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Development of therapy aids with electromyography technology for post-stroke patients

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ABSTRACT

Background: The prevalence of stroke in Indonesia has been increasing and has had a significant impact on individuals, families, and society. There is a pressing need for innovative assistive devices that support independent therapy and enhance patient motivation to improve post-stroke productivity. This study aimed to design and develop a post-stroke rehabilitation assistive device utilizing electromyography (EMG) technology.

Methods: This study employed a research and development (R&D) design. Data were collected through documentation studies, interviews with physiotherapists, observations, and focus group discussions (FGDs). A documentation study was conducted using the medical records of stroke patients. Interviews were conducted with physiotherapists, and observations were carried out to understand patients' therapeutic activities.

Results: This study provided alternative therapy by developing post-stroke rehabilitation aids with EMG technology. Based on the documentation study, 88% of patients experienced ischemic stroke with a good level of consciousness (E4V5M6), indicated by the Glasgow Coma Scale (GCS) score of 15.

Conclusion: This phenomenon supported the development of electrical therapy innovations to accelerate stroke recovery. This study successfully designed a hand therapy device using EMG technology to improve patients' motor function, particularly among those with E4V5M6 levels of consciousness and limited motor skills.

Keywords: electromyography technology, hand therapy, motor functions, post-stroke, rehabilitation.

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INTRODUCTION

Stroke is one of the leading causes of disability and death worldwide. It has a significant impact on patients' functions, particularly in Asian countries such as India, China, and Indonesia.[1] The prevalence of stroke in Indonesia has been increasing, which has broad implications for individuals, families, and communities. The prevalence rate of stroke has been reported to be higher in urban than rural areas, 0.5% among adults living in Jakarta and 0.8% nationwide.[2] In Indonesia alone, stroke accounts for approximately 19.42% of total deaths and ranks first among the leading causes of death per 100,000 population.[3]

The incidence and mortality rates of stroke continue to rise, highlighting the need for serious attention to its prevention and management. Stroke prevention plays an essential role in reducing the burden of this disease, particularly among individuals with risk factors such as hypertension, diabetes, smoking, obesity, and unhealthy lifestyles. Ischemic stroke occurs due to a blockage of blood flow to the brain, triggering cerebral ischemia-reperfusion injury. These injuries damage neurons through oxidative stress, inflammation, and mitochondrial dysfunction. In addition, increased expression of G protein-coupled receptor kinase 4 (GRK4) is known to exacerbate this process and contribute to greater neuronal damage.[4] Cryptogenic stroke accounts for approximately 40% of ischemic stroke cases in young adults and poses a significant socioeconomic burden.[5]

Post-stroke patients undergoing rehabilitation often present a high prevalence of sarcopenia, which is characterized by decreased skeletal muscle mass and strength. This reduction in muscle strength is negatively correlated with the phase angle value measured through bioelectrical impedance analysis (BIA), where a lower phase angle reflects poorer muscle condition. Sarcopenia contributes to limited recovery of physical function and dysphagia, thus affecting the overall rehabilitation prognosis.[6] Muscle strength training has been shown to effectively increase muscle strength in stroke patients, particularly during the chronic phase. Meta-analysis results indicate that this exercise is beneficial even without regulating intensity using repetition maximum, allowing flexible application in movement rehabilitation programs.[7]

Public awareness campaigns focusing on stroke prevention, recognition of signs and symptoms, and risk-reduction strategies have also become a major focus. In Indonesia, various innovations in movement-based rehabilitation tools have been introduced; however, this study focuses on developing affordable innovations that enable patients to perform independent exercises at home. Based on this background, this study aimed to develop finger and wrist therapy aids with motion sensors for post-stroke patients.

