31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Clinical Validated Computer-Aided Decision System to the Clubfeet Deformities

Tien Tuan DAO, Frédéric MARIN, and Marie Christine HO BA THO

Abstract— **A Computer-Aided Decision System (CADS) was developed in order to assess the abnormalities of the clubfeet deformities. Our system consists of four components: 1) a diagnosis-based ontology of the musculoskeletal system of the lower limbs 2) a database for collecting clinical observations of the clubfeet deformities, e.g. the birth classification 3) the decision tree method and a diagnosis algorithm in order to predict new issues 4) an interactive module for managing the interaction between patients, experts and the due CADS. The pathological decision tree of the relationships between different parameters concerning clubfoot (equinus, varus, medial derotation of the Calcaneo-MidForefoot Unit, supination, muscle function, and joint flexibility) was computed. Rule knowledge was deduced to classify the 3 grades of the clubfoot deformities (Moderate, Severe, Rigid). Our system was validated clinically with the real patient data obtained from the Infant Surgery Service in Robert Debré Hospital in Paris. The remote access into our system has been guaranteed through a dynamic Web-based interface. Our system was developed in order to allow a better assessment for improving the knowledge and thus the evaluation and treatment of clubfeet**

I. INTRODUCTION

Rotational abnormalities, clubfoot, and cerebral palsy are the most common pathologies of the musculoskeletal system of the children. Clubfoot is more related to the feet and concerns new born [1]. The congenital deformities can be appeared with unilateral or bilateral abnormalities. The main strategy of treatment is the conservative treatment with different approaches such as the Ponseti technique [2], Ilizarov technique [3], or the French technique ([4]-[5]). Each approach presents its robustness and also its disadvantages. Moreover, the efficiency comparison between different series is hardly realized due to the lack of common concepts. In order to allow the same language for pediatric orthopaedists who are involved in clubfoot, an International ClubFoot Study Group (ICFSG) has been founded. A nomenclature and a rating system [6] was proposed for facilitating the comparison of the results of the various series of clubfoot. Furthermore, the better understanding of clubfoot deformities improves the assessment, the treatment, and the long-term follow-up of clubfoot. But the question is how to broadcast, update, and share the knowledge skill in the medical and clinical research communities.

The computed-aided decision is a good solution to understand and model the pathology. The expert systems, the first generation of the computer-aided decision system, have been studied since 1976 with Mycin as one of older experts systems [7]. After that, many applications were developed in the medical diagnosis field ([8]-[9]). But these systems were not successful because they were black boxes. The diagnosis was done without the explanation about the pathological causes. Another ideal weakness of these experts systems is the interaction between patients (the users) and experts (surgeon, physiotherapist, etc) is poor and not friendly.

The new generation of the expert system was appeared with different terminologies such as Computer-Aided Diagnosis System, Computer-Aided Decision System. These systems were developed in order to allow an interactive interface between the system and the user. In the literature, there are many studies concerning these approaches but most of these systems were dedicated for one function in the diagnosis process, e.g. mammography [10], imaging treatment [11], otology [12]. Other limitation of these studies is the lack of post diagnosis process as the treatment and follow-up. Nowadays, the Web-based Expert System is widely developed [13]. The software development technologies such as J2EE and the expert system shell have many applications in real context [14]. On the other hand, the ontology appeared as a good solution to share the common comprehension of the structure of information between the researchers ([15]-[16]). Then it allows also the re-use of the knowledge in various systems. This approach is also applied to build the knowledge-based system using the accumulated knowledges to reason, diagnose or give adequate decisions [17]. But according to our knowledge ontology concerning biomechanics does not exist, we have initiated it recently for the musculoskeletal system [18].

The aim of this study was to develop a Computer-Aided Decision System (CADS) applied to the clubfeet deformities. An universally scoring system is integrated into our previous system [19] for classifying the grades of the clubfeet deformities (Moderate, Severe, Rigid). The assessment, conservative treatment and monitoring of the clubfeet deformities are also set up. Our system was validated clinically with the real patient data obtained from the Robert Debré hospital in Paris. Our system is developed in order to allow a better assessment for improving the knowledge and thus the evaluation and treatment of clubfeet.

