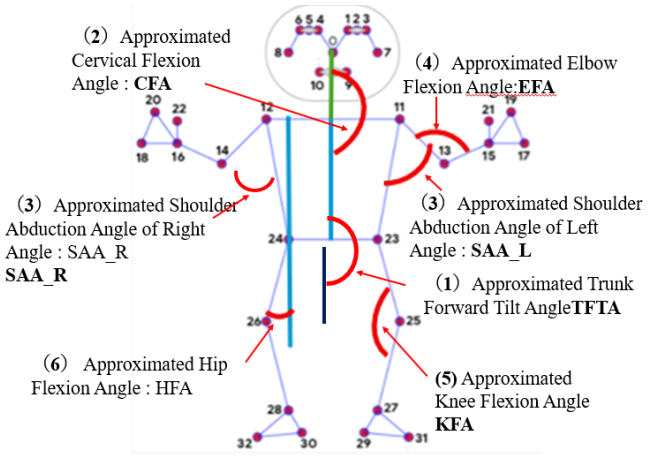


Figure 2. Definitions of the approximated angles.

Each angle was calculated using the following formula based on the inner product of two vectors A and B.

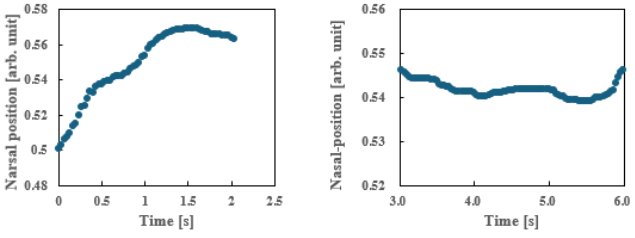
$$\theta = \cos^{-1}\left(\frac{\vec{A}\cdot\vec{B}}{\|\vec{A}\|\cdot\|\vec{B}\|}\right)$$

The vectors were derived from the coordinate data stored in the CSV files. Given that the video recordings were obtained from a slightly left upper oblique angle relative to the participant, all computed values were interpreted as approximate angles rather than as exact anatomical measurements.

III. EXPERIMENTAL RESULTS

A. *Evaluation of Nasal Displacement (Sway)*

Figure 3 illustrates an example of the nasal-position fluctuations of participant A when the participant stood on a weighing scale. Figures 3(1) and 3(2) correspond to the pre-dialysis and post-hemodialysis conditions, respectively. The recording time before hemodialysis was shorter because of simultaneous body-weight measurement. Although identical measurement durations would be ideal, no special instructions were provided to the participants, who followed their normal clinical procedures.

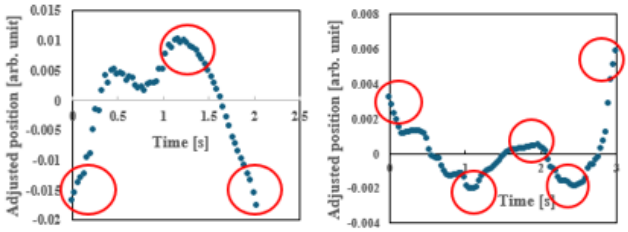


(1) (2)

Figure 3. Nasal position.

To remove the consistent directional drift, we applied a linear correction to the x-axis nasal-position data, adjusting the overall mean to zero. The corrected data are shown in Figure 4. The degree of nasal sway was calculated as the difference between the maximum positive and negative peaks. Red circles indicate the time points corresponding to these peaks. Additionally, if the values reached the measurement-range boundaries without forming clear peaks, they were counted as peak points. The numbers of transitions in the right and left directions are presented in Table II.

Before hemodialysis, all participants exhibited a consistent difference in the number of directional transitions between right and left movements. Hence, this index may be a useful quantitative indicator of postural changes related to hemodialysis.



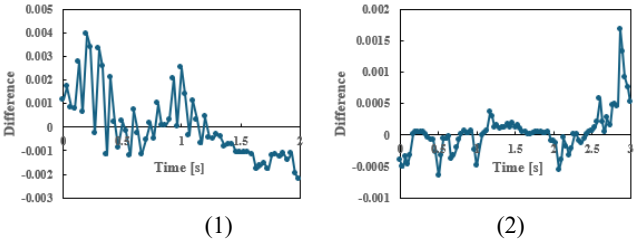
(1) (2)

Figure 4. Adjusted nasal position.

TABLE II. NUMBER OF TRANSITIONS.