METHODS

This study employed a research and development (R&D) design, which aimed to create an innovative product and evaluate its effectiveness.[8] The purpose of R&D research is to develop new products or improve the quality of existing products to ensure accountability.[9] The R&D development stages include idea generation, data collection, design, validation, testing, and production. The R&D process is planned and systematic to find, improve, develop, and test the effectiveness of more innovative, efficient, effective, and meaningful products, models, or methods.[10]

Data were collected through interviews with physiotherapists, observations, focus group discussions (FGDs), and simulations. The study was conducted from June to August 2025 at the "YAB" Physiotherapy Academy in Yogyakarta. Ethical approval was obtained from the Health Research Ethics Committee of the Ministry of Health Polytechnic, Republic of Indonesia (approval number: DP.04.03/e-KEPK.1/1002/2025; July 17, 2025). Interviews and observations were performed by the researchers to understand patients' therapeutic activities. The research activities related to prototype design and the integration of EMG technology were carried out at the Electronics Laboratory, Vocational School, Universitas Gadjah Mada. This study was limited to the design stage of a post-stroke therapy aid prototype incorporating electromyography (EMG) technology. The assessment of patients' levels of consciousness was conducted using the Glasgow Coma Scale (GCS), which includes three components: eye opening (E), verbal response (V), and motor response (M), targeting patients with E4V5M6 levels of awareness and limited motor skills. Qualitative data analysis followed the stages of data collection, data condensation, data display, and drawing conclusions.[11]

RESULTS

Characteristics of stroke patients

The results of the study of patient medical record documentation in the hospital showed that most stroke patients who underwent physical therapy had varying rates of recovery, which were influenced by the frequency and intensity of the treatment received.

The number of male stroke patients was twice as high as that of female patients. Based on the documentation study, 80% of patients had ischemic stroke (blockage stroke). Anamnesis data recorded that patients complained of limb weakness, difficulty speaking, dizziness, and nausea, and some had arrived at the hospital unconscious.

The majority of patients had an eye-opening score of 4 (spontaneous opening of eyes), a verbal response score of 5 (good orientation and fluent speech), and a motor response score of 6 (obeying commands). Combining these three aspects resulted in a total GCS score of 15, indicating a mild brain injury condition. Approximately 88% of patients with the E4V5M6 level of consciousness were in a general condition of compos mentis (CM). These findings suggested that patients with full awareness and maximum GCS still had a high chance of receiving optimal recovery interventions, as well as preventive measures against the risk of recurrent strokes.

Analysis of the design and development needs of post-stroke therapy aids

The results of in-depth interviews with physiotherapists showed that the process of restoring body function in stroke patients took a long time and required continuous therapy sessions. The success of the rehabilitation process was greatly influenced by the patient's motivation and active involvement during therapy. Physiotherapists stated that independent exercise at home, if done regularly according to the instructions of health workers, contributed significantly to accelerating patient recovery. However, it was found that many patients had difficulty carrying out exercises independently, especially outside of therapy sessions facilitated by hospitals. These difficulties included a limited understanding of correct training techniques, a lack of support tools, and a lack of direct supervision from medical personnel. Therefore, physiotherapists considered that the development of therapeutic aids that could be used independently and intensively by patients at home was necessary. The developed therapeutic aids were expected to increase the effectiveness of exercises and reduce patients' dependence on the presence of medical personnel during the rehabilitation process. This tool was expected to record and analyze the electrical activity produced by muscle contractions to assess the level of muscle activity during exercise. In addition, this tool was hoped to be integrated with real-time signal detection features and hand gesture compatibility.

The results of interviews with physiotherapists revealed that the types of hand movements recommended in rehabilitation exercises, including several movement patterns, aimed to restore fine and gross motor function. First, finger flexion and extension were basic exercises aimed at stimulating contraction and relaxation of the flexor and extensor muscles of the finger. These movements were essential for restoring the ability to grasp and release objects and basic daily activity skills. Second, the movement of grasping objects such as sponge balls or hand grips increased hand grip strength, which was essential for activities such as holding cutlery, brushing teeth, or carrying light items. Third, wrist extension and flexion movements aimed to improve the stability and mobility of the wrist joint, which played a role in adjusting the hand's position to objects. Fourth, finger abduction and adduction movements helped improve coordination between fingers and improved the ability to manipulate small objects, such as buttons and hold a pen. Fifth, forearm rotation exercises (forearm supination and pronation) were also recommended to improve movement control when patients used their hands to eat or write. This series of exercises aimed to restore muscle strength and train functional movement patterns that supported the patient's independence in daily activities (activities of daily living/ADL). Therefore, the designed therapeutic aids were expected to adapt to these variations of movements and provide feedback on the effectiveness of the movements performed by the patient during independent exercise.

