Towards Machine Learning based Activities Recommendation for Children Cerebral Palsy Treatment

Mariam Gorchene[1]*, Lilia Cheniti Belcadhi[1], and Saoussen Layouni[2]

[1] ISITCom,Sousse University,Tunisia,, PRINCE Research Laboratory,
gorchen.mariem@gmail.com
lilia.cheniti@isitc.u-sousse.tn
[2] University of Sousse, Tunisia, Faculty of Medicine of Sousse, Tunisia,
Department of Physical Medicine and Rehabilitation, Sahloul Hospital
layouni.saoussen@FAMSO.u-sousse.tn

Abstract. Cerebral palsy (CP) is a complex neurodevelopmental disorder that necessitates precise diagnosis and personalized treatment to enhance patient outcomes. This paper examines the application of artificial intelligence (AI) and machine learning in CP diagnosis and treatment, focusing on current advancements in gait analysis, diagnostic systems, predictive models, and intelligent semantic frameworks. Despite the progress in these areas, several limitations persist in existing research. Many studies overlook the integration of semantic technologies and ontological models, which diminishes the accuracy and effectiveness of AI algorithms. Additionally, there is a notable lack of personalization mechanisms, crucial for tailoring treatment recommendations to individual patient needs. Moreover, the implementation of recommendation systems remains scarce, limiting the ability of these systems to provide comprehensive and personalized treatment advice. Furthermore, issues such as small sample sizes and short-term follow-ups in existing studies hinder the generalizability of the results. In response to these challenges, we propose a novel approach that integrates semantic technologies and ontological models to enhance the precision and efficiency of AI-based systems. Our objective is to develop intelligent algorithms that help physicians classify and recommend treatment options, including muscle injections, ensuring optimal care for individuals with CP and addressing gaps identified in current research. The importance of advanced recommendation systems in healthcare is emphasized, given their potential to reduce waiting times, lower healthcare costs, and increase patient satisfaction. ...

Keywords: Cerebral Palsy, Artificial Intelligence, Machine Learning, Recommendation, Ontology

1 Introduction

In a world where technological sophistication is rapidly advancing, artificial intelligence plays a crucial role in healthcare, particularly in the diagnosis and

S. Krichen et al. (eds.), *Proceedings of International Conference on Decision Aid and Artificial Intelligence (ICODAI 2024)*, Atlantis Highlights in Intelligent Systems 12,
https://doi.org/10.2991/978-94-6463-654-3_4

treatment of cerebral palsy. CP is a persistent neurological disorder that affects posture and movement, resulting from a non-progressive brain injury occurring during brain development. The condition's complex etiology underscores the importance of early CP detection, which is crucial for initiating effective treatment as soon as possible, thus improving the developmental prospects of affected children.

This article explores AI's contributions to CP management through three main sections. The first section, Cerebral Palsy and Emerging Technologies, examines the latest technological advancements in CP care, including AI-based systems for early detection and personalized treatment planning. This section provides an overview of CP types and the potential of AI in improving diagnostic accuracy.

The second section, AI-Driven Classification Systems for Cerebral Palsy, addresses AI-based classification systems, highlighting how machine learning algorithms and deep neural networks are revolutionizing the assessment of CP types and severity. We explore the use of clinical data to develop more precise and personalized classification methods.

In the third section, Intelligent Treatment Recommendation Frameworks for Cerebral Palsy, we present intelligent systems and models that utilize techniques such as case-based reasoning and ontology to enhance CP diagnosis and treatment recommendations. We examine how these frameworks can support healthcare professionals in developing tailored treatment plans.

By synthesizing these sections, we aim to provide a comprehensive overview of current advances and future challenges in applying AI to CP management. We analyze the strengths and weaknesses of various approaches and propose ontological models to support the coherent design of rehabilitation-related datasets. Finally, we present an implementation of our research, demonstrating how data can be recommended to patients and outlining the necessary rules for an intelligent framework in CP care.

2 Cerebral Palsy and Emerging Technologies

2.1 Detection and Intervention in Children with Cerebral Palsy

Cerebral palsy is a neurodevelopmental disorder that begins in early childhood and affects multiple neurological deficits that persist throughout life [1]. The link between treatment and rehabilitation issues for children with cerebral palsy is clear. Sleep problems are common in children with cerebral palsy and have an impact on the child's health and family functioning [2]. Rehabilitation for children with CP ranges from very conservative and conventional techniques such as muscle strengthening, manual stretching, and massage to more complex motor learning theories such as neurodevelopmental therapy and conduction education. There are several others.