		Before	R-L	After	R-L
A	L	1	1	3	-1
	R	2		2	
B	L	1	1	2	0
	R	2		2	
C	L	2	1	3	0
	R	3		3	
D	L	1	1	2	1
	R	2		1	

Figure 5 shows the time-series differential analysis of the x-axis nasal position used to detect finer fluctuations. We assume that sign changes in the differential correspond to reversals in the direction of movement.



(1) (2)

Figure 5. Differential analysis of the x-axis nasal position.

B. *Approximated Trunk Forward Tilt Angle (TFTA)*

As an example, the results for subject B, which showed a large difference, are described. The mean trunk tilt angle for Subject B before hemodialysis was 163°, whereas after hemodialysis, it decreased significantly to 136°, indicating increased forward leaning.

Although the median may suppress the effect of outliers more effectively than the mean, the difference between these two values was within the range of the measurement errors. Therefore, this study adopted the mean value for evaluation.

C. *Approximated Cervical Flexion Angle (CFA)*

Figure 6 shows an example of changes in the approximated cervical flexion angle for Subject B. (1) and (2) correspond to pre-dialysis and post-dialysis, respectively. The mean angle was 163° and 146° pre- and post-dialysis, respectively. This result suggests increases in forward head posture and cervical flexion, possibly indicating fatigue or changes in postural control after hemodialysis.

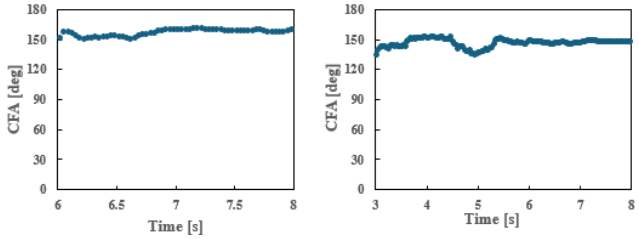


Figure 6. CFA for subject B pre- and post-dialysis.

D. *Approximated Shoulder Abduction Angle of Left and Right (SAA_L and SAA_R)*

Figure 7 presents the results for SAA_L of Subject A, where (1) and (2) correspond to pre- and post-dialysis, respectively. A significant change in the left shoulder abduction angle was observed. As shown in Figures (1) and (2), the mean pre-dialysis angle was 14°, and the mean angle decreased to approximately 8° post-dialysis-a reduction of nearly 50%. In contrast, the right shoulder abduction angle for the same subject changed by <1°.

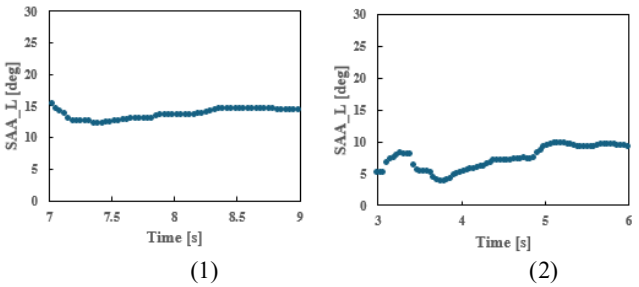


Figure 7. SAA_L for subject A pre- and post-dialysis.

Although not shown in the figure, Subject D exhibited the opposite trend, with a significant change in the right shoulder abduction angle, which decreased from approximately 30° to 15° after hemodialysis. These asymmetric changes may be influenced by not only individual differences in posture but also the oblique camera angle during data collection.

E. *Approximated Elbow Flexion Angle (EFA)*

Figure 8 shows the left elbow flexion angle for Subject C. (1) and (2) correspond to pre-dialysis and post-dialysis, respectively, as in the other figures. The angle increased from 105° before hemodialysis to 112° after hemodialysis. Although the absolute values were lower than those for Subjects A and D, the trend of increased flexion was consistent. In contrast, Subject B exhibited a slight decrease in flexion angle after hemodialysis.

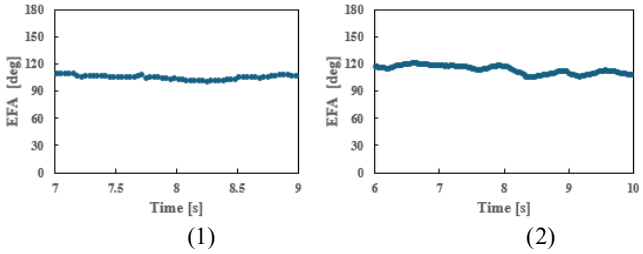


Figure 8. EFA for subject C pre- and post-dialysis.