These findings led to the need for the development of post-stroke therapy aids based on EMG technology. This technology was considered to have great potential in providing accurate and real-time physiological feedback based on the electrical activity of the muscles during exercise. In addition, this tool was expected to be adapted to the patient's condition and compatible with hand movements commonly performed in rehabilitation exercises. The development of this tool referred to the principle of user-centered design (UCD), taking into account the needs of users (patients and medical personnel) as the primary basis for design and functionality. With this tool, it was hoped that there would be an increase in the effectiveness of independent exercise at home, a decrease in dependence on healthcare facilities, and an improvement in the quality of life of post-stroke patients.

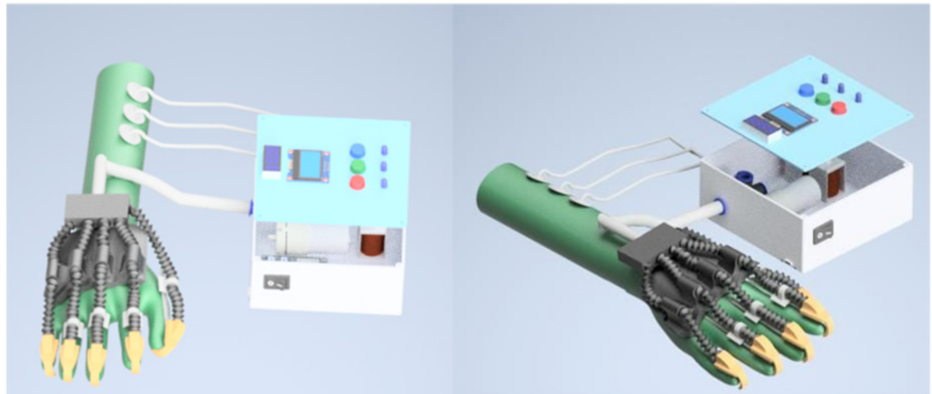

Figure 1. Design of electromyography (EMG)-based therapy aids

Product development of post-stroke hand therapy aids

The development of post-stroke hand therapy aids used materials that could support the product's function. The EMG sensor was one of the main components used in this system. This sensor was a type of surface EMG attached to the patient's skin to record signals of muscle electrical activity. These sensors were made of conductive electrodes, usually silver or silver chloride, and were equipped with medical adhesives to adhere well to the skin. The EMG signal processing module further processed the signal recorded by the EMG sensor. This module amplified, filtered, and processed weak EMG signals so that they could be converted into data that could be analyzed. The module consisted of electronics such as amplifiers, filters, and microcontrollers.

EMG-based therapy aids were designed to detect and utilize electrical signals generated by muscle activity to rehabilitate post-stroke patients with E4V5M6 levels of consciousness and motor limitations (**Figure 1**). The EMG sensor was placed on the surface of the patient's skin to capture the muscle's electrical signals as the patient attempted to move the finger. This signal was then sent to a processing system that analyzed and translated it into commands for the robotic actuator. The actuator provided motion assistance as needed. If the detected muscle activity was low, additional stimulation helped with finger movement. In addition, the system provided feedback to patients through a digital display or a supporting app, allowing adjustment of exercise intensity based on the patient's individual development to improve the effectiveness of therapy.

Electromyography-based post-stroke therapy aids (EMG) were designed to facilitate the motor rehabilitation of the hand through various therapeutic movements. The main functions of the tool included several types of movements. First, finger flexion and extension movements, which were bending and straightening the fingers of the hand alternately or simultaneously, aimed to increase the strength and flexibility of the finger muscles. Second, palm rotation movements, including pronation (turning the palm down) and supination (turning the palm up), improved the wrist's coordination and range of motion. Third, abduction and finger adduction movements were used to keep the fingers away from and closer to the middle axis of the hand, which was essential in developing fine motor skills and grip function. Implementing these movements in therapy sessions was expected to restore optimal hand-motor function in post-stroke patients with limited movement.

