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Exploring physical sensor integration in the design of cost-effective and wearable instrumented ankle foot orthosis: A systematic review

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Abstract

Background: The mechanical properties of Ankle-Foot Orthoses (AFOs) play a vital role in enhancing mobility and improving the quality of life in individuals recovering from stroke. Parameters such as stiffness, alignment, and kinetic-kinematic characteristics are critical aspects that require optimization in AFO design and evaluation.
Purpose: To investigate the advancement of physical sensor technologies applied in AFO systems. It focuses on enabling practitioners and researchers to obtain objective, real-time data on fitting outcomes, while addressing the limitations associated with traditional, bulky, or high-cost instrumentation.
Method: A literature-based review was conducted to analyze the implementation of various physical sensors integrated into AFOs. Sensor selection was examined in relation to targeted biomechanical outcomes, with attention given to each sensor's operational strengths and constraints to inform optimal usage.
Results: Findings indicate that physical sensors significantly enhance data acquisition related to AFO fitting and performance by offering accurate, efficient, and user-friendly measurement capabilities. The diversity of available sensors allows for customization based on specific research or clinical objectives, although careful consideration must be given to each sensor's limitations.
Conclusion: The integration of physical sensors into AFO systems represents a promising direction in orthotic development, facilitating evidence-based assessments through wearable and cost-effective technologies. Strategic sensor selection is essential to maximizing the accuracy and utility of AFO outcome measurements in both clinical and research settings.

Keywords: **Ankle Foot Orthosis; Gait analysis; Mechanical properties; Physical sensors.**

INTRODUCTION

Muscle weakness, spasticity, and structural misalignment of the lower limbs are among the common physical impairments experienced by stroke survivors, which significantly contribute to a decline in their quality of life. Stroke remains a major cause of adult disability globally, including in Indonesia. According to the 2018 Basic Health Research (Riskesdas), the prevalence of stroke in the Indonesian population aged 15 years and older, based on a physician's diagnosis, is 10.9 per mille, affecting an estimated 2,120,362 individuals (Kementerian Kesehatan RI, 2018). One of the most debilitating consequences of stroke is impaired mobility, with only approximately 50% of survivors regaining sufficient ambulation (Suwanwela, 2014). The extent and location of brain injury largely determine the severity of functional impairments following a stroke. It is estimated that 40–60% of post-stroke patients exhibit structural gait abnormalities, often necessitating the use of an Ankle-Foot Orthosis (AFO) as part of their rehabilitation (Bath & Lees, 2000).

Ankle-Foot Orthosis (AFO) is a commonly prescribed assistive device aimed at improving gait

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patterns and minimizing walking deviations in individuals post-stroke. The orthosis enhances gait efficiency by optimizing joint positioning and correcting abnormal ankle plantar flexion (equinus) and knee hyperextension (genu recurvatum) during stance phase (Bleyenheuft, Bleyenheuft, Hanson, & Deltombe, 2010; Buurke, 2005; Owen, 2010). Two key design parameters—stiffness and alignment—must be precisely adjusted to maximize the orthosis's effectiveness. Suboptimal configuration can lead to joint discomfort, compromised mobility, and further medical complications in stroke rehabilitation (Kobayashi, Orendurff, Singer, Gao, Daly, & Foreman, 2016).

The integration of sensor and actuator technologies in the development of Ankle-Foot Orthoses (AFOs) is aimed at objectively evaluating the orthosis's mechanical properties through both mechanical and electrical methodologies. In the context of gait control, these mechanical characteristics serve as critical output parameters and can be assessed using mechanical actuators or electrical systems governed by algorithms embedded in microcontrollers, computers, or other control interfaces (Kobayashi, Orendurff, Singer, Gao, & Foreman, 2017). Recent research has focused on various mechanical performance metrics, including bending stiffness (Arch, Stanhope, & Higginson, 2016; Ielapi, Vasiliauskaite, Hendrickx, Forward, Lammens, Van Paepegem, & De Beule, 2018; Ringleb, Armstrong, Berglund, Kitaoka, & Kaufman, 2009), damping stiffness (Nouri, Wang, Li, & Wen, 2023; Papi, Maclean, Bowers, & Solomonidis, 2015), assistive torque (Kobayashi, Leung, & Hutchins, 2011), and overall motion analysis. AFOs equipped with damping stiffness control have demonstrated advantages in terms of reduced weight, lower cost, and improved user safety (Adiputra, Nazmi, Bahiuddin, Ubaidillah, Imaduddin, Abdul Rahman, & Zamzuri, 2019). The utilization of such instrumentation in previous studies has enabled researchers and orthotic practitioners to derive objective outcomes from orthotic fittings (Li & Hsiao-Wecksler, 2013).

