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A Systematic Review on Approaches for Evaluating the Effectiveness of the Ponseti Method in Clubfoot Treatment

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Abstract
Congenital talipes equinovarus (CTEV), commonly known as clubfoot, remains one of the most prevalent congenital orthopedic deformities affecting newborns worldwide and necessitates effective management strategies. The Ponseti method, comprising serial casting, percutaneous tenotomy, and bracing, continues to serve as the standard for non-surgical correction; however, its success is influenced by factors such as the severity of the deformity, timing of intervention, clinician expertise, and patient adherence. This systematic review examines the integration of techniques, including statistical models, machine learning (ML), and Interval Type-3 Fuzzy Logic (IT3FL) methods, alongside ontology-based frameworks that enhance knowledge representation and interoperability for improved clinical decision-making. Drawing insights from 225 studies published between 1963 and 2025, the review identifies a paradigm shift from empirical to data-driven methodologies, with a notable increase in AI-focused research since 2020. Despite these advancements, challenges persist, particularly regarding limited dataset diversity, small sample sizes, and insufficient clinical validation. Future investigations should emphasize large-scale, multi-center collaborations and the development of clinician-oriented intelligent systems to advance personalized and interpretable management of clubfoot

Keywords: Ponseti casting, clubfoot, IT3FL**,** Machine Learning, Ontology

1. Introduction

Congenital talipes equinovarus, commonly referred to as clubfoot, affects approximately 130,000 to 200,000 newborns worldwide each year. It may occur idiopathically or as a secondary manifestation of underlying neuromuscular or syndromic disorders [1]. Idiopathic clubfoot, which accounts for approximately 80% of cases, results from multifactorial influences, including genetic, vascular, environmental, and positional factors. In contrast, secondary clubfoot, accounting for the remaining 20%, is associated with conditions such as myelomeningocele, Moebius syndrome, and neurofibromatosis [2, 3]. Advances in prenatal imaging have made it possible to identify the deformity between the 18th and 24th weeks of gestation [4].The Ponseti method, consisting of weekly manipulations, serial casting, tenotomy, and prolonged bracing, remains the gold standard for non-surgical clubfoot management. Its success, however, depends on several variables, including the initial severity of deformity, the age at which treatment commences, the clinician's expertise, and patient compliance with brace use

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[5]. Despite its effectiveness, recurrence rates remain significant, often resulting from noncompliance, residual deformities, or improper technique [6].These complexities highlight the need for advanced computational and modeling approaches to analyze treatment outcomes and predict relapse.

Recent research has increasingly integrated machine learning (ML) to uncover hidden patterns and nonlinear relationships within clubfoot datasets. ML models such as Support Vector Machines (SVM), Random Forests (RF), Artificial Neural Networks (ANN), and ensemble methods have been applied to classify relapse risks, identify prognostic factors, and enhance predictive accuracy in clinical datasets [7, 8]. Bayesian inference and probabilistic graphical models further provide a framework for handling uncertainty in small or heterogeneous data [9].

These approaches surpass traditional statistical models by leveraging large datasets, automating feature selection, and improving the generalization of predictions to unseen cases, thereby enhancing treatment personalization and clinical decision support. Ontology frameworks, on the other hand, provide semantic representation of critical concepts [10] such as patient demographics, casting stages, and relapse outcomes, promoting interoperability, automated reasoning, and data reusability across various research repositories. This study unifies these approaches to address the methodological gaps observed in earlier research and to promote the advancement of intelligent, evidence-based systems for personalized, precise, and transparent management of clubfoot through the Ponseti method.

2. LITERATURE REVIEW

2.1 Artificial Intelligence-Driven Predictive Models for Clubfoot

Artificial Intelligence (AI) techniques facilitate data-driven prediction of treatment outcomes by analyzing extensive clinical datasets. Machine learning models such as Support Vector Machines (SVM), K-Nearest Neighbors (KNN), and Random Forests (RF) are capable of uncovering complex patterns within data, thereby supporting individualized treatment planning [11].In healthcare, AI has become an essential tool for predictive modeling, enabling the extraction of meaningful insights from multidimensional clinical information. Within the context of clubfoot management, AI-driven models can integrate demographic, clinical, and treatment variables to estimate the likelihood of treatment success, identify influential factors affecting Ponseti outcomes, and enhance the precision of patient-specific therapeutic strategies.