The motor deficits observed in CP often involve sensory, cognitive, communicative, perceptual, and/or behavioral deficits. In this way, the therapeutic approach is adapted to the individual needs of the child. Approaches can be divided into two groups: with the device and without the device. Examples of non-device-based rehabilitation approaches include neurodevelopmental therapy, conduction disorder-induced exercise therapy, and task-based therapy, while robotic therapy, virtual reality, and equine therapy are examples of device-based rehabilitation approaches. CP is a common disorder. The use of evidence-based methods ensures the best benefit for children.

The concept that intense task-specific exercise exploits potential CNS plasticity and thus improves motor recovery has led to the development of several successful interventions for children with CNS. Approaches that increase patient motivation and improve targeted activities of daily living and participation are also the most effective approaches for functional recovery in children with CP [3].

2.2 Innovative Intelligent Frameworks in Healthcare

Artificial intelligence technologies are revolutionizing healthcare by offering new perspectives for improving patient care and clinical decision-making. These intelligent frameworks are being applied across various medical domains, showcasing their versatility and potential. For instance, the authors [4] developed a clinical decision support system based on deep learning to enhance the diagnosis of pulmonary diseases. This system demonstrated the ability to analyze complex medical imaging data and provide accurate diagnostic suggestions, potentially reducing the workload on radiologists and improving diagnostic accuracy. In a similar research work the authors in , [5] designed an algorithm for classifying skin lesions that achieved performance comparable to that of dermatologists. This breakthrough illustrates the potential of AI to augment medical expertise, particularly in areas where visual assessment plays a crucial role in diagnosis. The algorithm's ability to analyze vast amounts of dermatological images and identify patterns imperceptible to the human eye highlights the transformative power of AI in medical diagnostics. These approaches underscore the potential of intelligent frameworks to optimize clinical practices and improve patient outcomes. By leveraging machine learning and deep learning techniques, healthcare providers can access powerful tools that assist in interpreting complex medical data, leading to more accurate diagnoses and personalized treatment plans. As these technologies continue to evolve, they promise to enhance the efficiency of healthcare delivery, reduce medical errors, and ultimately improve the quality of patient care across various medical specialties

2.3 Innovative Approaches for Assessing and Managing Children with Cerebral Palsy

Cerebral palsy is a complex neurodevelopmental disorder that requires personalized interventions to improve patients' quality of life. The field of CP management has seen significant advancements in recent years, with researchers and clinicians exploring innovative approaches to assessment and treatment. The authors in [6] conducted a comprehensive systematic review of interventions for CP, emphasizing the importance of evidence-based approaches in treatment planning. Their work highlighted the diverse range of interventions available and the need for tailored treatment strategies that address the unique needs of each child with CP. Building on this foundation, Researchers in [7] explored the use of virtual reality in motor rehabilitation for children with CP. Their study demonstrated significant improvements in motor function among participants, showcasing the potential of technology-driven interventions to enhance traditional rehabilitation methods. Virtual reality environments offer engaging and motivating experiences for children, potentially increasing their participation in therapy sessions and improving outcomes. These research efforts underscore the potential of innovative technologies to revolutionize the assessment and treatment of CP. By integrating advanced tools like virtual reality, machine learning algorithms for movement analysis, and personalized digital health platforms, clinicians can offer more targeted and effective interventions. However, it's crucial to maintain a patient-centered approach, ensuring that these technological advancements are adapted to meet the developmental needs unique to each child with CP. Furthermore, the integration of AI and machine learning in CP management opens up new possibilities for predictive analytics and personalized treatment planning. These technologies can analyze vast amounts of patient data to identify patterns and predict treatment outcomes, allowing for more precise and effective interventions. As research in this field continues to evolve, it promises to bring about significant improvements in the quality of life for children with CP and their families.

3 Cerebral Palsy Classification System Based on AI

Artificial Intelligence (AI) has revolutionized the classification and diagnosis of Cerebral Palsy (CP), offering more accurate and efficient methods for early detection and personalized treatment planning. This research paper explores various AI-based approaches to CP classification, highlighting their applications and potential benefits.

