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Original Article

Design, implementation, and evaluation of the smartphone-based application for dental treatment in oral and dental injuries

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Abstract
Background: Injuries to the mouth and teeth due to various incidents have a high prevalence in society; therefore, it is necessary to diagnose them and provide a suitable treatment plan for them. The purpose of this research is to design, implement and evaluate smartphone-based software for dental treatment in oral and dental injuries in pediatric patients.
Methods: This study is an applied-production study conducted in three stages: The first step is the preparation and design of algorithms, the second stage is the introduction of diagnostic and therapeutic algorithms into the software system, and in the third stage, the software system is evaluated for its efficiency and accuracy in diagnosing and providing a treatment plan. The samples were all 77 patients who were referred to the trauma department of Shiraz Dental School from June to July 2019.
Results: There was a significant correlation between the resident and the professor's diagnosis with the software diagnosis, with 92.2% complete compliance, 3.9% relative compliance, and 3.9% non-compliance (kappa value = 0.91, *P* value < 0.0001).
Conclusion: The accuracy and high speed of diagnosis and the offered treatment plan for all types of oral and dental trauma were acceptable. However, the software cannot replace a specialist and should be used in combination with expert opinion.
Keywords: Dental trauma, Application, Treatment

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Introduction

Injuries to the mouth and teeth have a high prevalence in society. Therefore, it is necessary to diagnose them and provide a suitable treatment plan for them. Quick and accurate diagnosis of injury and the timely provision of adequate care could prevent complications.

Diagnosis in dental trauma is a complex process in which dentists match the symptoms of the patient with their knowledge and experience; this is not easy for students and novice dentists.[1] An acceptable dental diagnosis is prone to error caused by numerous factors. This could be the outcome of an ever-developing knowledge of dentistry. A dental practitioner whose knowledge is not up-to-date is likely to encounter difficulty in reaching a diagnosis for the injuries. Moreover, the heavy workload tends to wear out a dentist's ability to process information and make a definitive decision.[2] Early detection of such diseases prevents their progression and leads to appropriate treatment. Computer-based methods are being increasingly used to improve such medical services.[3] Medical science develops at such a pace that every medical professional encounters a great challenge trying to keep up with the latest knowledge. Computer systems can provide practitioners with this vast information. The clinical experience presented by such systems could surpass that of a lifetime.[4]

Artificial intelligence is one of the domains of computer science that combines computer technology with the simulation of human intelligence.[5] An artificial intelligence system can be in the form of an expert system that has the power to process issues related to a specialized domain and provide a conclusion.

Expert systems are competent means to diagnose issues and come up with solutions as they can point out the cause of the problem and provide a solution to resolve the problem.[6] Expert systems are science-oriented computer programs that have been designed to assist the practitioner throughout diagnosis and treatment planning. These

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systems help the practitioner in decision-making.[7]

Azizi and Mohammadi Khorasani[2] designed and evaluated the efficiency of a decision support system (computer software) aimed at diagnosing soft tissue lesions; in the evaluative phase, 61 oral lesion cases in the Department of Oral Medicine of Ahvaz School of Dentistry were chosen, and the cases and their diagnostic data were presented to three groups of observers, including three oral medicine specialists, 30 general dentists, and 30 senior dental students. They were asked to make a diagnosis both with and without the use of the software. The application of the said software proved to be reliable and beneficial.

Khoramian Tusi and Zeynali[8] introduced an expert system based on Bayesian Networks used for determining treatment plans in cases of pediatric dental caries. This system was supposed to assist both dentists and dental students in treatment planning when they faced difficult cases. In this system, the symptoms were the input variables and the output was treatments. The Bayesian Network was designed based on 13 symptoms of caries used for diagnosis and five related treatments. To determine the relationship between variables, a k-means clustering algorithm was used. The proposed system was evaluated by real patient scenarios and the results showed an acceptable accuracy.

Savabi et al[9] designed a smart software aimed at creating a treatment plan for removable partial dentures; to evaluate this software, the treatment plan output for 40 most common causes of partial edentulism was compared to textbooks and previously collected opinions of medical faculty members. Following the comparison, 36 out of 40 treatment plans were approved. Based on the results, which showed a 90% approval, this program was deemed efficient.

Expert systems are used in a variety of fields including caries detection, oral radiograph interpretation, oral lesion diagnosis, and orthodontics.[8] Even so, a smart system tasked with the recognition and treatment of orofacial trauma has not been introduced yet. An expert system capable of quick and accurate processing of data concerning diagnosis and offering treatment plans for orofacial trauma could be of great use for the achievement of fast and accurate results and reduction of errors and complications.

This study aimed to design, implement, and evaluate a smartphone-based application for dental treatment in oral and dental injuries in children.

Methods

This is an applied-production (software design) study. This study was conducted in three stages: the first stage was preparing and designing the algorithms; the second stage was transferring diagnostic and therapeutic algorithms to the software system and in the third stage was evaluating the efficiency and accuracy of the software system in diagnosing and presenting a treatment plan. The target population for the software evaluation was all the patients referred to the Trauma Department of Shiraz Dental School in June and July 2019.

The sample size consisted of 77 patients. Sampling was done through sequential non-random sampling.

The knowledge database for the algorithms was collected from reliable sources, including textbooks, the *Color Atlas of Traumatic Injuries to the Teeth* (Eds. Jens O. Andreasen, Frances M. Andreasen, and Lars Andersson, 4th Edition), *Cohen's Pathways of the Pulp Expert Consult* (International Association of Dental Traumatology Dental Trauma Guidelines, Revised 2012), radiographic characteristics, clinical presentation, and further diagnostic data.