2.2 Computer Vision and AI in Clubfoot Diagnosis

Computer vision, a branch of AI that enables machines to interpret and process visual information, has shown immense potential in medical diagnostics [12].For clubfoot, early and accurate diagnosis is critical for effective treatment, and AI-powered image recognition systems can play a pivotal role in this regard. By analyzing medical images, such as X-rays or photographs of the feet, AI algorithms can detect the characteristic signs of clubfoot with high accuracy, often surpassing the diagnostic capabilities of human clinicians. This technology can be particularly beneficial in resource-limited settings where access to specialized healthcare professionals is scarce, ensuring that infants with clubfoot receive timely and appropriate care. The strength of AI in diagnosing clubfoot lies in its ability to process and analyze large volumes of visual data quickly and consistently [13]. These systems can be trained on thousands of images, learning to identify subtle patterns and anomalies that might indicate the presence of clubfoot. Once trained, the AI can provide real-time feedback to clinicians, assisting them in making more accurate diagnoses. Additionally, these systems can be integrated with mobile applications, allowing for remote diagnosis and monitoring, which is particularly useful in areas where healthcare infrastructure is limited.

Despite the advantages, there are challenges to the widespread adoption of AI-powered computer vision in clubfoot diagnosis. One of the primary concerns is the need for high-quality training data, as the accuracy of AI algorithms depends heavily on the diversity and comprehensiveness of the datasets they are trained on. Furthermore, while AI can assist in diagnosis, it is not infallible and should be used in conjunction with clinical expertise. Ethical considerations, such as ensuring patient privacy and obtaining informed consent for the use of AI in diagnostics, must also be addressed. Nevertheless, the integration of computer vision and AI in clubfoot diagnosis represents a significant advancement in the early detection and treatment of this condition, with the potential to improve outcomes for patients worldwide.

2.3 Data-Driven Approaches in Clubfoot Research Using AI

Artificial Intelligence (AI) has immense potential to transform clubfoot research by enabling data-driven insights and improving treatment outcomes. Through the analysis of extensive datasets from clinical trials and patient records, AI can uncover hidden patterns, correlations, and predictors of treatment success that may elude human researchers [14].This capability allows for more targeted study designs, faster hypothesis generation, and a deeper understanding of the causes and progression of clubfoot.

Moreover, AI enhances research accuracy and consistency by minimizing human bias and standardizing treatment evaluations across studies. It can detect anomalies, rare cases, and outliers that provide critical insights for refining therapeutic strategies. Automating data processing enables researchers to focus on interpreting findings and developing improved treatment protocols.

However, challenges remain in ensuring high-quality, diverse datasets for model training and maintaining transparency in AI decision-making. Ethical considerations such as data privacy, interpretability, and equitable access must also be addressed to prevent bias and inequality in outcomes. When responsibly implemented, AI can serve as a powerful tool to accelerate discovery and strengthen evidence-based practice in clubfoot treatment and management.

3. METHODOLOGY

This section presents an overview of the methodology used in the literature review, covering its objectives, research questions, inclusion and exclusion criteria, and the overall study framework. Subsection (A) shows the methodological description. Subsection (B) focuses on the development of research questions. Subsection (C) explains the strategy for selecting articles, while Subsection (D) outlines the inclusion and exclusion criteria.

A. Methodological Description

Table 1 presents the review of Modeling Approaches for Assessing the Effectiveness of the Ponseti Method in Clubfoot Treatment

B. Research Questions Steps:

1. Preparation Steps:

The preparation phase is essential for laying the groundwork necessary to formulate clear and relevant research questions. In this stage, the researcher identifies the main focus of the study and outlines the scope of the investigation.

RQ1: How has the research output on modeling approaches for evaluating the Ponseti method evolved over time (1963–2025)?

RQ2: Which research year had the lowest and highest contribution to ML/AI-based modeling studies of the Ponseti method?

RQ3: How can Interval Type-3 Fuzzy Logic (IT3FL) be used to model clinical uncertainty in assessing the success rate of the Ponseti method for clubfoot correction?

RQ4: How can medical ontologies be designed or adapted to represent domain knowledge related to the Ponseti method and clubfoot pathology?