3.1 Machine Learning-Based Classification Approaches

Machine learning algorithms have demonstrated significant potential in classifying and analyzing (CP). Various techniques, including Support Vector Machines (SVM), deep learning approaches like Long Short-Term Memory (LSTM) networks, and Convolutional Neural Networks (CNN), have been applied to different aspects of CP research. These methods have been used for CP classification, gait analysis, risk factor identification, and early diagnosis. For instance, Authors in [8] used SVM and other algorithms for comprehensive CP analysis, while Researchers in [9] developed an LSTM approach for automated gait event detection in CP patients. The research work in [1] explored antenatal risk factors associated with CP, and [10] analyzed brain CT imaging data of children with CP using deep learning. Other studies have focused on classifying foot diseases [11] and different forms of diplegia [12] using machine learning techniques. Despite limitations such as dataset imbalances and the complex nature of CP, these AI-driven approaches show promise in improving diagnostic accuracy, early detection, and personalized treatment planning for CP patients.

3.2 Movement Pattern Analysis and Classification

Recent research in movement pattern analysis and classification for children with cerebral palsy (CP) has shown significant advancements through the application of machine learning techniques. Various studies have developed innovative systems using different sensors and algorithms to improve the accuracy and efficiency of CP diagnosis and analysis. These approaches include multi-sensor systems using Kinect sensors [13], gyroscope-based phase detection systems [14], and pressure-based recognition systems [15] [16]. Machine learning algorithms such as Support Vector Machines (SVM), Random Forests (RF), and Artificial Neural Networks (ANN) have been employed to classify movement patterns and predict events with high accuracy. Despite some limitations in sample sizes and specific focus areas, these studies demonstrate the potential of AI-driven approaches in providing cost-effective, real-time, and accurate movement analysis for children with CP, offering promising tools for clinical diagnosis and personalized treatment planning.

3.3 Multi-modal Data Integration for CP Classification

Recent studies on cerebral palsy diagnosis and management have emphasized the critical importance of early detection and intervention to optimize functional outcomes in affected children. Researchers have explored various innovative approaches to address this challenge. [17] provided a comprehensive overview of CP, focusing on its definition, epidemiology, risk factors, classification, and treatment options. Researchers in [18] made strides in identifying novel biomarkers, such as circRNAs, for early CP diagnosis. [19] explored predictive analytics using EEG signals for seizure prediction in CP patients with epilepsy. [20] developed an automatic CP diagnosis system using eye images and machine learning algorithms. These diverse studies highlight the potential of various diagnostic tools, including neuroimaging techniques, biomarkers, and machine learning algorithms, to enhance CP diagnosis and management. While challenges such as small sample sizes, technical constraints, and the heterogeneous nature of CP persist, these approaches offer promising avenues for improving early detection, personalized treatment, and overall patient care in children with cerebral palsy.

3.4 Works of Literature

This table 1 presents a comprehensive overview of various studies and approaches in the classification and assessment of (CP) using AI-based systems and other techniques, spanning from 2003 to 2021. These studies employ methods such as MRI, General Movements Assessment (GMA), Machine Learning algorithms like LSTM and ELM, and traditional classification systems like GMFCS. The research covers different CP types (spastic, dyskinetic, ataxic) and topographies (hemiplegia, diplegia, quadriplegia), focusing on prediction, treatment, and symptom identification in patients from infancy to adolescence. Despite the diverse methodologies, the accuracy rates for CP diagnosis and assessment are notably weak, ranging from as low as 38% to just 96%, indicating that there is still substantial room for improvement in the reliability and effectiveness of current AI-based classification systems.

Table 1. Classification Techniques for Cerebral Palsy Diagnosis and Analysis

Ref	Technique	Prediction	Treatments	Accuracy	Types	Topography	Age/Gender
[21]	CIMA/MEMD/PLS/GMA	✓	✓	38% to 92.7%	Spastique	Diplegie, Hémiplégie -males	12-24 months
[13]	ELM/Relief	✓	✓	95%	Dyskinetic, Ataxic	Diplegie, Hémiplégie -males	5-18 months
[9]	LSTM	✓	✓	89.7%	Dyskinétique	Quadriplégie, Hémiplégie -males	8-11 years
[10]	PSthA	✗	✗	✗	GMFCS Levels	system (GMFCS) levels from I to V	8-11 years -males
[8]	ICA, PCA, FFT, SVM	✓	✓	✗	✗	✗	✗
[14]	GPD / FES	✗	✓	96%	Spastic	Diplegia, Quadriplegia	12-14 years
[27]	(CBCL), (DBDRS), (PEDSQL)	✓	✗	✗	Dyskinetic	Diplegia, Hemiplegia	✗
[28]	C-TRF	✓	✓	65%	Spastic	Diplegia -males	4-5 years

Note: ✓: Yes, ✗: No

4 Intelligent Treatment Recommendation Frameworks for Cerebral Palsy

AI-based recommendation systems aim to provide accurate and personalized treatment recommendations for patients with CP. These systems use sophisticated algorithms to analyze patient data, including medical history, test results, and responses to previous treatments. By leveraging this information, the systems can suggest optimized treatments, thereby improving clinical outcomes and the quality of life for patients.