Despite these advancements, several practical challenges remain in the implementation of sensor- and actuator-based AFO systems. Chief among these are the high cost and bulkiness of current instrumented AFO setups, which hinder their use in clinical settings. Gait laboratories, often required for comprehensive testing, demand dedicated facilities and resources that are not widely accessible due to their expense, despite being considered the gold standard for orthotic evaluation. Moreover, the repetitive nature of gait trials necessary for data collection can induce fatigue in patients, particularly in individuals with compromised neurological function, such as post-stroke patients.

Given these limitations, this review aims to provide insights and identify future research opportunities in the application of physical sensors and actuators in AFO development. Special emphasis is placed on determining sensor technologies that are best suited for clinical implementation, particularly for stroke rehabilitation cases.

RESEARCH METHOD

This review identifies and examines seventeen peer-reviewed studies published within the last decade that focus on the application of sensor technologies in Ankle-Foot Orthosis (AFO) systems, specifically for the purpose of measuring mechanical properties such as stiffness, alignment, torque, and motion dynamics. A comprehensive literature search was conducted across three major scientific databases—PubMed, ScienceDirect, and Semantic Scholar—ensuring a broad and multidisciplinary scope of relevant publications. The search process was finalized in December 2024, utilizing a combination of keywords related to AFO, sensor integration, and biomechanical assessment to ensure the inclusion of high-quality and thematically relevant studies. After removal of empty links, citations, other language entries, and duplicates, 1290 items remained for title and, thereafter, 130 items for abstract review. Ten publications met the inclusion criteria.