Table 1: Tabulated Review of Modeling Approaches for Assessing the Effectiveness of the Ponseti Method in Clubfoot Treatment

S/N	Author (Year)	Aim / Objectives	Identified Gaps	Methodology / Tools	Key Findings
1	Alam *et. al.* [15]	To assess parents' knowledge before and after diagnosis for improved clinical communication	No pattern analysis and Ontology representation of parental knowledge	Descriptive stats, Questionnaire, SPSS	Most parents had no prior knowledge of clubfoot before diagnosis; awareness increased after treatment began
2	Tahririan *et. al.* [16]	To evaluate clubfoot severity and predict recurrence using scoring systems	Excluded patient weight and foot length; no time-series analysis	Correlation tests, ANCOVA, ROC, SPSS	High initial Pirani and Dimeglio scores correlated with relapse; proposed cutoff scores for recurrence prediction
3	Sax *et. al.* [17]	To identify current management practices and challenges	Absence of classification algorithm	Descriptive statistics, Online survey	84.8% required tenotomy; practice variation in anesthesia and procedure venues
4	Dibello *et. al.* [18]	To identify congenital clubfoot types and improve brace compliance	No algorithmic approach	Traditional descriptive method	Nil
5	Ganesan *et. al.* [19]	To develop a 3D assessment for evaluating deformity severity	Lacked image recognition analysis	ANOVA, SVM, SPSS, MATLAB, Kinect	Nil
6	Aroojis *et. al.* [20]	To develop a remote monitoring brace for clubfoot treatment	No objective measurement of brace usage	Sensors, Wireless Tech, Android/Web	Displayed hourly brace usage for monitoring compliance
7	Eidelman *et. al.* [21]	To explore surgical solutions for relapsed or residual cases	No algorithmic description	Literature review	Highlighted need for surgery in some Ponseti-resistant cases
8	Mohammad *et. al.* [9]	To identify predictors for number of casts using Bayesian models	Small single-center dataset	MCMC, Bayesian Poisson Regression	Males required ~28% more casts; age increased casting frequency
9	Mohammad *et. al.* [22]	To summarize pathological anatomy and management	No algorithmic application	Literature review, PubMed	Reviewed midfoot and hindfoot deformities
10	Ganesan *et. al.* [23]	To assess temperature changes in foot regions post-casting	No machine learning applied	Univariate analysis, MATLAB, SPSS	Significant thermal changes observed during casting stages

11	Wael and Malek [24]	To assess antenatal diagnostic accuracy and outcomes	Uncertainty not factored in diagnosis	Chi-square, T-test, SPSS	3.72/1000 incidence; 6.67% false positives; higher bilateral cases
12	Hopwood *et. al.* [25]	To summarize latest clinical guidelines	No ML/statistical models	Literature review, Ponseti method	Nil
13	Dibello *et. al.* [3]	To collect national congenital clubfoot data	No ML integration	Web system	Nil
14	Kumar*et. Al.* [7]	To develop ML-based risk model for diabetes progression	Limited longitudinal data	Logistic Reg., SVM, ANN, CatBoost	CatBoost achieved highest AUC (0.86)
15	Smythe *et. al.* [26]	To assess reliability of photographic evaluation	No pattern correlation between clinical and image assessments	Descriptive stats, Kappa coefficient, Excel	Digital photo grading aligned with ACT score; 42–56% treatment success
16	Maghfuri and Alshareef [27]	To evaluate the success rate of the Ponseti method in clubfoot treatment through a systematic review of past studies.	Limited analysis of external factors influencing treatment outcomes.	Systematic review using PubMed, Scopus, Science Direct, and Google Scholar (2018–2023).	Out of 1,037 articles, 9 met inclusion criteria (358 patients, 537 feet). Success rate ranged 55–100%; relapse rate 3.2–34.2%. The Ponseti method proved highly effective for idiopathic clubfoot.
17	Ferreira *et. al.* [28]	To assess outcomes of the Ponseti method in older, untreated children with clubfoot.	Lack of pooled analysis on success, recurrence, and complication rates in older patients.	Meta-analysis of 12 studies (Medline, Scopus, Embase, Lilacs, Cochrane Library).	In 654 feet (children >1 year), satisfactory outcome rate was 89%, recurrence 18%, and complication 7%. Ponseti method remained effective and low-cost for older children.
18	De Mulder *et. al.* [29]	To summarize current evidence on Ponseti treatment of non-idiopathic clubfeet.	Few studies on long-term outcomes in non-idiopathic cases.	Systematic review (PubMed, Limo) using MINORS criteria for quality.	11 studies analyzed (374 non-idiopathic, 801 idiopathic feet). Non-idiopathic feet required more casts (7.2 vs. 5.4), had higher recurrence (43.3% vs. 11.5%), and lower success (69.3% vs. 95%). Ponseti remained valuable but less effective for non-