F. *Approximated Knee Flexion Angle (KFA)*

Figure 9 illustrates the knee flexion angle for Subject D. (1) and (2) correspond to pre-dialysis and post-dialysis, respectively, as in the other figures. The pre-dialysis angle was 167°, and the angle increased to 180° after hemodialysis, indicating near-complete extension. Similar tendencies were observed in other participants, suggesting that detecting small changes in knee flexion may be challenging using this method.

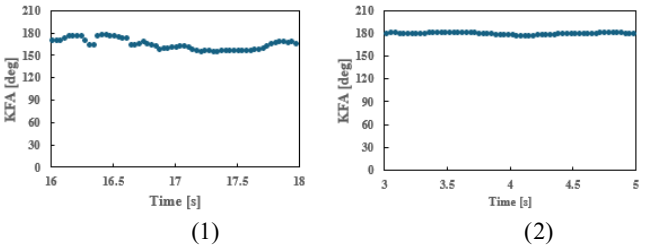


Figure 9. KFA for subject D pre- and post-dialysis.

G. *Approximated Hip Flexion Angle (HFA)*

Although hip flexion angle is typically assessed during gait, this study evaluated it in a static standing posture. Because of the short recording duration and oblique camera positioning, the accuracy was limited. Nevertheless, directional changes in the flexion angle were observed in

two participants, potentially reflecting the physiological changes caused by hemodialysis. Future improvements in measurement precision and inclusion of dynamic assessments could enable a more detailed analysis.

A summary list of all calculation results is shown in Table III.

TABLE III. MEASURED VALUE FOR EACH EVALUATION ITEM.

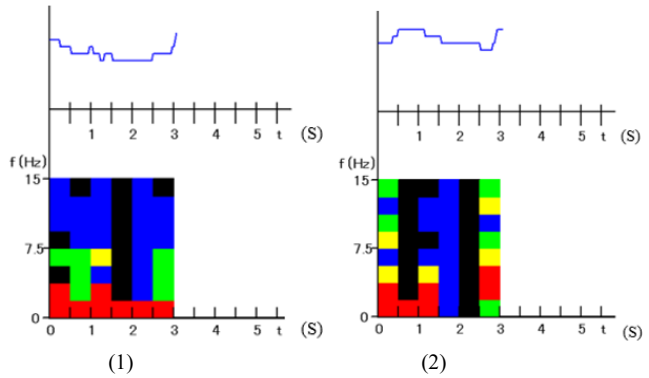
		nose	TFTA	CFA	SAA_Left	SAA_Right	EFA	KFA
		Dif	deg	deg	deg	deg	deg	deg
A	BFR	6.50E-02	161	147	14.3	19.3	100	166
	AFT	7.70E-03	177	137	7.70	13.1	118	140
	Ratio	0.11	1.10	0.93	0.54	0.68	1.18	0.84
B	BFR	7.20E-02	163	163	18.0	9.60	120	160
	AFT	5.60E-02	136	146	13.3	14.7	112	161
	Ratio	0.78	0.83	0.90	0.74	1.53	0.93	1.00
C	BFR	2.60E-02	165	156	20.3	30.3	105	149
	AFT	3.20E-02	165	152	23.5	26.8	112	149
	Ratio	1.23	1.00	0.97	1.16	0.88	1.07	1.00
D	BFR	4.30E-02	152	151	24.8	30.6	116	167
	AFT	4.10E-02	154	142	22.1	14.7	124	180
	Ratio	0.95	1.01	0.94	0.89	0.48	1.07	1.08

H. *Spectral Analysis of Knee Movement*

As part of the assessment of postural stability, we performed a time–frequency analysis of the x-axis (lateral) knee position data obtained via MediaPipe. Despite the short recording time, we applied a Discrete Fourier Transform (DFT) using a 1-s sliding window to obtain spectrograms capturing the temporal changes in frequency content.

The input data were extracted from 30-fps videos with the Nyquist frequency set to 15 Hz. The spectrograms were visualized with time on the horizontal axis and frequency on the vertical axis. The spectral magnitude (square root of the power spectrum) at each time–frequency point was color-coded using a five-level gradient: black (minimum), blue, green, yellow, and red (maximum).

Figure 10 shows an example for Subject A. (1) and (2) correspond to the left and right knees, respectively.