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RESEARCH RESULTS

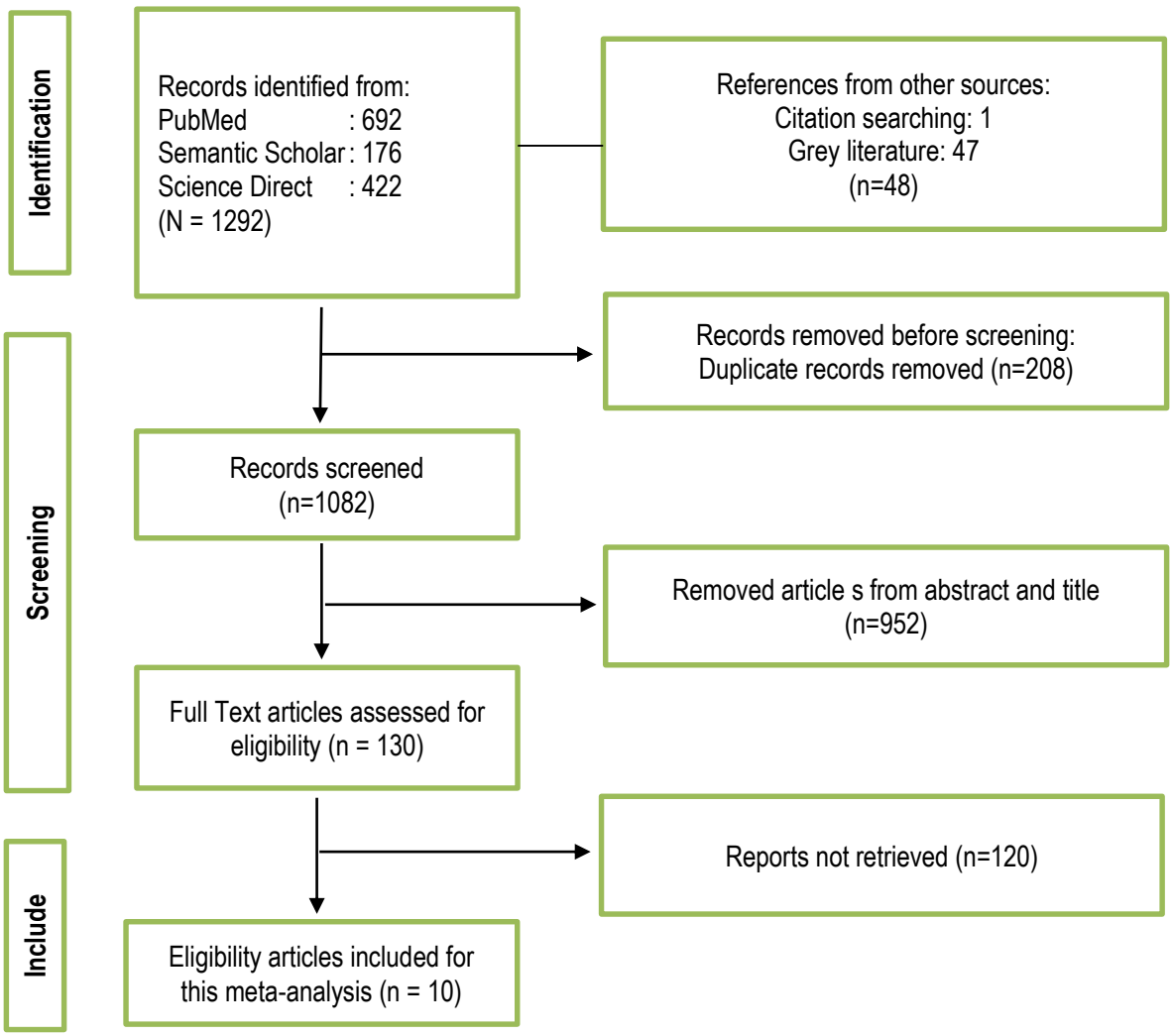


Figure Flow Prism Diagram

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Table Summary of Review Articles

(Author, Year) (Country)	Purpose	Method	Results
(Waterval et al., 2019) (Netherlands)	To improve gait, persons with calf muscle weakness can be provided with a dorsal leaf spring ankle foot orthosis (DLS-AFO).	Thirty-seven individuals	Results indicate this is caused by an individual trade-off between ankle angle and ankle power affected differently by AFO stiffness. We therefore recommend that the AFO stiffness should be individually optimized to best improve gait.
(Sutdet et al., 2019) (Thailand)	To investigate the optimum inclination in a Rigid Tuned Ankle Foot Orthosis (RT-AFO) in order to stabilize stance knee kinematics in the sagittal plane for stroke patients with 10–30 genu recurvatum	Three dimensional gait measurements	These results highlight the potential to optimize inclination of a Rigid Tuned Ankle Foot Orthosis for patients affected by stroke and also indicate the potential clinical applications of tuning the AFO in rehabilitation treatment of stroke patients.
(Ploeger et al., 2019) (Netherlands)	to evaluate the effects of modifying the stiffness for two spring-like AFO types with shoes-only as reference on gait outcomes in three individuals with calf muscle weakness due to polio.	3D gait biomechanics	Modifying AFO stiffness in individuals with non-spastic calf muscle weakness resulted in substantial differences in ankle biomechanics and walking energy cost with no effect on speed.
(Kim et al., 2021) (South Korea)	to validate the ability of available IMUs to accurately measure the ankle joint angles by comparing the ankle joint angles measured using a wearable device with those obtained using a motion capture system during running.	Gait analysis	The results showed that the day-to-day reliability was excellent (0.974 and 0.900 for sagittal and frontal plane, respectively), and the validity was good in both sagittal (r = 0.821, p < 0.001) and frontal (r = 0.835, p < 0.001) planes for ankle joints. In conclusion, we suggest that the developed device could be used as an alternative tool for the 3D motion capture system for assessing ankle joint kinematics.