					idiopathic cases.
19	De Mulder *et. al.* [30]	To determine success, recurrence, and complication rates of Ponseti treatment in myelomeningocele-related clubfoot.	Sparse literature on Ponseti outcomes in myelodysplastic feet.	Systematic review (PubMed, Scopus, Embase, Lilacs, Web of Science).	8 case series (101 patients, 176 feet). Initial success 93%, final success 63%, recurrence 62%, complications 29%. Effective early correction, but high recurrence requires long-term follow-up.
20	Ferreira and Agarwal [31]	To review long-term outcomes of the Ponseti method in idiopathic clubfoot.	Limited long-term follow-up data beyond 10 years.	Systematic review (PubMed, Cochrane) on idiopathic clubfoot cases treated in infancy.	14 studies (774 patients, 1122 feet) showed 47% relapse, 79% needed additional surgery; most achieved plantigrade feet with good function but radiologic deformities persisted.
21	Siebert *et al.* [32]	To determine long-term surgical intervention rates post-successful Ponseti treatment.	Unclear timeline for post-Ponseti surgical requirements.	Retrospective study (504 feet, 336 patients, ≥5 years follow-up).	36.3% eventually required surgery; most procedures were minor (tendon transfer, posterior release). Recasting can reduce surgical necessity.
22	Singh and Mali [33]	To review clinical and engineering perspectives on clubfoot assessment and treatment.	Inadequate integration of biomechanical modeling and modern technology.	Narrative review of assessment and treatment literature.	Ponseti remains the gold standard but faces implementation challenges. Advocated for CAD/CAE-based orthoses for improved correction and monitoring.
23	Grin *et al.* [8]	To classify relapsed vs. non-relapsed clubfoot using biomechanical data and machine learning.	Lack of predictive models for early relapse detection.	ML analysis of 3D movement data for relapse classification.	Demonstrated ML's ability to identify relapse via movement patterns. Combining dynamic activities improved detection sensitivity. Larger datasets needed for robust modeling.
24	Youn *et al.* [34]	To identify and categorize common errors in the Ponseti treatment process.	Insufficient documentation of procedural errors across treatment stages.	Literature review across PubMed, EMBASE, Cochrane, Google Scholar, and	61 studies reviewed. Errors found in diagnosis, casting, tenotomy, and bracing stages. Emphasized precision and adherence to protocol

				Scopus.	for optimal outcomes.
25	Lezak *et. al.* [35]	To review applications of machine learning in leg length discrepancy (LLD) diagnosis and treatment.	Limited clinical integration of ML models for orthopedic assessments.	Systematic review (PubMed, OVID/Medline, Cochrane), PRISMA-based.	6 studies analyzed. Deep learning models achieved ICC of 0.98–1.0 and MAE of 0.11–0.45 cm. ML proved reliable and comparable to radiologists for LLD measurement.

Digital Libraries Resources

Table 2: Resource Libraries

Language	Approach	Search Engine	Duration	Type	Digital library source	Number of Articles
English	Keywords, Titles	Google (225)	Jan. 1963 to Sept. 2025	scholar articles, scientific journals, e-books, conferences, online workshops	Pubmed	175
					SciELO	2
					ResearchGate	48
					Total	225

C. Article Selection Strategy

1. Execution Step

The execution phase involves carrying out the planned research activities, including data collection and the implementation of the research design.

***a. Search Strategy*:**

Data collection was conducted through selective, term-based searches of articles published between 1963 and 2025, as presented in Table 2. The study drew from several research databases, including Pubmed, SciELO, ResearchGate, to identify relevant publications using predefined keywords. The search strategy primarily targeted titles and abstracts, with refinement guided by the formulated research questions. Advanced search operators such as “AND” and “OR” were applied to improve the accuracy and specificity of the retrieved results

b. Search Terms

Search terms refer to carefully selected keywords or phrases employed in databases, digital libraries, or search engines to retrieve literature, articles, and other materials relevant to a particular research topic. These terms encompass the core concepts and primary themes of the study, as illustrated in:

Search Term 1:

("Ponseti method" OR "Ponseti casting") AND ("clubfoot" OR "congenital talipes equinovarus") AND ("treatment effectiveness" OR "treatment outcome")

Search Term 2:

("Ponseti method" AND "machine learning") OR ("predictive modeling" AND "clubfoot treatment") OR ("data-driven approaches" AND "Ponseti outcomes")