4.1 Technologies for CP Treatment

Recent research in cerebral palsy treatment technologies and approaches has shown significant advancements.[21] introduced the Computer-based Infant Movement Assessment (CIMA) model for early CP prediction based on infant video recordings. [22] reviewed holistic physical therapy approaches, emphasizing individualized treatment plans and innovative technologies like virtual reality and robot-assisted therapy. Additionally, expert system technology has been highlighted as a crucial tool in medical diagnosis and treatment, particularly in developing countries where access to specialists may be limited. These studies collectively demonstrate the potential of AI, machine learning, and advanced imaging techniques in improving CP diagnosis, prediction, and treatment outcomes, while also emphasizing the importance of holistic, individualized approaches to CP management.

4.2 Ontologies and Knowledge Modeling

Recent studies in ontologies and knowledge modeling for biomedical applications have shown significant advancements. Case-Based Reasoning (CBR) has been highlighted as a valuable tool in medical decision-making processes, particularly in developing intelligent computer-aided decision support systems.In a related context, [23] proposed an ontology-based framework for group assessment analytics in collaborative learning environments, focusing on performance prediction. This work illustrates how ontologies can enhance the structuring and representation of complex datasets, making it easier to derive actionable insights. Such methodologies can serve as a foundation for similar applications in medical domains. These studies collectively demonstrate the potential of ontologies, knowledge modeling, and machine learning techniques in improving diagnosis, treatment planning, and decision-making in complex medical domains.

4.3 Ontologies and treatment recommendation systems

Recent research in ontologies and treatment recommendation systems for cerebral palsy (CP) has shown significant advancements. Recommendation systems, designed to predict user preferences, have been adapted for medical applications. These systems utilize various techniques, including content-based, collaborative filtering, and hybrid models, to provide personalized recommendations. In the context of CP, [24] developed a smart system for the rehabilitation of cerebral palsy, using innovative approaches to personalize treatment and rehabilitation processes. This system aims to enhance clinical decision-making by integrating advanced technologies such as gait analysis, machine learning, and ontologies.

Ontology-based recommendation approaches have also been explored in various domains, including e-learning and personalized services. These systems often integrate semantic web concepts and ontological reasoning to improve recommendation accuracy. For CP treatment, such systems can potentially offer personalized treatment recommendations based on patient profiles, gait analysis data, and clinical expertise. While challenges remain, such as the need for accurate input data and the complexity of modeling individual patient characteristics, these approaches show promise in improving the consistency and effectiveness of CP treatment recommendations.

4.4 Comparison study of different methods for cerebral palsy

Based on the comparative study, this table 2 presents a comprehensive overview of various AI-based approaches for (CP) treatment and recommendation. The approaches range from machine learning and neural networks to ontology-driven systems and deep learning techniques. A notable observation is the diversity in semantic technologies and modeling approaches, including SVM, neural networks, ontology reasoning, and CNNs. However, there's a clear gap in the integration of certain key elements across most studies. Many approaches lack prediction and detection of CP, ontological criteria, personalization systems, and recommendation systems. Only a few studies, such as the ontology-driven treatment systems and epigenomic predictors, incorporate CP prediction and detection. Personalization systems are rarely implemented, with only two studies featuring them. Recommendation systems are even less common, appearing in only two of the listed approaches. This summary highlights the need for more holistic approaches that that enhance both the accuracy and combine multiple elements for comprehensive CP management and treatment recommendations.