In summary, the development of finger and hand therapy aid products for stroke patients in mild conditions with a good level of consciousness can be seen in **Table 1**. **Table 1** explains the key components and functional features developed to support independent rehabilitation practice at home. One of the essential aspects of this tool was the use of surface EMG (sEMG) sensors capable of picking up electrical signals from muscle activity when the patient was trying to move a finger. This signal was then processed through a signal processing module equipped with amplifiers and filters to ensure the data obtained was clean and could be interpreted accurately. The information from the sensor was used by a mini actuator that provided adaptive movement assistance, especially when the patient's muscle strength was insufficient to produce whole movement. These components were integrated into the mechanical structure of the exoskeleton, which was designed following the anatomy of the hand and was made of lightweight and flexible materials for comfortable use during long periods of exercise.

In addition to supporting therapeutic movements such as finger flexion-extension, hand pronation-supination, and finger abduction-adduction, the tool was also equipped with an app-based digital interface. The application provided real-time visual feedback, stored training data, and helped motivate patients by reporting therapy progress. Overall, the

Table 1. The specification of wrist and finger therapy aids in development

No	Main Components/ Features	Development Description	Function	Supported Movements	Additional Technical Specifications
1	Surface EMG Sensor (sEMG)	The sensor is attached to the skin surface of the arm or hand	Detects muscle electrical signals when the patient tries to perform movements	Early detection for flexion, extension, and other finger movements	Ag/AgCl electrode, hypoallergenic medical adhesive, reusable
2	Signal Processing Module	Amplifier and filter array with integrated microcontroller	Amplify and filter EMG signals, Converting signals into digital data	Analyzes signal strength for movement activation according to muscle capabilities	Amplifier low-noise, bandpass filter (20–500 Hz), ADC 10-bit
3	Actuator Motor Mini / Servo	Connected to a mechanical frame attached to the hand	Providing movement assistance if muscle signals are insufficient (assistive therapy)	Finger flexions, wrist rotation, abduction–finger adduction	Low-torque servo-motor, responsive, lightweight material
4	Mechanical Structure of Hand Exoskeleton	A lightweight frame made of flexible and strong material, ergonomically designed	Provides a motion support framework according to the physiological direction of the fingers and wrists	Flexion, extension, pronation, supination, abduction and adduction	PLA/TPU material, adjustable strap, universal S–L size
5	Visual Interface/ Digital Application	Screen-based display or smartphone app	Display real-time feedback, motivate patients, store progress	Not directly moving, but supporting visual-based therapy	Android app with practice score features, daily reminders
6	Adaptive Training Mode	The exercise mode can be customized based on the patient's initial muscle strength.	Adjust the intensity of assistance to the patient's level of progress	Adjust all movements with real-time muscle capabilities	Adaptive algorithms, patient progress databases
7	Resources	Power from rechargeable batteries	Provides energy supply for sensors, actuators, and interfaces	–	7.4V Li-ion battery, 2000 mAh, USB-C charging
8	Security Features	Actuator power limitation and system fault alarm	Prevents excessive movement, protects patients from injury	All movements within physiological limits	Auto shut-off system, sensor fault indicator

tool's specifications addressed common challenges stroke patients faced during independent practice, such as the lack of technical support and difficulty maintaining exercise consistency. Adaptive features, ease of use, and progress monitoring capabilities made this tool a potential innovation for an effective and sustainable home-based rehabilitation system.

DISCUSSION

Characteristics of post-stroke patients

Stroke is a disease that requires continuous healing and rehabilitation over a relatively long period until the patient is declared recovered and can return to activities independently. Consistency in following a therapy program is a significant challenge in restoring motor function in stroke patients. Stroke is the condition with the highest disability-adjusted life years (DALY) and needs to be addressed as the leading cause of the overall disease burden in the world with effective prevention, treatment, and rehabilitation strategies.[12]