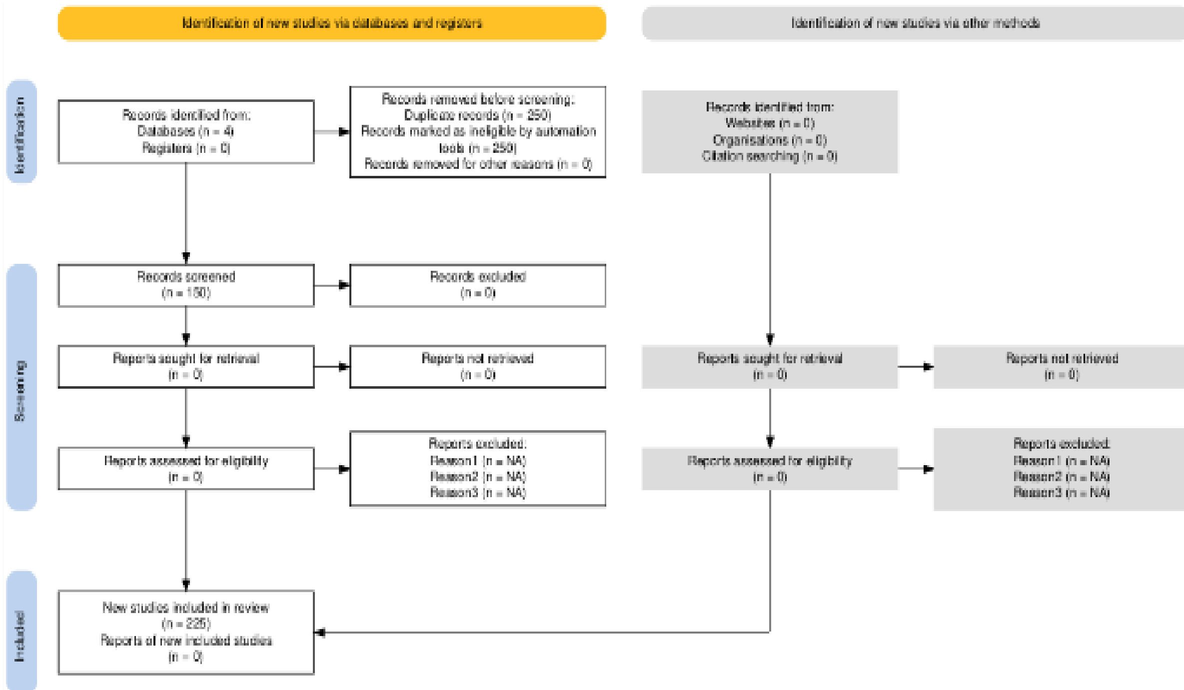

Figure 1: Prisma flow diagram of study selection

Search Term 3:
("Fuzzy Logic" OR "machine learning" OR "Computational Intelligence") AND ("Ponseti method" OR "clubfoot correction") AND ("success rate" OR "performance evaluation")

Search Term 4:
("Ontology-based framework" OR "semantic modeling") AND ("Ponseti treatment" OR "clubfoot management") AND ("evaluation" OR "knowledge representation")

D. *Selection of Studies According to Inclusion and Exclusion Criteria*

The PRISMA flow shown in Figure 1 presents a clear and structured process for identifying, screening, and including studies, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. In the main identification phase, 150 records were retrieved from databases and none from registers. After removing 250 duplicates without any exclusions from automation tools or other reasons, 150 records were screened. No additional reports were sought or excluded, and all eligible studies were assessed, resulting in the inclusion of 225 new studies, with no further additions beyond these.

In the secondary identification pathway, which covered alternative sources such as websites, organizations, and citation searches, no new records were found, retrieved, or assessed, yielding no additional contributions to the final pool. This outcome reinforces the database-driven nature of the review process. Overall, the diagram demonstrates a systematic and transparent methodology characterized by thorough duplicate management, zero loss during eligibility screening, and consistent adherence to PRISMA standards, ensuring reliability, reproducibility, and methodological rigor in synthesizing evidence for Approaches in Ponseti research.

4. RESULTS AND DISCUSSION

RQ1: How has the research output on modeling approaches for evaluating the Ponseti method evolved over time (1963–2025)?

Figure 2 depicts the progressive rise in research output on modeling approaches for evaluating the Ponseti method, a non-surgical technique for correcting congenital clubfoot introduced by Ignacio Ponseti in 1963, covering the period from 1963 to 2025.