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(Author, Year) (Country)	Purpose	Method	Results
(Daryabor et al., 2022) (Iran)	To determine and compare the effect of ankle-foot orthosis (AFOs) types on functional outcome measurements in individuals with (sub)acute or chronic stroke impairments.	Methodological quality assessment of 30 studies	An AFO can improve ambulatory function in stroke survivors. Future studies should explore the long-term effects of rehabilitation using AFOs and compare differences in orthotic designs.
(Santini et al., 2023) (Switzerland)	to describe and raise medical awareness of this evidence-based phenomenon, which we commonly observe in our daily practice.	classic three-month post-operative adaptation phase	The three-month POAP is a physiological transition phase in which the foot passes through a second peak of healing inflammation, adapting to the normal load of the foot and ankle. It is of paramount importance to know its characteristics and be able to differentiate it from other pathological conditions.
(Kobayashi et al., 2019) (United States)	to investigate the effects of changing AFO ankle alignment on lower limb joint kinematics and kinetics with constant dorsiflexion and plantarflexion resistance in individuals post-stroke.	Giat analysis	The alignment of the articulated AFO was suggested to play an important role in improving knee joint kinematics and kinetics in stance through improvement of ankle joint kinematics while walking in individuals post-stroke. Future studies should investigate long-term effects of AFO alignment on gait in the community in individuals post-stroke.
(Arch et al., 2016) (USA)	To develop and combine a model of a customized passive-dynamic ankle–foot orthosis with a healthy musculoskeletal model and use simulation tools to explore the influence of passive-dynamic ankle–foot orthosis bending stiffness on plantar flexor function during gait.	Quasi-static forward dynamic simulations tracked experimental gait data	Simulations predicted that the passive-dynamic ankle–foot orthoses substituted for soleus but not gastrocnemius function. Induced acceleration analyses revealed the passive-dynamic ankle–foot orthosis acts like a uniarticular plantar flexor by inducing knee extension accelerations, which are counterproductive to natural knee kinematics in early midstance.

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(Author, Year) (Country)	Purpose	Method	Results
(Daryabor et al., 2022) (Iran)	To determine and compare the effect of ankle-foot orthosis (AFOs) types on functional outcome measurements in individuals with (sub)acute or chronic stroke impairments.	A random-effect model	An AFO can improve ambulatory function in stroke survivors. Future studies should explore the long-term effects of rehabilitation using AFOs and compare differences in orthotic designs.
(Santos et al., 2024) (Portugal)	To identify, categorize, and critically evaluate the various sensors used in smart insoles, focusing on their technical specifications, application scopes, and validity.	methodological approach facilitated a robust and comprehensive analysis.	The search identified 33 qualifying studies. Proper analysis revealed a dominance of pressure sensors, with accelerometers and gyroscopes also being widely used. Critical applications included gait analysis, posture correction, and real-time athletic and rehabilitation feedback. The review also examined the relative effectiveness of different sensor configurations.

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DISCUSSION

The torque generated around the ankle joint by an Ankle-Foot Orthosis (AFO), commonly referred to as stiffness, is a key mechanical parameter and can be quantitatively assessed through the inclination of the moment-angle curve, expressed in newton-meters per degree (Nm/°) of rotational movement (Bregman, Rozumalski, Koops, De Groot, Schwartz, & Harlaar, 2009). During a normal gait cycle, the ankle typically exhibits a range of motion from approximately 7 degrees of dorsiflexion to 20 degrees of plantarflexion (Lakany, 2008). Initial investigations on stiffness were primarily directed at comparing the mechanical stiffness of the lower limb musculature with that of various AFO materials and designs (Lunsford, Ramm, & Miller, 1994). More recent studies have explored the peak flexibility moments of AFOs by examining their behavior during ankle dorsiflexion and plantarflexion phases (Cappa, Patane, & Pierro, 2003; Ploeger, Waterval, Nollet, Bus, & Brehm, 2019).

The current direction of research in AFO stiffness has evolved toward optimizing therapeutic outcomes, particularly by tailoring stiffness properties to improve functional gait performance. Accordingly, many researchers have focused on analyzing the relationship between AFO stiffness and gait biomechanics, including the impact of stiffness on parameters such as walking energy expenditure (Miyazaki, Yamamoto, & Kubota, 1997; Ploeger et al., 2019; Waterval, Nollet, Harlaar, & Brehm, 2019). Mechanical stiffness in AFOs is typically evaluated using either bench testing or functional testing methodologies (Kobayashi et al., 2011). Bench testing involves the use of specialized mechanical apparatus to assess stiffness in a controlled setting without user interaction, whereas functional testing captures stiffness measurements while the AFO is worn and actively used during walking. These two approaches serve essential roles in determining the optimal alignment of the AFO, informing gait analysis and biomechanical studies, guiding clinical decisions related to orthotic prescription and customization, matching stiffness properties to individual patient profiles, and ensuring consistent product quality in orthotic manufacturing (Ploeger et al., 2019; Waterval et al., 2019).