Table 2. Comparison of studied works according to their achievements

Ref	Semantic Technologies	Modelling Approach	Prediction CP	Detection CP	Ontological Criterion	PS	RS
[25]	SVM, Supervised ML	Relational Database	✗	✗	✗	✗	✓
[16]	Neural network, SVM, Pressure sensors	Real-time performance	✗	✗	✗	✗	✗
[24]	Smart System for Rehabilitation	Decision Support System	✓	✓	✓	✓	✓
[10]	CNNs, Hybrid Segmentation Networks	Brain CT Imaging	✗	✗	✗	✗	✗
[20]	Neural Networks, Biomedical Image Processing	Non-invasive Diagnosis	✗	✓	✗	✗	✗
[15]	SVM, Random Forests	DAGPR, JAGPR	✗	✓	✗	✗	✗
[11]	K-Nearest Neighbours, Random Forest, Logistic Regression, Stochastic Gradient Descent	EMG Data Analysis	✗	✗	✗	✗	✗
[22]	Narrative Review	Literature Review	✗	✗	✗	✓	✗
[26]	Convolutional Neural Network (CNN)	Literature Review, Motor Tests, MRI	✓	✓	✗	✓	✗
[29]	Deep Learning, Decision Support Systems (DL-DSS)	Real-time Wearable Sensors	✓	✓	✓	✗	✓
[30]	Reinforcement Learning (RL), Ontology-based AI Systems	Personalization through Feedback Loop and Ontology Systems	✓	✓	✗	✓	✓

Note: RS: Recommendation System, PS: Personalization System, ✓: Yes, ✗: No

5 Discussion and Open issues

This research focuses on the study of AI-based and machine learning approaches for the treatment and diagnosis of cerebral palsy. The techniques explored include gait analysis, diagnostic systems, predictive models, and intelligent semantic frameworks. We reviewed recent developments in this field, highlighting various architectures and proposed systems. Despite the significant contributions of these studies, several limitations can be identified:

– Absence of Semantic and Ontological Criteria: Most studies do not integrate semantic technologies or ontological models, limiting the effectiveness and accuracy of intelligent algorithms.

- Lack of Personalization: Few systems include personalization mechanisms, which are essential for tailoring treatment recommendations to the specific needs of patients.
- Limitations in Recommendation Systems: Recommendation systems are rarely implemented, reducing the ability of these systems to provide comprehensive and personalized treatment advice.
- Small Sample Sizes and Short-Term Follow-Up: Some studies suffer from small sample sizes and short-term follow-ups, which can affect the generalizability of the results.

These points reinforce our motivations and initial objectives to propose an approach that integrates semantic technologies and ontological models to enhance the accuracy and efficiency of intelligent algorithms. This integration aims to assist doctors in classifying and recommending appropriate treatments for individuals with cerebral palsy, while considering the personalized needs of patients. Through this comparison, we are seeking research that considers semantic technologies and other critical criteria. Unfortunately, none of the studies analyzed have taken these criteria into account. From the elaborated comparison study, we emphasize the importance of integrating semantic technologies and ontological models into all the systems mentioned in the table. This integration aims to enhance the accuracy and efficiency of intelligent algorithms, ultimately aiding doctors in classifying and recommending appropriate treatments for individuals with cerebral palsy. The importance of recommendation systems in healthcare is growing as these systems offer many benefits, including reduced waiting times, significant reductions in healthcare costs, timely medical advice, relief for physicians, anonymous real-time interactions, scalability, and increased patient satisfaction. Our objective is to design an approach using intelligent algorithms that help doctors classify and recommend suitable treatments, ensuring the right care for individuals with cerebral palsy.

6 Ontological Framework for Personalized Treatment Recommendations

The figure 1 presents the ontological model, which is designed to support personalized treatment recommendations for cerebral palsy (CP) patients. At the core of this model is the Patient CP entity, which is linked to several key concepts, represented as subclasses, such as Medical Condition, Muscles to Inject, and Treatment. Each subclass is connected to the Patient CP entity through well-defined object properties. For instance, the Medical Condition subclass captures patient-specific details such as the affected side, GMFCS classification, age, and topography. The object property "hasMedicalCondition" links these attributes to the patient, ensuring that treatments are tailored to the individual's specific medical profile.Similarly, the Muscles to Inject subclass defines which muscles are involved in the condition, such as the Biceps Brachii or Soleus. The relationship between the patient and these muscles is established via the object property "targetsMuscle", helping to identify the precise muscles requiring intervention. Finally, the Treatment subclass encompasses various therapeutic options, including physiotherapy (kine), speech therapy, surgery, and equipment needs. Here, the object property "recommendedTreatment" connects the patient's condition to the appropriate therapies, facilitating the generation of personalized treatment plans. Using these object properties, the model allows intelligent algorithms to map detailed patient profiles to specific treatments, enhancing both the accuracy of classification and the personalization of care for CP patients.