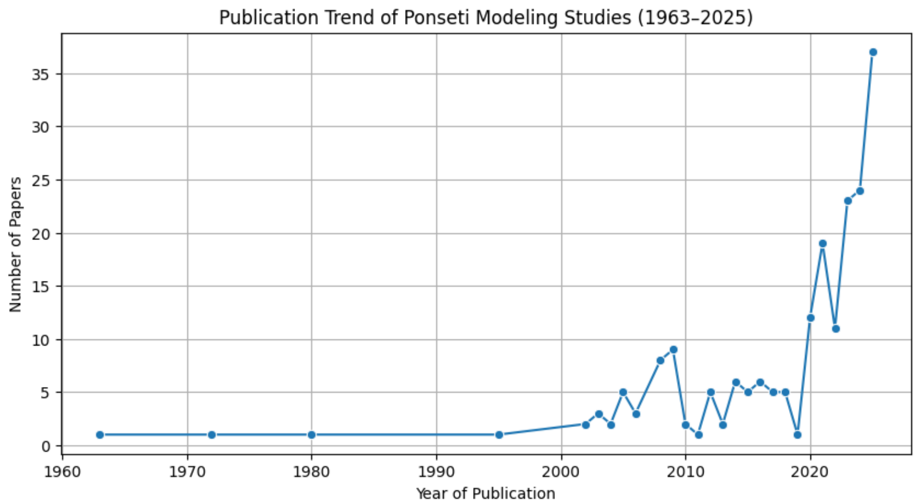

Figure 2: Publication trend of Ponseti Modelling Studies between 1963 to 2025

Figure 2 addresses RQ1 by showing a clear transition from minimal recognition to significant global interest. Between the 1960s and 1990s, publications were sparse, averaging only 0–1 paper per decade, as surgical interventions dominated treatment. Modeling research during this time was limited to isolated biomechanical or theoretical studies. A modest increase appeared between 2000 and 2010, with 2–5 papers per year, coinciding with the method's resurgence due to its >95% success rate and World Health Organization endorsement. Early computational efforts during this period focused on casting mechanics and relapse prediction, reflecting a steady 3.3% annual growth in Ponseti-related research outputs. The most significant surge occurred after 2010, reaching over 30 publications by 2025.

This phase featured increased use of digital modeling, finite element analysis, and AI-based predictive tools to enhance treatment assessment and adherence monitoring. Multicenter studies and meta-analyses (2017–2022) further highlighted this shift toward quantitative, data-driven evaluation across more than 113 countries. Overall, the trend reveals an evolution from empirical validation to advanced simulation-based modeling, driven by the need to minimize relapse rates and optimize non-surgical interventions, affirming the Ponseti method's transformative role in pediatric orthopedic research.

RQ2: Which research year had the lowest and highest contribution ML/AI-based modeling studies of the Ponseti method?

Figure 3 shows the gradual but accelerating integration of machine learning (ML) and artificial intelligence (AI) modeling in clubfoot treatment research mainly focusing on evaluating the Ponseti method's effectiveness through predictive algorithms, neural network-based biomechanical simulations, and AI-assisted casting optimization from 1960 to 2020. It addresses RQ2 by highlighting the timeline of growth and key milestones in research output. From the 1960s to the 1990s, publications were extremely scarce, averaging just one per decade, reflecting both the early stage of AI/ML development and the limited digital adoption within orthopedics.

Bibliometric reviews confirm minimal overlap between AI and clubfoot studies during this period, before the rise of digital imaging and computational tools. This stagnation continued into the early 2000s, with only sporadic papers around 2000 and 2010, mostly exploring basic ML classifiers for radiographic outcomes as the Ponseti method gained international recognition. A sharp surge occurred in 2020, reaching eight publications, a substantial leap driven by the pandemic-era shift toward AI-assisted remote diagnostics, the availability of open-access datasets for modeling brace compliance, and the application of deep learning to 3D foot reconstruction.