This work was not supported by any organization

T.T Dao is with CNRS UMR 6600 Biomécanique et Bio-ingénierie, Université de Technologie de Compiègne, Compiègne, France tien-tuan.dao@utc.fr

F. Marin is with CNRS UMR 6600 Biomécanique et Bio-ingénierie, Université de Technologie de Compiègne, Compiègne, France frederic.marin@utc.fr

M.C Ho Ba Tho is with CNRS UMR 6600 Biomécanique et Bio-ingénierie, Université de Technologie de Compiègne, Compiègne, France marie-christine.hobatho@utc.fr

II. METHODS

A. System Architecture

The architecture of our system is illustrated in Fig. 1. The CADS is resulting from a combination of different components: a diagnosis-based ontology, named OSMMI (Ontologie du Système Musculosquelettique des Membres Inférieurs); a database to collect the clinical observations; a statistical model developed by the decision tree method and a diagnosis algorithm. The interactive module is constituted of three parts consecutively: diagnosis, conservative treatment, and follow-up.

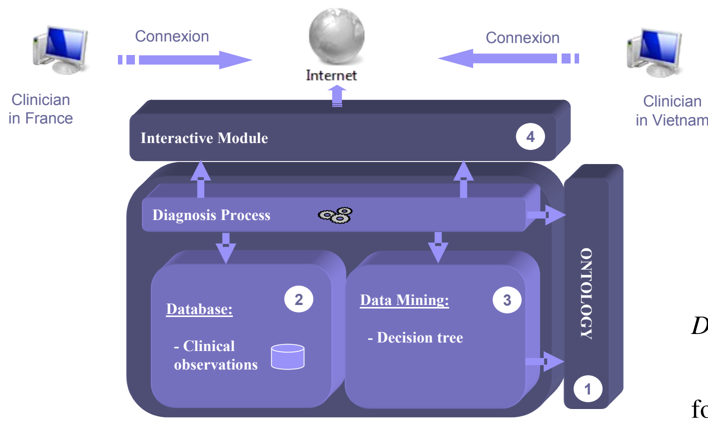


Fig. 1. Architecture of our system

B. OSMMI Ontology

First, the conceptual structure of the OSMMI has to be established in order to have a general sight of ontology. Second, we start to create the OSMMI using the platform Protégé 2000 [20]. Based on built ontology, the last component is the construction of the part of reasoning. The knowledge extraction process was developed by the following steps: 1) the enumeration of the important terms; 2) the definition of the classes and their hierarchy; 3) the definition of the properties of the classes - attributes; 4) the definition of the facets of the attributes: cardinality, types of value, domain, etc and finally the creation of the instances (see [18] for more details).

C. Statistical Model

Decision tree method is used to generate the reasoning scheme of the pathologies concerning the musculoskeletal system of the lower limbs. The algorithm named C4.5 [21] is used to generate the pathological decision tree. The C4.5 generates the rule set by using C4.5 algorithm with strong generalization ability and strong comprehensibility. The rules generated are in conjunctive form such as if A and B then C where both A and B are the rule antecedents, C is the rule consequence. C4.5 uses a divide-and-conquer approach for growing decision tree. The growing process used the information gain criterion of Quinlan as the attribute selection measure. Based on the rule base generated from C4.5 algorithm and also on the new clubfoot pre-treatment evaluation form of the ICFSG, the diagnosis algorithm of the clubfeet deformities was developed and presented as below:

Clubfoot Diagnosis Algorithm
Input: The facts base of clinical observations of the clubfoot deformities FBC. The rule-based knowledge base of the clubfoot deformities RKBC
Output: A grade of the clubfoot deformities G.
Begin

(0) Define the necessary function add for summarizing the total score
(I) Load the rule-based knowledge base RKBC into the inference system
(II) Enter the facts base FBC
(III) Execute the RETE algorithm [22] to fire the corresponding rules and facts
(IV) Search, store, and return the grade G of the clubfoot deformities
(V) STOP

End.

D. Experimental data

A dataset of 1000 (700 for the learning phase and 300 for the testing phase) clubfeet cases (105 Moderate, 868 Severe, 27 Rigid) was used for constructing the pathological decision tree ([4]-[5]). All informative parameters of clubfoot dataset are described in the Table. I. These parameters were used to construct the pathological decision tree of clubfoot deformities.