The ability to measure stiffness in AFOs is closely tied to the use of sensor technologies. Sensors play a crucial role in capturing accurate and objective data on stiffness, serving as the primary tools in both laboratory and real-world testing environments. Various sensor types have been applied in this field, selected based on their suitability for measuring dynamic mechanical properties in clinical and research contexts. A strain gauge is an instrument designed to measure changes in voltage or applied force, typically represented by strain. It consists of a patterned metal foil mounted on a flexible plastic substrate that exhibits changes in electrical resistance when subjected to mechanical deformation (Gupta, Loh, & Pedtke, 2020). This sensor is widely adopted due to its high accuracy, resolution, and overall reliability. Beyond its application in orthotic devices, strain gauges are also extensively utilized in research involving interface pressure within prosthetic sockets.

Strain gauges were employed to evaluate the mechanical characteristics of an Ankle-Foot Orthosis (AFO), specifically to quantify the assistive moment generated by the AFO during running. For this purpose, electrical resistance strain gauges were strategically attached to the surface of the orthosis. The findings revealed that the strain values obtained from the strain gauges closely corresponded to those measured by extensometers, validating the strain gauges' accuracy when applied to viscoelastic materials. Although there was an average variation of approximately 11% between the two measurement methods, the results confirmed a consistent correlation between the recorded strain levels, indicating that strain gauges are a reliable tool for assessing mechanical performance in such materials.

A load cell is a type of force sensor commonly used to convert mechanical load or force into an electrical voltage signal. This voltage change corresponds to the magnitude of the applied load or pressure. Load cells are often used in conjunction with strain gauges, which detect pressure changes and are typically configured into a Wheatstone bridge circuit. The Wheatstone bridge comprises four

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resistors arranged in a specific series-parallel configuration to enhance measurement sensitivity and accuracy. A Sensy™ 2712 load cell was mounted on the rear end of a linear motor to quantify external moments and detect compressive forces within an AFO system. This setup enabled the collection of stiffness data, which was further analyzed using Python-based computational tools to derive the range of motion during gait analysis. The results demonstrated that the experimental apparatus could effectively measure the AFO's stiffness throughout a defined motion range without causing damage to the instrument (Ielapi et al., 2018).

In general, alignment is defined as the initial angle placed on the joint in the sagittal plane. The resistive moment of the AFO in the direction of plantarflexion and/or dorsiflexion is located at the ankle joint. In clinical settings, AFO alignment is critical for improving gait in post-stroke patients. The alignment will be determined by the ankle joint's range of motion and the lower limb joint's muscular strength, which aims to help the rocker function in the easel and the distance of the foot in the swing (Kobayashi, Orendurff, Hunt, Gao, LeCursi, Lincoln, & Foreman, 2019). When an alignment has been set but has not yet received the optimum function, it can be done to slightly change the angle by adding material both at the plantar surface of the AFO or the shoe. This setting is called tuning (Owen, 2010) and is one of the important methods for achieving the expected optimum alignment (Sutdet, Polhan, Prakotmongkol, Poomulna, Trifani, Iswana, & Tharin, 2019).

The IMU is a sensor instrument that allows transmitting motion measurement data to a computer in real-time and immediately getting feedback. This sensor can collect 3D data (x, y, and z) using a combination of 3 (three) sensors: accelerometer, gyroscope, and magnetometer. The IMU is a lighter, smaller, and easier-to-use sensor instrument than a 3D laboratory gait system. The IMU has been evaluated and proven promising in estimating the kinematic angles of the lower extremity joints, including the hips, knees, and ankles, as well as upper posture (Kim, Hong, Oh, Lee, Kee, & Lee, 2021).

In the study, IMU was chosen to replace the role of gait laboratory 3D. A total of 10 participants were paired with 2 (two) IMU sensors embedded in the leg dorsum (sensor 1) and on the shin bone (tibia) (sensor 2) on the right foot. The placement of the two sensors must be parallel to each other, as well as parallel to the floor, to obtain accurate calculations. The results showed that the reliability test for the use of IMU on the digital and coronal sides was very good (ICC=X:0.974, Y:0.9).

Currently, the evaluation of orthosis interventions is carried out at the ankle joint kinematics and kinetics level, as well as other more proximal joints (knee joint and hip joint) with the application of 3 Dimension (3D) gait analysis. The results of the analysis of such interventions can be considered as testing the technical quality of the orthosis therapy that the medical rehabilitation team has established since the main effect of AFO is to affect the functioning of the ankle joints and the foot. Parameter results from 3D gait analysis, both comprehensive list and particular joint work, which in the event that it appears a move towards typicality as an impact of the utilization of orthotics, can at that point be considered significant to demonstrate the viability of orthosis intervention on the patient's body function (Harlaar, Brehm, Becher, Bregman, Buurke, Holtkamp, & Nollet, 2010). In addition, this evaluation is also expected to provide strong evidence to create a prescribing guide in the future. The validity tests showed that both IMU measurements from both sagittal and coronal had significantly high values.