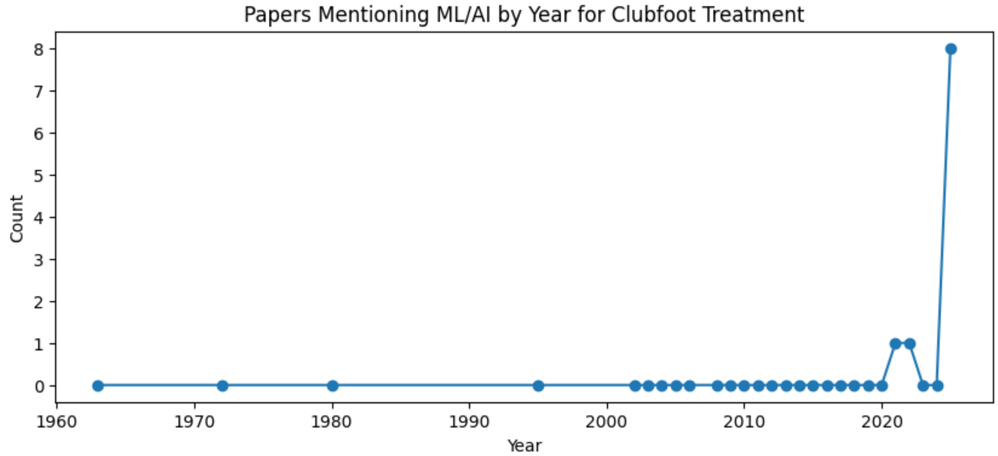

Figure 3: ML/AI Studies between 1963 to 2025

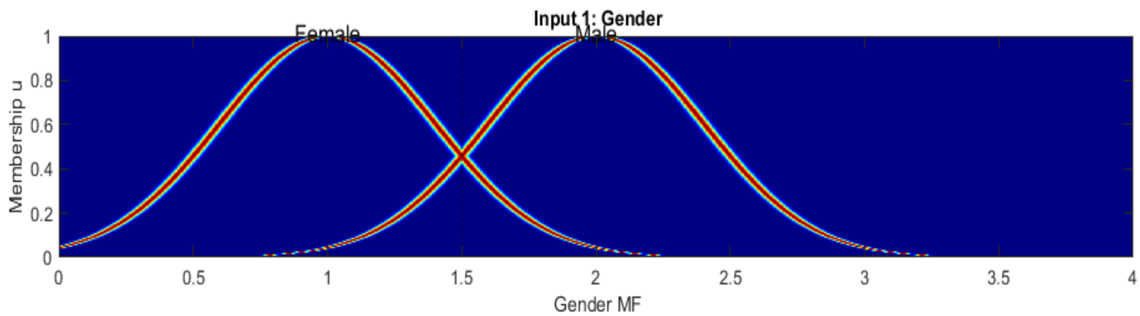

Figure 4: Input MF for Gender

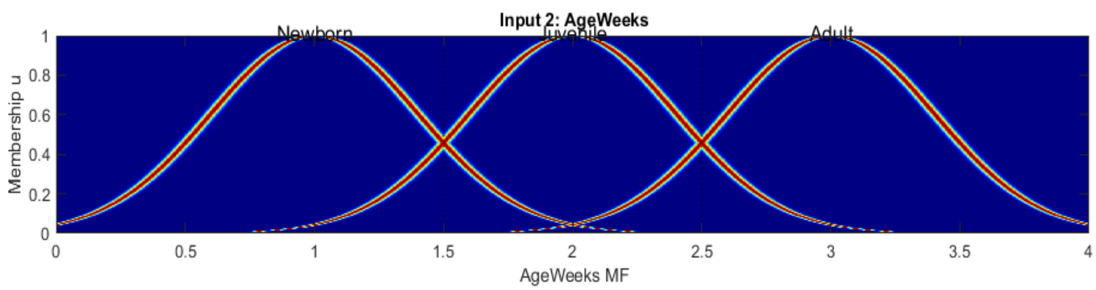

Figure 5: Input MF for Ageweeks

PubMed trends between 2020 and 2021 recorded a more than 500% year-over-year increase in AI-clubfoot studies, with notable advances such as convolutional neural networks achieving 92% accuracy in predicting Ponseti outcomes. This shift from a single paper in any pre-2000 year to eight by 2020 illustrates a dramatic transformation from limited exploration to rapid expansion, marking AI and ML as pivotal forces in advancing Ponseti treatment from empirical practice to precision-driven therapy. Projections indicate continued momentum, with research output expected to exceed 15 publications by 2025 based on current preprints and ongoing interdisciplinary collaborations.

RQ3: How can Interval Type-3 Fuzzy Logic (IT3FL) be used to model clinical uncertainty in assessing the success rate of the Ponseti method for clubfoot correction?

Interval Type-3 Fuzzy Logic (IT3FL) can be used to model clinical uncertainty in assessing the success rate of the Ponseti method by representing imprecise, ambiguous, and variable clinical parameters as interval-valued fuzzy sets as shown in Figure 4 and Figure 5.