TABLE I
CLUBFOOT DATA SET: NAME, SHORT DESCRIPTION OF ALL PARAMETERS

Name	Short description
Equinus deformity (eq)	equinus angle in the sagittal plane
Equinus flexibility (eqf)	flexibility level (stiffness, flexible, reducible) of the equnius angle
Varus deformity (vr)	varus deviation angle in the frontal plane
Varus flexibility (vrf)	flexibility level (stiffness, flexible, reducible) of the varus angle
Midfoot Supination deformity (su)	combination angle of the midtarsal foot supination and the medial rotation of the calcaneo-forefoot unit
Midfoot Supination flexibility (suf)	flexibility level (stiffness, flexible, reducible) of the midfoot supination angle
Calcaneo-MidFoot Unit deformity (de)	derotation angle around the talus of the calcaneo-forefoot block
Calcaneo-MidFoot Unit flexibility (def)	flexibility level of the calcaneo-midfoot unit angle
Cavus deformity (cv)	state of the cavus
Ankle Dorsiflexors (adf)	state of muscles function in ankle dorsiflexors
Ankle Plantar flexors (apf)	state of muscles function in ankle plantar flexors
Invertors (inv)	state of muscles function in foot invertors
Evertors (eve)	state of muscles function in foot evertors
Toe Extensors (te)	state of muscles function in toe extensors
Toe Flexors (tf)	state of muscles function in toe flexors

III. RESULTS

A partial pathological decision tree of the clubfoot deformities is presented in Fig. 2. Each internal node tests a clubfoot parameter. Each branch corresponds to clubfoot parameter value. Each leaf node assigns a grade of the clubfoot deformities (Moderate, Severe, and Rigid). The branch connecting the origin with a leaf node is a rule generated in conjunctive form. For example, the most right branch in the clubfoot decision tree demonstrates the following clauses (cavus = Yes and equinus deformality $\succ$ 0 and varus flexibility $\succ$ 1 and Calcaneo-MidFoot Unit deformity $\succ$ 0 and Ankle Dorsiflexors = Non-Reactive and Evertors = Non-Reactive), then the grade of the clubfoot is Rigid.

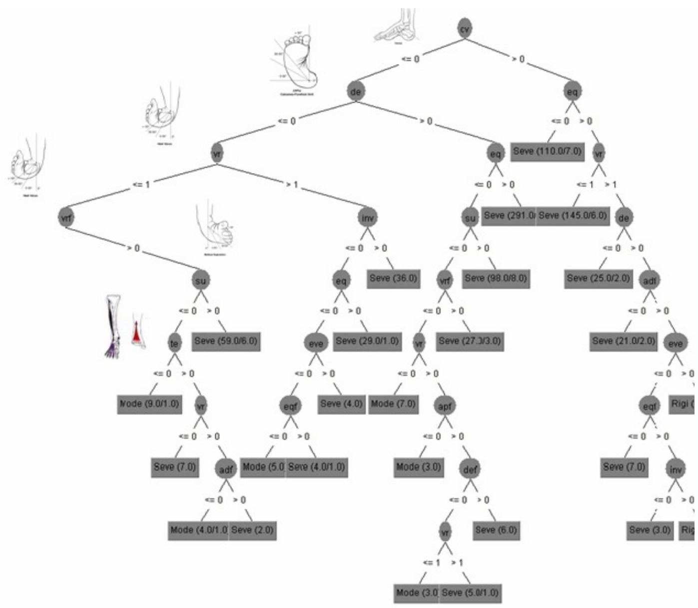


Fig. 2. Partial decision tree of the clubfoot deformities

The rule set of the clubfoot deformities is generated from the pathological decision tree and based on the new clubfoot pre-treatment evaluation form of the ICFSG. A total point of 20 is calculated (Grade I [Moderate: 1 to 6], Grade II [Severe: 7 to 14], Grade III [Rigid: 15 to 20]). An example of the equinus deformity is illustrated in the Table. II. In the rule-based knowledge of the clubfoot deformities, 50 rules are deduced and 24 facts are used for classifying the grade of the clubfoot deformities (moderate, severe, rigid)

The web-based interfaces of the CADS are illustrated in Fig. 3. The assessment, conservative treatment and monitoring of the clubfoot deformities are set up.