The demographic and clinical characteristics of stroke patients form the basis for designing therapeutic aids for post-stroke patients. The proportion of male stroke patients is twice that of female patients, which can be attributed to differences in lifestyle, stress levels, and the prevalence of comorbidities.[7,13–15] Another difference was that women aged 18–65 have better health indicators compared to men.[13] Stroke survivors with full consciousness and mild brain injury have a better prognosis, enabling them to cooperate more effectively during rehabilitation programs. Clinical characteristics that affect the risk of other stroke-related diseases include stroke severity, lesion volume, lesion location, multiplicity, and recurrence.[16]

The GCS scale is a tool used to assess the level of consciousness in patients with brain injuries, including those who have suffered a stroke. The GCS detects eye, verbal, and motor responses by assigning a score from 3 to 15.[17,18] A GCS score of 15 indicates that the patient has a mild brain injury condition. Increased systemic inflammatory biomarkers such as neutrophil-to-lymphocyte ratio (NLR), platelet-to-lymphocyte ratio (PLR), systemic immune-inflammation index (SII), and systemic inflammation response index (SIRI) show a significant negative correlation with GCS scores during stroke patient care. These findings suggest that high systemic inflammation is associated with poorer recovery of consciousness, making it an important indicator in prognosis and the determination of more personalized therapy strategies.[19]

Stroke patients with E4V5M6 awareness showed the potential for faster recovery if they received appropriate and targeted therapy.[20,21] Consistent with these findings, previous studies in cases of sASDH reported that the combination of atorvastatin and low-dose dexamethasone in patients with similar conditions resulted in significant clinical improvement, allowing patients to be discharged within seven days.[22]

Analysis of the design and development needs of post-stroke therapy aids

EMG technology in post-stroke rehabilitation allows for the implementation of more adaptive and measurable therapies.[23,24] The development of this therapeutic tool is also expected to increase patient motivation for independent exercises. Self-training is one of the popular solutions to repeat previously performed training models.[25,26] Rehabilitation of hand dexterity in subacute stroke patients should integrate visual terminal feedback and visuospatial skills training, as both contribute significantly to motor learning.[27]

Epidemiological data in Indonesia show that stroke is one of the non-communicable diseases with increasing prevalence. Most stroke patients experience impaired motor function, especially in the hands and fingers, due to central nervous system damage. Patients with an E4V5M6 level of consciousness respond well to verbal stimuli and motor commands but still face difficulties initiating and controlling hand movements independently. This condition emphasizes the importance of rehabilitative technology that can facilitate intensive and independent motor training. Another study developed a therapeutic innovation, resuscitative endovascular balloon occlusion of the aorta (REBOA), to treat hemorrhagic shock in patients with blood pressure of 82/64 mmHg, heart rate of 140/min, and E4V5M6 awareness level.[28]

Significant challenges exist in restoring motor function in stroke patients, especially in fingers that require fine muscle coordination. Limitations in independent exercises and the lack of adaptive aids are the main obstacles to achieving rehabilitation targets. Based on these findings, the initial design and development process focused on using EMG technology as an innovative approach to meet these needs. EMG technology allows real-time recording of muscle electrical activity to provide accurate and relevant physiological feedback. The EMG-based post-stroke therapy aids were designed to be individually adapted to the patient's motor ability level. This technology is considered capable of increasing rehabilitation effectiveness, strengthening patient motivation for independent exercise, and accelerating overall motor function recovery.

The findings highlight the importance of developing innovative rehabilitation devices tailored to post-stroke patients with limited motor abilities. While this research focused on designing an EMG-based therapeutic prototype, the development of assistive rehabilitation technologies has become increasingly diverse in recent years. Beyond EMG-based therapy, researchers have introduced innovations to enhance patient motivation and treatment outcomes. Studies have incorporated functional magnetic resonance imaging (fMRI) to understand brain activation patterns and support rehabilitation strategies.[29] Future research should integrate interdisciplinary approaches, including electroencephalography (EEG) for real-time monitoring, transcranial magnetic stimulation (TMS) for promoting cortical plasticity, visual mirror observation priming to enhance motor recovery, and transcranial direct current stimulation (tDCS) through TRANSPORT2 to support post-stroke rehabilitation.[30–32] Collectively, these approaches provide promising alternatives to enhance functional recovery and improve post-stroke patients' quality of life.