Generally, a 3D walk investigation is carried out in a walk research facility using a motion capture system with multiple instruments. A gait lab system uses instruments including at least six cameras to capture walking movements from several directions, at least one force plate to measure the ground reaction force (GRF), a reflecting marker, a set of computers along with customized programs, and course an operator to run the system.

Many studies of gait analysis in post-stroke patients measure biomechanical parameters such as kinetics and kinematics, i.e., peaks of ankle joint angles during plantarflexion and dorsiflexion, peak moments and angles of the knee and hip joints when flexion and extension, up to walking speed and cadence (Kobayashi et. al., 2016; Kobayashi et. al., 2017; Waterval et al., 2019). Instruments in a gait laboratory include, among others: 8 Vicon MX-T40

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cameras Oxford, UK; 2 piA1000-48gc Basler cameras, Germany; and 3AMTI force plates, Massachusetts, USA. In addition, there are 38 trajectories markers placed on several parts of the bodily regions in accordance with the instruction manual full-body plug-in model for gait. Some studies also use treadmill machines to analyze energy costs and running speed (Kobayashi et. al., 2016; Kobayashi et. al., 2017).

However, there are drawbacks to this gait laboratory. This system requires a special place and a huge amount of funds, so not all health service facilities and research facilities can have this system. Many researchers today are developing wearable sensors that are more practical to use and cheaper. Here are some of the sensors used to measure kinetics and kinematic parameters.

A mechanical sensing device called a force plate is used to quantify the ground response forces and moments that are present during human movement. The force plate relies on using a load cell to determine the force. Load cells can contain several elements, such as piezoelectrics, strain gauges, and beam load cells. When a force is applied to the plate, the sensor is bent, changing the rated voltage in accordance with the applied force. Sensors positioned in a variety of orientations can be used to estimate the three-dimensional force's direction and magnitude. The force plate can also measure the center of pressure, the center of force, and the moment around its axes (Kobayashi et. al, 2011; Lamkin-Kennard, & Popovic, 2019). In order to assess the kinetic aspects of gait performance, force plates are often put in a gait laboratory. The combination of force plate and infrared camera technology is known to be very accurate in collecting kinetics and kinematics data, so it has become the gold standard in testing the outcomes of assistive interventions, both orthoses, and prostheses. The force plate's sampling rate is 1000 Hz, whereas the camera's sampling rate is 100 Hz (Kobayashi, et. al., 2017).

Electric goniometers and torsiometers (torsional goniometers) in the biomechanical field are used to measure the angle of the joints directly. In practice, a goniometer is used by practitioners to measure the magnitude of the flexion-extension and the kinematics of the adduction-abduction angle, while the torsiometer is used to measure the axial rotation (for example, pronation/supination of the forearm or rotation of the spine). Electric goniometers and torsiometers are typically constructed of two end blocks joined by springs to protect the composite wire. Biometrics Ltd.'s goniometer is one of the reference product instruments for biomechanical measurement. The instrument is light (8 - 29 g) and has less than 5% cross talk, an accuracy of roughly 2 degrees when measured more than 90 degrees from the neutral position, and better repeatability of 1 degree. It is able to sample at speeds of up to 5000 Hz (Lamkin-Kennard, & Popovic, 2019). An electrical goniometer can also be used to detect the phases of heel contact and toe-off while running (Miyake, Kobayashi, Fujie, & Sugano, 2020; Daryabor, Kobayashi, Yamamoto, Lyons, Orendurff, & Akbarzadeh Baghban, 2022). Determining the two phases aims to establish a method whose data can be measured in real-time and detect changes in time points in one of the phases in the current cycle. Furthermore, the data is expected to be used as input to make position changes automatically and directly when the user uses the wearable sensor.