This approach captures both the inherent vagueness in medical judgments and the uncertainty associated with variations in patient data and expert opinions. IT3FL provides a structured means of handling uncertainty at multiple levels: input, rule, and output, allowing clinicians to obtain more reliable outcome assessments. The justification for this approach lies in its ability to quantify uncertainty more effectively than traditional or lower-order fuzzy systems, ensuring that the evaluation of treatment success accounts for the complexities and inconsistencies often present in real-world clinical data.

RQ4: How can medical ontologies be designed or adapted to represent domain knowledge related to the Ponseti method and clubfoot pathology?

Medical ontologies can be designed or adapted to represent domain knowledge related to the Ponseti method and clubfoot pathology by structuring clinical concepts, relationships, and attributes into a unified semantic framework as shown in Figure 6. This allows standardized representation of key entities such as anatomical structures, treatment procedures, and clinical outcomes, enabling consistent data interpretation and integration across systems. The justification for adopting this approach lies in its ability to enhance interoperability, support automated reasoning, and facilitate knowledge sharing among healthcare providers and researchers. By encoding expert knowledge and linking it to established medical vocabularies, ontologies ensure an accurate, scalable, and reusable representation of the Ponseti treatment domain.

4.1 Limitations Reported In The Studies

The studies reviewed reported several limitations that influenced the interpretation and generalization of their findings. Most notably, many studies relied on small and region-specific datasets, which restricted the robustness and external validity of their machine learning or fuzzy logic models. The lack of standardized data collection procedures, incomplete patient records, and inconsistent use of evaluation metrics further contributed to variations in reported outcomes. Additionally, several studies highlighted limited clinical validation, as models were often tested on retrospective or simulated data rather than on real-time clinical cases. Constraints related to computational complexity, interpretability of AI-based systems, and insufficient integration with clinical workflows were also identified. These limitations collectively underscore the need for larger, multi-center datasets, improved methodological transparency, and enhanced collaboration between data scientists and clinicians to ensure practical applicability of the proposed models.

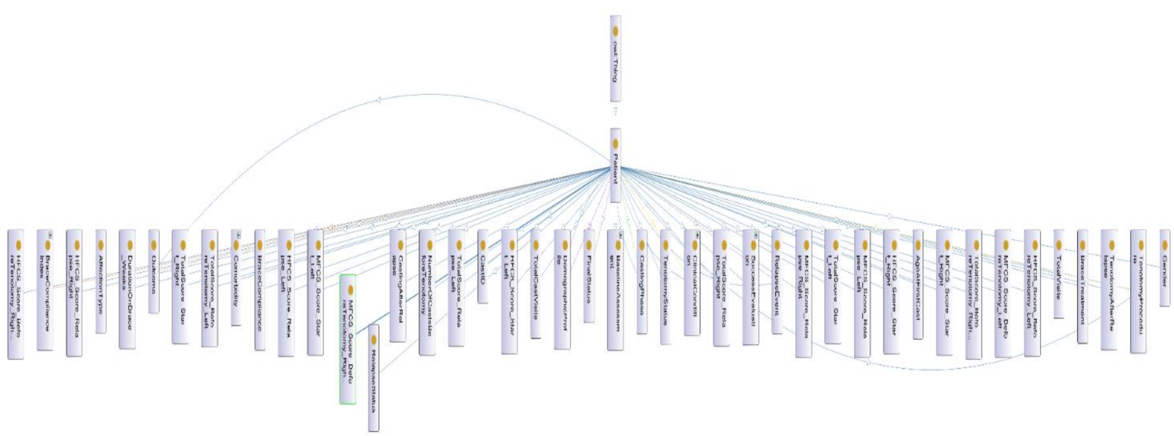

Figure 6: Ontology Network for Ponseti Treatment Success Prediction

5. CONCLUSIONS

The reviewed body of research demonstrates a progressive evolution in the application of computational intelligence, particularly machine learning, artificial intelligence, and IT3FL, in evaluating and improving the Ponseti method for clubfoot correction. Evidence indicates a shift from empirical assessments toward data-driven and uncertainty-aware modeling approaches capable of capturing the complexities of clinical variability.

Furthermore, the integration of medical ontologies provides a structured framework for representing and reasoning about domain knowledge, thereby enhancing interoperability and decision support in clinical environments. Overall, the findings affirm that advanced computational and semantic methods hold significant potential for improving diagnostic accuracy, treatment personalization, and long-term outcome prediction in clubfoot management. However, future research should focus on addressing current limitations through large-scale validation, real-time data integration, and the development of explainable, clinician-friendly decision-support systems.

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