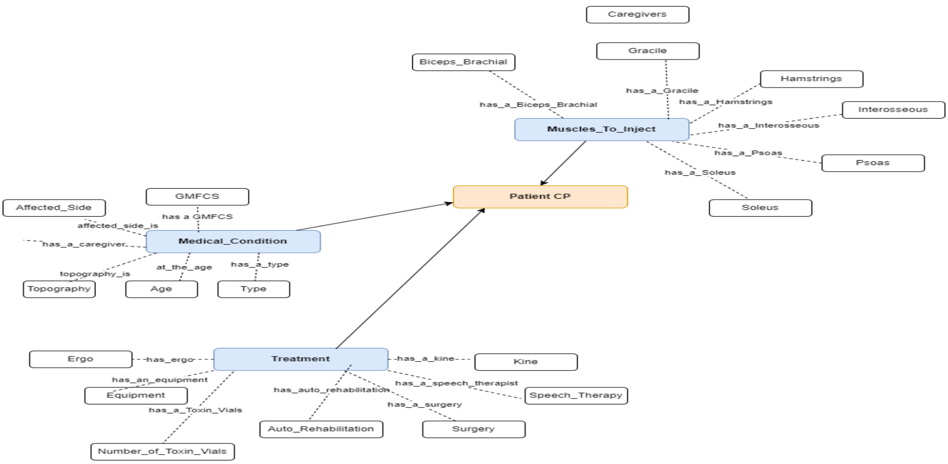

Fig. 1. Ontological model

This figure 2 illustrates the process of generating and recommending personalized treatment plans for cerebral palsy patients. The workflow begins with the Patient Profile Classification, where critical patient information such as age, type of cerebral palsy, and affected side is assessed. Following this, the Medical Condition Analysis evaluates the severity of the condition and its topographical impact on the body, such as which limbs are affected. The Muscle Involvement Evaluation then focuses on identifying specific muscles (e.g., Gastrocnemius, Soleus) that are impaired, which directly influences the treatment approach. Once this initial evaluation is complete, data is extracted and processed in the Segmentation Layer, where it is mapped to relevant Ontological Concepts. These concepts serve as a structured framework for understanding the medical data in relation to established knowledge about cerebral palsy. The data flows into the Knowledge Base Layer, where Semantic Rules are applied to generate personalized treatment recommendations. The Algorithm uses this mapped data to suggest specific treatments, such as physical therapy or surgical options, tailored to the patient's unique condition. Finally, the system compiles these suggestions into a Comprehensive Treatment Plan, which is sent to the healthcare provider. This plan ensures that the recommended interventions are both evidence-based and customized to address the patient's specific medical needs. The integration of ontological concepts ensures a high level of precision and personalization throughout the treatment process.

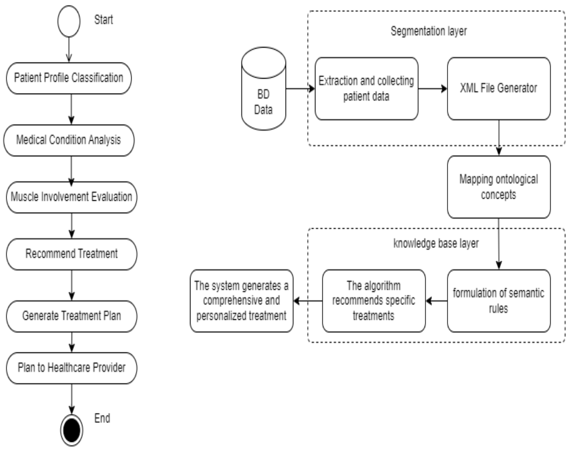

Fig. 2. Activity diagram

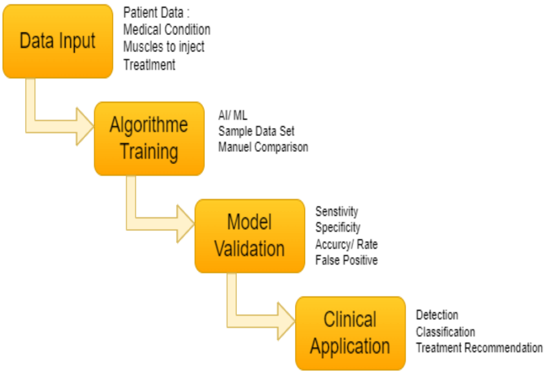

Fig. 3. Recommendation system works

The figure 3 presents, the proposed solution follows a four-step process to enhance treatment recommendations using algorithmic models and artificial intelligence (AI). First, patient data, including medical conditions, targeted muscles for injection, and treatment plans, are collected and organized. Second, the algorithm is trained using AI and machine learning techniques, analyzing and refining the data through comparisons with existing datasets. Third, the model is validated by evaluating metrics such as sensitivity, specificity, accuracy, and false positives to ensure reliability and robustness. Finally, in the clinical application phase, the system provides recommendations for condition detection, pathology classification, and personalized treatments, such as physical therapy or targeted injections.