CONCLUSIONS

Over the past decade, studies reviewed in this article have demonstrated the effective application of physical sensors in Ankle-Foot Orthosis (AFO) systems. These sensors have proven capable of providing accurate and reliable measurements of key mechanical parameters, including stiffness, alignment, as well as kinetic and kinematic variables. The integration of such sensor-based data has significant clinical implications, particularly in supporting therapists in delivering more targeted and effective rehabilitation interventions for stroke patients. Evidence from multiple studies suggests that employing a combination of different sensor types can enhance the richness and precision of the collected data while maintaining cost-efficiency.

This approach offers a viable alternative to conventional gait laboratories, which often require large-scale, expensive equipment and dedicated facilities. Nevertheless, the field continues to present opportunities for advancement, particularly in the refinement of sensor technologies, the development of novel methodological frameworks, and the integration of artificial intelligence or machine

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learning techniques. These innovations hold considerable potential in contributing to the emergence of intelligent or "smart" AFO systems designed specifically to support the complex rehabilitation needs of individuals with post-stroke gait impairments.

REFERENCES

Adiputra, D., Nazmi, N., Bahiuddin, I., Ubaidillah, U., Imaduddin, F., Abdul Rahman, M. A., & Zamzuri, H. (2019, January). A review on the control of the mechanical properties of ankle foot orthosis for gait assistance. In *Actuators* (Vol. 8, No. 1, p. 10). MDPI.

Arch, E. S., Stanhope, S. J., & Higginson, J. S. (2016). Passive-dynamic ankle–foot orthosis replicates soleus but not gastrocnemius muscle function during stance in gait: insights for orthosis prescription. *Prosthetics and orthotics international*, *40*(5), 606-616.

Bath, P. M., & Lees, K. R. (2000). Acute stroke. *BMJ, 320*(7239), 920-923.

Bleyenheuft, C., Bleyenheuft, Y., Hanson, P., & Deltombe, T. (2010). Treatment of genu recurvatum in hemiparetic adult patients: a systematic literature review. *Annals of physical and rehabilitation medicine*, *53*(3), 189-199.

Bregman, D. J. J., Rozumalski, A., Koops, D., De Groot, V., Schwartz, M., & Harlaar, J. (2009). A new method for evaluating ankle foot orthosis characteristics: BRUCE. *Gait & posture*, *30*(2), 144-149.

Buurke, J. H. (2005). Walking after stroke co-ordination patterns & functional recovery.

Cappa, P., Patane, F., & Pierro, M. M. (2003). A novel device to evaluate the stiffness of ankle-foot orthosis devices. *J. Biomech. Eng.*, *125*(6), 913-917.

Daryabor, A., Kobayashi, T., Yamamoto, S., Lyons, S. M., Orendurff, M., & Akbarzadeh Baghban, A. (2022). Effect of ankle-foot orthoses on functional outcome measurements in individuals with stroke: a systematic review and meta-analysis. *Disability and rehabilitation*, *44*(22), 6566-6581.

Gupta, S., Loh, K. J., & Pedtke, A. (2020). Sensing and actuation technologies for smart socket prostheses. *Biomedical engineering letters*, *10*(1), 103-118.

Harlaar, J., Brehm, M., Becher, J. G., Bregman, D. J., Buurke, J., Holtkamp, F., & Nollet, F. (2010). Studies examining the efficacy of ankle foot orthoses should report activity level and mechanical evidence. *Prosthetics and orthotics international*, *34*(3), 327-335.

Kobayashi, T., Orendurff, M. S., Singer, M. L., Gao, F., Daly, W. K., & Foreman, K. B. (2016). Reduction of genu recurvatum through adjustment of plantarflexion resistance of an articulated ankle-foot orthosis in individuals post-stroke. *Clinical Biomechanics*, *35*, 81-85.

Kim, B. H., Hong, S. H., Oh, I. W., Lee, Y. W., Kee, I. H., & Lee, S. Y. (2021). Measurement of ankle joint movements using IMUs during running. *Sensors*, *21*(12), 4240.

Kobayashi, T., Orendurff, M. S., Singer, M. L., Gao, F., & Foreman, K. B. (2017). Contribution of ankle-foot orthosis moment in regulating ankle and knee motions during gait in individuals post-stroke. *Clinical Biomechanics*, *45*, 9-13.

Kobayashi, T., Leung, A. K., & Hutchins, S. W. (2011). Techniques to measure rigidity of ankle-foot orthosis: a review. *Journal of rehabilitation research and development*, *48*(5), 565-576.