The validation of our system is reported in Fig. 4.

IV. DISCUSSION

In this study, a computer-aided decision system was developed in order to investigate the assessment, the conservative treatment and follow-up of the clubfoot deformities. The use of the diagnosis-based ontology for formalizing the rule-based knowledge is a new approach helping to improve the diagnosis decision. In the other hand, our system was developed to broadcast and share the knowledge skill in the medical and clinical research communities.

TABLE II

RULE-BASED KNOWLEDGE OF THE CLUBFOOT DEFORMITIES: EXAMPLE OF THE EQUINUS DEFORMITY

Function	Definition
R1	(defrule r1 (Deviation Equinus Sagittal-plane 90-45)) $\Rightarrow$ (assert (Point-1 4)))
R2	(defrule r2 (Deviation Equinus Sagittal-plane 45-20)) $\Rightarrow$ (assert (Point-1 3)))
R3	(defrule r3 (Deviation Equinus Sagittal-plane 20-0)) $\Rightarrow$(assert (Point-1 2)))
R4	(defrule r4 (Deviation Equinus Sagittal-plane 0-N20)) $\Rightarrow$ (assert (Point-1 1)))
R5	(defrule r5 (Deviation Equinus Sagittal-plane N20)) $\Rightarrow$ (assert (Point-1 0)))

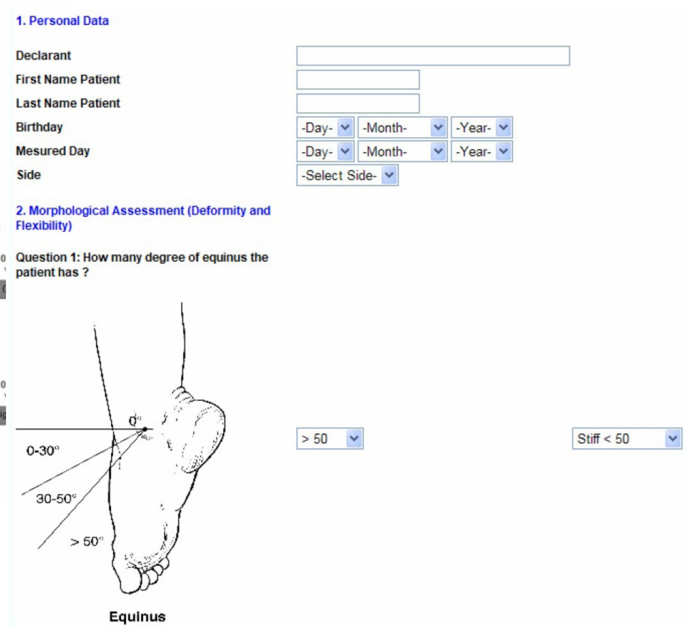
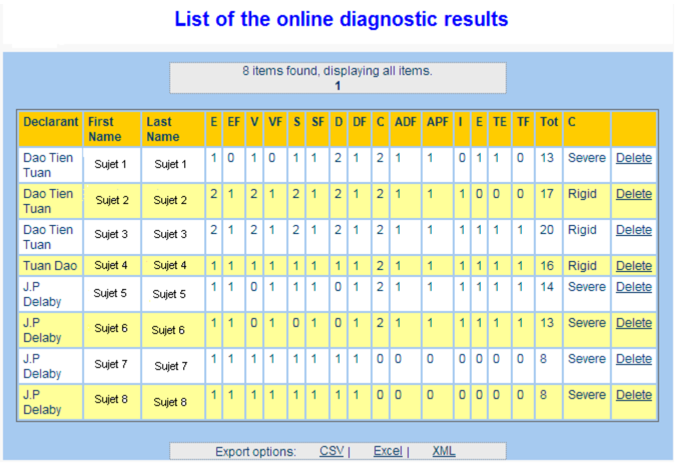


Fig. 3. The web-based interface of the universally scoring system

The conservative treatment and follow-up techniques used in our system was presented with a user-friendly interface. The visualization of the conservative treatment and follow-up was well defined throughout a step by step process. The technique and data used is guaranteed by the physiotherapists working over years at the hospital of Robert Debré in Paris in France. Our system has been validated successfully with the real patient data obtained from the Infant Surgery Service of this hospital.