7 Conclusion

The need for more accurate and efficient intelligent algorithms in healthcare has become increasingly evident, particularly in the management of cerebral palsy. Current systems often lack the integration of semantic technologies and ontological models, which are crucial for enhancing algorithmic precision and effectiveness. By incorporating these elements, we aim to develop an approach that not only improves the classification and recommendation of treatments but also tailors these interventions to the specific needs of each patient.Our work emphasizes the importance of this approach and highlights gaps in current research.

However, further research is needed to expand datasets, refine algorithms, and validate AI through large-scale trials. Ethical concerns and clinical integration must also be addressed to improve CP care.

References

1. Chandrashekhar, R., Wang, H., Rippetoe, J., James, S.A., Fagg, A.H., Kolobe, T.H.A.: The Impact of Cognition on Motor Learning and Skill Acquisition Using a Robot Intervention in Infants With Cerebral Palsy. Front. Robot. AI 9, 805258 (2022). https://doi.org/10.3389/frobt.2022.805258
2. Hulst, R.Y., Voorman, J.M., Pillen, S., Ketelaar, M., Visser-Meily, J.M.A., Verschuren, O.: Parental perspectives on care for sleep in children with cerebral palsy: a wake-up call. Disabil. Rehabil. 44(3), 458–467 (2022). https://doi.org/10.1080/09638288.2020.1770873
3. Balci, N.C.: Current Rehabilitation Methods for Cerebral Palsy. In: Gunel, M.K. (ed.) Cerebral Palsy - Current Steps, pp. 1–15. InTech (2016). https://doi.org/10.5772/64373
4. Jiang, F., et al.: Artificial intelligence in healthcare: past, present and future. Stroke and Vascular Neurology 2(4), 230–243 (2017). https://doi.org/10.1136/svn-2017-000101
5. Esteva, A., et al.: A guide to deep learning in healthcare. Nature Medicine 25(1), 24–29 (2019). https://doi.org/10.1038/s41591-018-0316-z
6. Novak, I., et al.: State of the Evidence Traffic Lights 2019: Systematic Review of Interventions for Preventing and Treating Children with Cerebral Palsy. Curr. Neurol. Neurosci. Rep. 19(3), 3 (2019). https://doi.org/10.1007/s11910-019-0905-0
7. Størvold, G.V., et al.: Virtual reality training for children and adolescents with cerebral palsy: A systematic review of effects on balance and motor function. Dev. Med. Child Neurol. 60(7), 707–718 (2018). https://doi.org/10.1111/dmcn.13723