Kobayashi, T., Orendurff, M. S., Hunt, G., Gao, F., LeCursi, N., Lincoln, L. S., & Foreman, K. B. (2019). The effects of alignment of an articulated ankle-foot orthosis on lower limb joint kinematics and kinetics during gait in individuals post-stroke. *Journal of biomechanics*, *83*, 57-64.

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DOI: https://doi.org/10.33024/minh.v8i6.1288

Lakany, H. (2008). Extracting a diagnostic gait signature. *Pattern recognition*, *41*(5), 1627-1637.

Lamkin-Kennard, K. A., & Popovic, M. B. (2019). Sensors: natural and synthetic sensors. *Biomechatronics; Academic Press: Cambridge, MA, USA*, 81-107.

Ielapi, A., Vasiliauskaite, E., Hendrickx, M., Forward, M., Lammens, N., Van Paepegem, W., & De Beule, M. (2018). A novel experimental setup for evaluating the stiffness of ankle foot orthoses. *BMC Research Notes*, *11*(1), 649.

Li, Y. D., & Hsiao-Wecksler, E. T. (2013, June). Gait mode recognition and control for a portable-powered ankle-foot orthosis. In *2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR)* (pp. 1-8). IEEE.

Lunsford, T. R., Ramm, T., & Miller, J. A. (1994). Viscoelastic properties of plastic pediatric AFOs. *JPO: Journal of Prosthetics and Orthotics*, *6*(1), 3-9.

Miyake, T., Kobayashi, Y., Fujie, M. G., & Sugano, S. (2020). Gait event detection based on inter-joint coordination using only angular information. *Advanced Robotics*, *34*(18), 1190-1200.

Miyazaki, S., Yamamoto, S., & Kubota, T. (1997). Effect of ankle-foot orthosis on active ankle moment in patients with hemiparesis. *Medical and Biological Engineering and Computing*, *35*(4), 381-385.

Nouri, A., Wang, L., Li, Y., & Wen, C. (2023). Materials and manufacturing for ankle–foot orthoses: a review. *Advanced Engineering Materials*, *25*(20), 2300238.

Owen, E. (2010). The importance of being earnest about shank and thigh kinematics especially when using ankle-foot orthoses. *Prosthetics and orthotics international*, *34*(3), 254-269.

Papi, E., Maclean, J., Bowers, R. J., & Solomonidis, S. E. (2015). Determination of loads carried by polypropylene ankle–foot orthoses: A preliminary study. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, *229*(1), 40-51.

Ploeger, H. E., Waterval, N. F., Nollet, F., Bus, S. A., & Brehm, M. A. (2019). Stiffness modification of two ankle-foot orthosis types to optimize gait in individuals with non-spastic calf muscle weakness–a proof-of-concept study. *Journal of foot and ankle research*, *12*(1), 41.

Ringleb, S. I., Armstrong, T., Berglund, L. J., Kitaoka, H. B., & Kaufman, K. R. (2009). Stiffness of the Arizona ankle-foot orthosis before and after modification for gait analysis. *JPO: Journal of Prosthetics and Orthotics*, *21*(4), 204-207.

Santini, S., Marinozzi, A., Herrera-Pérez, M., Tejero, S., Wiewiorski, M., de Cesar Netto, C., & Valderrabano, V. (2023). The classic three-month post-operative adaptation phase in foot and ankle surgery—an expert perspective. *Journal of Clinical Medicine*, *12*(19), 6217.

Santos, V. M., Gomes, B. B., Neto, M. A., & Amaro, A. M. (2024). A systematic review of insole sensor technology: recent studies and future directions. *Applied Sciences*, *14*(14), 6085.

Sutdet, P., Polhan, N., Prakotmongkol, V., Poomulna, J., Trifani, F., Iswana, T., & Tharin, S. (2019). The effect of tibia inclination on gait pattern of stroke patients with genu recurvatum who wear an Ankle Foot Orthosis: A pilot study. *Technology and Disability*, *31*(3), 77-82.

Suwanwela, N. C. (2014). Stroke epidemiology in Thailand. *Journal of stroke*, *16*(1), 1.

Waterval, N. F., Nollet, F., Harlaar, J., & Brehm, M. A. (2019). Modifying ankle foot orthosis stiffness in patients with calf muscle weakness: gait responses on group and individual level. *Journal of NeuroEngineering and Rehabilitation*, *16*(1), 120.

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