In the literature review, there are many approaches to construct the predictive medical model such as the artificial neural network, the support vector machine, the decision tree. The comparison between these methods was done in



List of the online diagnostic results

8 items found, displaying all items.
1

Declarant	First Name	Last Name	E	EF	V	VF	S	SF	D	DF	C	ADF	APF	I	E	TE	TF	Tot	C	
Dao Tien Tuan	Sujet 1	Sujet 1	1	0	1	0	1	1	2	1	2	1	1	0	1	1	0	13	Severe	Delete
Dao Tien Tuan	Sujet 2	Sujet 2	2	1	2	1	2	1	2	1	2	1	1	1	0	0	0	17	Rigid	Delete
Dao Tien Tuan	Sujet 3	Sujet 3	2	1	2	1	2	1	2	1	2	1	1	1	1	1	1	20	Rigid	Delete
Tuan Dao	Sujet 4	Sujet 4	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	16	Rigid	Delete
J.P Delaby	Sujet 5	Sujet 5	1	1	0	1	1	1	0	1	2	1	1	1	1	1	1	14	Severe	Delete
J.P Delaby	Sujet 6	Sujet 6	1	1	0	1	0	1	0	1	2	1	1	1	1	1	1	13	Severe	Delete
J.P Delaby	Sujet 7	Sujet 7	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	8	Severe	Delete
J.P Delaby	Sujet 8	Sujet 8	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	8	Severe	Delete

Export options: CSV | Excel | XML

Fig. 4. The report of the validation of our system: different output formats (CSV, Excel, XML) facilitate the statistics of the classification for the clinicians

the previous study [23], the decision tree method shows its robustness, its strong generalization ability (see [23] for more details). The results of the decision tree method are in form of the reduction rule set and it is easy understanding. For the clubfeet, the error rate of the rule base generated from the decision tree method is 0.14 %. The patient data of the Infant Surgery Service of the Hospital of Robert Debré was used to validate our system.

The classification of the grades of the clubfeet deformities is developed as a universally scoring system. The comparison between the studies of the clubfeet deformities before and after the treatment is done based on this component. An online web-based interface is developed. This facilitates the diagnosis and reduces the medical cost of the patient.

V. CONCLUSIONS AND FUTURE WORKS

A clinical validated computer-aided decision system for the clubfeet deformities is developed. An universally scoring system and a remote treatment program were integrated. Different components and a multi-layers architecture are also addressed. The application of the clubfoot deformities is reported. Rule-based knowledge is deduced to classify the grade of clubfoot deformities. The assessment, conservative treatment and follow-up are set up. The remote access into our system is guaranteed through a dynamic Web-based interface. Our system is developed in order to allow a better assessment for improving the knowledge and thus the evaluation and treatment of clubfeet.

In perspectives, we could perform an extension module to evaluate and optimize the efficiency of the physical therapy of the clubfeet deformities.

VI. ACKNOWLEDGMENTS

This present study is dedicated to Professor Henri Bensahel, Orthopaedic Surgeon at the Hôpital de Robert Debré, Service de Chirurgie Infantile, Paris, France. The authors gratefully acknowledge his strong input and contribution giving special value to this work.

REFERENCES

[1] JC. Stephen, B. Birender, CK. Cronan, TK. Nigel, Clubfoot, *Current Orthopaedics*, vol. 22, 2008, pp 139-149.

[2] IV. Ponseti, Congenital clubfoot. Fundamentals of treatment, *Oxford: Oxford University Press*, 1996.

[3] KB. Jeffrey, S. Raymond, Correction of severe residual clubfoot deformity in adolescents with the Ilizarov technique, *External Fixation Techniques for the Foot and Ankle*, 2004 pp 571-582.

[4] H. Bensahel, A. Dimeglio, P. Souchet, Final evaluation of clubfoot, *J Pediatr Orthop B*, vol. 4, 1995, pp 137-41.