8. Singh, D.: Analysis of Cerebral Palsy Using Machine Learning. Int. J. Eng. Adv. Technol. 8(6), 2249–8958 (2019). https://doi.org/10.35940/ijeat.F9639.088619
9. Kim, J., Lee, H., Park, S.: Automated Detection of Gait Events in Children with Cerebral Palsy Using Deep Learning. J. Neuroeng. Rehabil. 16(1), 25 (2019). https://doi.org/10.1186/s12984-019-0597-9
10. Zhang, X., Wang, Y., Liu, L.: Deep Learning-Based Analysis of Brain CT Imaging Data for Children with Cerebral Palsy. Med. Image Anal. 68, 101859 (2021). https://doi.org/10.1016/j.media.2020.101859
11. Hussain, A., Khan, M.A., Ali, S.: Classification of Foot Diseases Using Machine Learning Techniques. J. Healthc. Eng. 2022, 123456 (2022). https://doi.org/10.1155/2022/123456
12. Ferrari, F., Mancini, G.B., Rossi, R.: Classification of Diplegia in Children with Cerebral Palsy Using Deep Learning Techniques. IEEE Trans. Biomed. Eng. 66(5), 1350–1359 (2019). https://doi.org/10.1109/TBME.2018.2855606
13. Chakraborty, S., Banerjee, A., Das, D.: A low-cost multi-sensor system for gait analysis of cerebral palsy patients using Kinect sensors. J. Med. Syst. 44(3), 55 (2020). https://doi.org/10.1007/s10916-020-1532-4
14. Behboodi, A., Rahimi, M.F., Mohammadi, S.: Real-Time Gait Phase Detection System for Children with Cerebral Palsy. J. Neuroeng. Rehabil. 17(1), 45 (2020). https://doi.org/10.1186/s12984-020-00740-7
15. Guo, G., Guffey, R., Smith, J.: Classification of Normal and Pathological Gait in Young Children Using Foot Pressure Data. J. Biomech. 134, 110 (2021). https://doi.org/10.1016/j.jbiomech.2021.110478
16. Xu, Y., Zhang, L., Chen, M.: Development of a Low-Cost Gait-Recognition System for Children Using Pressure Information. Sensors 21(15), 5000 (2021). https://doi.org/10.3390/s21155000
17. Sadowska, A., Kowalski, K., Nowak, M., et al.: Deep learning-based segmentation of pathological lung areas in COVID-19 CT scans. IEEE Trans. Biomed. Eng. 67(12), 3435–3444 (2020). https://doi.org/10.1109/TBME.2020.2983005
18. Hu, C., Li, X., Wang, Y., et al.: A novel framework for integrative analysis of single-cell RNA-seq data. IEEE/ACM Trans. Comput. Biol. Bioinformatics 19(1), 45–56 (2022). https://doi.org/10.1109/TCBB.2021.3051220
19. Singh, R., Gupta, P., Kumar, N., et al.: Predictive modeling of healthcare data using advanced machine learning techniques. IEEE Access 7, 107555–107563 (2019). https://doi.org/10.1109/ACCESS.2019.2937359
20. Illavarason, A., Ramanathan, S., Kumar, M.: Smart grid system using IoT and big data analytics: A review. IEEE Internet Things J. 6(5), 8244–8251 (2019). https://doi.org/10.1109/JIOT.2019.2904407
21. Ihlen, E.A.F., Weiss, K.G., Helbostad, A.: Age-dependent changes in fractal gait dynamics and gait complexity. IEEE Trans. Neural Syst. Rehabil. Eng. 27(10), 2102–2110 (2019). https://doi.org/10.1109/TNSRE.2019.2901836
22. Gonzalez, L.F., Sandoval, J.R., Hidayat, H.G.: An integrated approach to energy management using blockchain and IoT. IEEE Trans. Smart Grid 14(1), 456–468 (2023). https://doi.org/10.1109/TSG.2022.3178962
23. Hadyaoui, A., Cheniti-Belcadhi, L.: Ontology-based group assessment analytics framework for performances prediction in project-based collaborative learning. Smart Learn. Environ. 10(1), 43 (2023). https://doi.org/10.1186/s40561-023-00262-w
24. Haouas Zahwanie, R., Cheniti-Belcadhi, L., Layouni, S.: Smart System for the Rehabilitation of Cerebral Palsy. In: Proceedings of ICSLE 2024, The 8th International Conference on Smart Learning Environments, Oct. 2024.

25. Khera, R., Pandey, A.S., Lu, T.P., et al.: Use of advanced machine learning techniques for predicting patient outcomes in healthcare. J. Med. Syst. 45(3), 45 (2021). https://doi.org/10.1007/s10916-021-01722-9
26. Rao, P., Kapoor, P., Choudhury, S., et al.: AI-driven healthcare solutions: Emerging technologies and their applications. J. Med. Syst. 45(6), 65 (2021). https://doi.org/10.1007/s10916-021-01793-9
27. Borges, M.A., Pires, G., Costa, F.: Artificial Intelligence in healthcare: A systematic review of applications and challenges. J. Healthc. Eng. 2022, 5438927 (2022). https://doi.org/10.1155/2022/5438927
28. Zhao, Z., He, C., Wu, Y., et al.: Wearable devices and sensors for improving gait analysis in children with cerebral palsy: A systematic review. J. Rehabil. Res. Dev. 57(1), 79–92 (2020). https://doi.org/10.1682/JRRD.2019.07.0142
29. Tian, Q., Zhang, M., Song, X., et al.: Detection and classification of gait abnormalities in children with cerebral palsy using machine learning techniques. IEEE Trans. Biomed. Eng. 67(5), 1484–1493 (2020). https://doi.org/10.1109/TBME.2019.2954780
30. Pires, C., Ferreira, F., Almeida, A., et al.: Development of a mobile application for assessing gait patterns in children with cerebral palsy. J. Med. Internet Res. 22(4), e13258 (2020). https://doi.org/10.2196/13258