Product development of post-stroke therapeutic aids

The development of hand therapy aids for post-stroke patients based on EMG includes several key features. First, an EMG sensor detects electrical activity of the patient's muscles during finger and wrist movements and allows adjustment of stimulation according to patient response. Second, a robotic motion mechanism using an actuator assists finger movement according to the specified training pattern. Third, adaptive interactions adjust therapy intensity based on detected muscle activity to match the patient's abilities. Fourth, a real-time monitoring and feedback system provides progress data through a digital interface allows continuous evaluation and therapy adjustment. Finally, an ergonomic design ensures ease of use so patients can operate the device independently without direct supervision. These features are expected to improve rehabilitation effectiveness and accelerate post-stroke motor function recovery. The NeuroLife EMG system is an innovative therapeutic aid that records and encodes high-resolution EMG for real-time control through assistive devices.[33]

The development of this product integrates microcontrollers to process data, which are then sent to a microcontroller or minicomputer that runs the therapy algorithm and controls the user interface. These devices typically use microcontroller boards such as Arduino, Raspberry Pi, or other minicomputers. Advanced microcontrollers, or single-board computers, are capable of running a variety of processes independently and are used in a wide range of applications, including advanced industrial devices.[34] The system also includes a user interface, such as a touchscreen, computer, or mobile device, to facilitate interaction. This interface displays visual and audio feedback and allows users to set up therapy programs, including components such as an LCD screen, speakers, and supporting software.

Additionally, the system can be equipped with an actuator, such as an electric motor, pneumatic actuator, or robotic device, to provide assistance or resistance according to therapy needs. The actuator consists of a drive motor and a motor control circuit. To support the system, auxiliary devices such as cables, batteries, and device cases are used to ensure safe and adequate operation. The therapist's role evolves into a responsible supervisor, selecting the optimal therapy protocol for each patient. EMG signals provide valuable information that helps the therapist optimize motor recovery.[23]

Although technological innovations such as EMG-based devices, EEG, TMS, mirror visual feedback, and tDCS offer promising alternatives for post-stroke rehabilitation, physiotherapists remain indispensable. They provide critical feedback to prevent incorrect movements during independent rehabilitation. Effective communication and professional supervision are still required to ensure technology-assisted rehabilitation is conducted safely and yields optimal outcomes.[35]

This study was limited to the design stage of an EMG-based post-stroke therapy prototype and did not include clinical testing or validation. Findings focused only on patients with E4V5M6 awareness levels, limiting generalizability to more severe cases. Data were derived from medical records and qualitative interviews, which may introduce bias. The study did not measure rehabilitation outcomes quantitatively and was conducted in a single setting with limited resources. Further research is required to test effectiveness, safety, and scalability in broader populations.

CONCLUSION

The research and development process of post-stroke therapy aids based on EMG technology has undergone a comprehensive stage to ensure its effectiveness and safety for patients with E4V5M6 awareness levels and motor limitations. Starting from identifying user needs, the tool's design included key features such as an EMG sensor to detect muscle activity, a robotic motion mechanism to assist finger movement, adaptive interactions that adjust therapy intensity, and real-time monitoring and feedback through a digital interface.

Further research is needed to develop the prototype of the therapeutic device before it is tested on patients. It is hoped that the therapy aid prototype can later be disseminated for independent practice by physiotherapists and used directly by patients and families. Continuous monitoring and evaluation will ensure that the tool provides optimal benefits in improving the motor function of post-stroke patients.

ETHICAL CLEARANCE

The research protocol was reviewed and approved by the Health Research Ethics Committee of the Ministry of Health Polytechnic, Republic of Indonesia (Ethical Approval Number: DP.04.03/e-KEPK.1/1002/2025; July 17, 2025).

CONFLICT OF INTEREST

The authors declare that they have no financial or personal conflicts of interest in connection with this study.

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AUTHOR CONTRIBUTIONS

SCB led the study design, data analysis, and manuscript drafting and served as guarantor. BS assisted in methodology, literature review, and manuscript preparation. LDS contributed to intellectual content and manuscript editing. PAS supported clinical investigation, statistical analysis, and manuscript review. SA contributed to experimental and clinical investigations as well as data acquisition and analysis.

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