(1) (2)

Figure 10. Spectrogram.

IV. DISCUSSION

A. *Nasal Displacement (Sway)*

No special instructions were given to either the staff or participants regarding the measurement process. Consequently, there was variability in the timing of body-weight measurements and duration of video recording. This variability must be considered when comparing results, and standardization of measurement conditions is desirable for future studies.

As shown in Table I, all participants exhibited the same number of lateral movements along the x-axis of the nose before hemodialysis. This suggests that pre-dialysis movements followed a consistent pattern and that the difference in movement count could serve as a quantitative indicator of postural sway or instability.

Without applying a linear correction to the nasal x-axis data, the observed movement tended to form a plateau (biased in a constant direction), making it difficult to define the motion boundaries. However, measuring the duration of such sustained bias may provide an alternative evaluation metric.

Moreover, the time-series differencing of nasal-position data can capture subtle movements. Applying the DFT to these differential data may allow the extraction of periodicity or distinctive frequency components, suggesting the potential for advanced sway analysis and quantitative assessment of individual differences.

B. *Estimated Cervical Flexion Angle*

Figure 6 illustrates the changes in the estimated cervical flexion angles. The results for Participant B indicated a decrease from a mean of 163° before hemodialysis to 146° after hemodialysis, implying an increase in cervical flexion. This may reflect a forward head posture or changes in neck alignment after hemodialysis, which may be associated with physical fatigue or altered postural control.

C. *Estimated Elbow Flexion Angle*

An increase in elbow flexion angle may suggest changes in muscle tone or improved body stability. In contrast to Participant B, these results highlighted the significance of individual variations. Furthermore, differences between the dominant and nondominant limbs, including the presence of a hemodialysis shunt, should be considered in future investigations.

D. *Estimated Knee Flexion Angle*

A trend toward full extension (approaching 180°) was observed. This may reflect muscle relaxation or changes in standing posture stability. However, measurement errors due to oblique camera angles rather than frontal views may have also contributed to this outcome.

E. *Estimated Knee Flexion Angle*

Although hip flexion is typically evaluated during gait, this study employed a brief static assessment with

participants standing on a scale and the camera positioned obliquely. These conditions limit the precision of angle estimation. Nevertheless, the differences in flexion direction between the two participants suggested physical state changes induced by hemodialysis. High-precision measurements and evaluations during motion are expected to enable more detailed analysis in the future.

Table IV summarizes the evaluations at each estimated joint-angle point based on the results and discussion. Here, a change of 5% or more but less than 10% is indicated by the symbol ○, and a change of 10% or more is indicated by the symbol ◎. Because each participant's health status varies, correlations based on this will also be necessary.

The Intradialytic weight loss (%) were 4.2%, 4.8%, 5.3%, and 6.0% for Subjects A, B, C, and D, respectively. Although the present results focused on postural changes and did not directly reflect these fluid removal rates, a more accurate evaluation can be achieved by conducting a comprehensive analysis based on the indicators examined in this study, supplemented with individual physical function data and information such as medication.

F. Spectrogram

Because the spectral intensity corresponding to the passage of time is obtained, the variation in the frequency components can be obtained and used to improve the accuracy of the motion analysis by making some correspondence with the image. However, in this measurement, the upper frequency limit is set to 15 Hz every 0.5 s.

V. CONCLUSION

In this study, we evaluated the changes in the physical condition of patients before and after hemodialysis using the estimated joint angles (elbow, knee, and hip) as key indicators. A comparative analysis of these joint angles obtained via simple image processing revealed changes in the flexion angle (increase or decrease) in some participants after hemodialysis. These findings suggest that the observed angle variations may reflect changes in physical condition or postural instability associated with hemodialysis. However, limitations of this approach, including oblique camera placement and static assessment conditions, are evident. In future studies, it will be important to integrate more accurate sensor-based measurements with dynamic assessments to continuously evaluate individual changes before and after hemodialysis.

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TABLE IV. EVALUATION RESULTS.

		nose	TFTA	CFA	SAA_Left	SAA_Right	EFA	KFA
		Dif	deg	deg	deg	deg	deg	deg
A	Ratio ≧5% ○ ≧10% ◎	◎	◎	○	◎	◎	◎	◎
B		◎	◎	○	◎	◎	X	X
C		◎	X	X	◎	◎	X	X
D		○	X	○	◎	◎	X	○