[5] P. Souchet, H. Bensahel, TN. Christine, G. Pennecot, Z. Csukonyi, Functional treatment of clubfoot: a new series of 350 idiopathic clubfeet with long-term follow-up, *Journal of Pediatric Orthopaedics Part B*, vol. 13, 2004, pp 189-196.

[6] H. Bensahel, K. Kuo, M. Duhaime, the International ClubFoot Study Group, Outcome evaluation of the treatment of clubfoot: the international language of clubfoot, *J Pediatr Orthop B*, vol. 12, 2003, pp 269-271.

[7] EH. Shortliffe, *Computer based medical consultations: Mycin*, New York, Amer, Elsevier; 1976.

[8] M. Fieschi, *Sphinx : un système expert d'aide à la décision en médecine*, Thèse Biologie Humaine, Fac. Mdecine Marseille, 1983.

[9] G. Botti, M. Fieschi, D. Fieschi, M. Joubert, An expert system for computer-aided decision in diabetes therapeutic, *Path. Biol.*, vol. 2, 1985, pp 101-106.

[10] M. Christiane, A. Malich, M. Facius, U. Grebenstein, D. Sauner, SOR. Pfleiderer, WA. Kaiser,, Are unnecessary follow-up procedures induced by computer-aided diagnosis (CAD) in mammography? Comparison of mammographic diagnosis with and without use of CAD, *European Journal of Radiology*, vol. 51, 2004, pp 66-72.

[11] E. Pietka, A. Gertych, K. Witko, Informatics infrastructure of CAD system, *Computerized Medical Imaging and Graphics*, vol. 29, 2005, pp 157-169.

[12] SG. Leigh, HE. Robert, DA. Marcus, Clinical decision support systems and computer-aided diagnosis in otology, *OtolaryngologyHead and Neck Surgery*, 2007, pp 21-26.

[13] GP. Moynihan, DJ. Fonseca, PTDA2: A Web-Based Expert System for Power Transmission Design, *Progress in Expert Systems Research*, 2007, pp 1-24.

[14] B. Tomic, V. Devedzic, J. Jovanovic, A. Andric, Expert Systems Revisited: A practical approach, *Progress in Expert Systems Research*, 2007, pp 119-152.

[15] S. Stefan, H. Udo, Towards the ontological foundations of symbolic biological theories, *Artificial Intelligence in Medicine*, vol. 39, 2007, pp 237-250.

[16] B. Thomas, D. Maureen, Logical properties of foundational relations in bioontologies, *Artificial Intelligence in Medicine*, vol. 39, 2007, pp 197-216.

[17] LR. Daniel, D. Olivier, B. Yasser, G. David, D. Parvati, AM. Mark, Using ontologies linked with geometric models to reason about penetrating injuries, *Artificial Intelligence in Medicine*, vol. 37, 1961, pp 167-176.

[18] TT. Dao, F. Marin, MC. Ho Ba Tho, "Ontology of the musculoskeletal system of the lower limbs", *in Proceedings of the 29th Annual International Conference of the IEEE EMBS*, 2007, pp. 386 - 389.

[19] TT. Dao, F. Marin, MC. Ho Ba Tho, Computer-Aided Decision System (CADS) to diagnose pathologies concerning the musculoskeletal system of the lower limbs, *Computer Methods in Biomechanics and Biomedical Engineering*, Supplement 1, 2008, pp.73-74.

[20] NF. Noy, M. Crubezy, RW. Fergerson, H. Knublauch, SW. Tu, J. Vendetti, MA. Musen, "Protégé-2000: an open-source ontology-development and knowledge-acquisition environment", *AMIA Annu Symp Proc*, 2003, 953.

[21] JR. Quinlan, *C4.5 Programs for Machine Learning*, Morgan-Kaufmann Publishers, 1993.

[22] CL. Forgy, Rete: A Fast Algorithm for the Many Pattern-Many Object Pattern Match Problem, *Artificial Intelligence*, vol. 19, 1982, pp 17-37.

[23] TT. Dao, F. Marin, MC. Ho Ba Tho, "Predictive mathematical models based on data mining methods of the pathologies of the lower limbs", *in Proceedings of the 4th European Conference of the International Federation for Medical and Biological Engineering*, 2008, pp. 1803-1807.