Based on features of each oral lesion, a set of questions were prepared, intended to facilitate reaching a definite diagnosis (Figure 1). What is important in diagnosing lesions and designing the right treatment plan is the proper sequence of questions; the questions should be arranged in such a way that answering them can lead the dentist to a definitive diagnosis in a step-by-step manner and provide a proper treatment plan in the end. After confirming the structure of the algorithms based on the resources and their confirmation by a root canal therapist, the second step was to build the application.

In the second phase, a software company (Dadeh Negar DatisPars) introduced the algorithms into the software system, using PHP, VUEJS software, and MySQL database, and eventually, the "Oral Trauma Web Application" was prepared. In the third stage (software evaluation) 77 patients referred to the Trauma Department of Shiraz Dental School were used. The procedures were as follows: after each patient entered the Trauma Department of Shiraz School of Dentistry, they were examined by an endodontics resident. Subsequently, the clinical presentations and radiographs recorded by the resident were confirmed by a professor. The diagnosis and treatment plan for the trauma inflicted on the patient were recorded in the patient's file by the professor and the resident. After these steps, the clinical signs and radiographs confirmed by the professor were entered into the oral trauma application, and the diagnosis and treatment plan provided by the software were recorded in a form 1; The patient's demographic information, the name of the resident and the professor, and the diagnosis and treatment plan provided by the resident and the professor were also recorded in the form. After that, the level of compliance between the diagnosis and treatment plan of the professor and the resident and the diagnosis and treatment plan of the software was determined; there were three levels of compliance: 1) Full compliance: the diagnosis and treatment plan provided by the software is 100% consistent with that of the resident and the professor, 2) Non-compliance: the diagnosis and treatment plan of

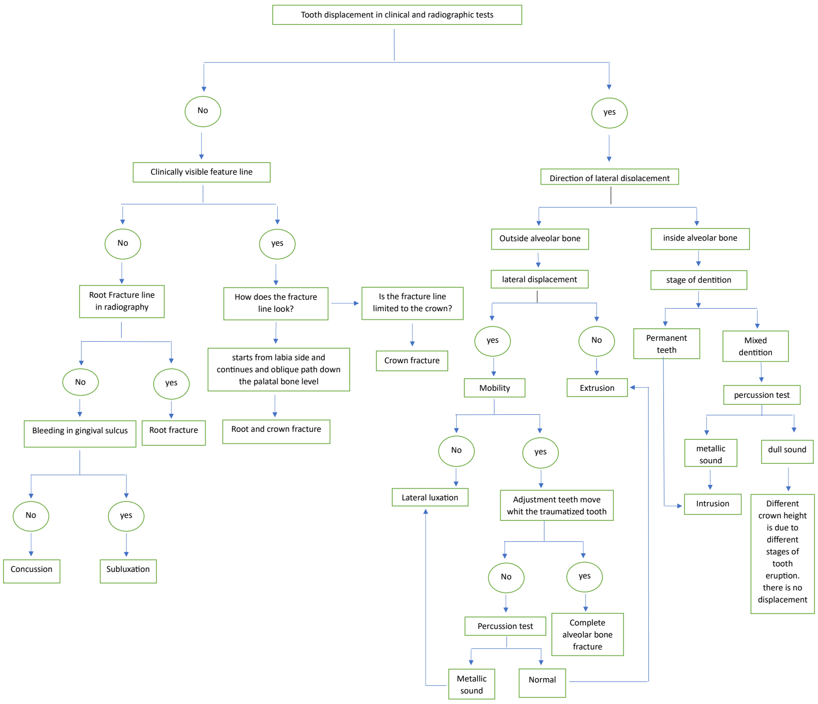

Figure 1. One of the algorithms used in the software.

the professor and the resident do not correspond to the diagnosis and treatment plan of the software, and 3) Relative compliance: If the diagnosis and treatment plan of the professor and the resident are consistent with the diagnosis and treatment plan of the software in some cases, or one is more complete than the other.

Data were analyzed by descriptive statistics and Kappa statistical test by SPSS software.

Results

Every system or software that is designed and built must be evaluated and tested for its efficiency to be determined. To evaluate this study, information concerning 77 patients was used and the results were as follows:

There was 92.2% full compliance, 3.9% relative compliance, and 3.9% mismatch between the diagnosis provided by the software and the professor and the resident; The cases of non-compliance were related to lateral luxation, and the cases of partial compliance were related to cases in which teeth sustained several different types of trauma.

The kappa test was used to measure the agreement between the two groups, of which 77 cases showed complete agreement between the software detection and the professor and resident's diagnosis (kappa value = 0.91 and $P < 0.0001$). The frequency of consistency between the diagnosis of the professor and the resident and diagnosis of the software are shown in Tables 1 and 2.

Based on the information of the 77 cases examined, there was 66.2% full compliance, 28.6% relative compliance, and 5.2% non-compliance between the two groups; based on the type of injury, the frequency of compliance between the treatment plan proposed by the software and that of the professor and the resident is shown in Tables 3 and 4.

Discussion

The present research was conducted to design, implement, and evaluate a smartphone-based application for dental treatment in oral and dental injuries in children.

According to the findings, this software showed acceptable performance; out of the 77 cases examined, there was a 92% complete match, and a 3.8% relative match between the diagnoses of the two groups. Concerning the treatment plan, the professor and the resident compared to the software showed 66% full compliance and 28% relative compliance, and considering software diagnosis, among the 77 cases examined, there were 71 cases of full compliance, 3 cases of relative compliance, and 3 cases of non-compliance. There were three relative compliance cases in which one tooth sustained several different types of trauma, but the software was only able to diagnose one type of trauma due to the limitations of the algorithmic method. As mentioned, one of the weaknesses of the algorithmic method is that it cannot solve the problem of uncertainty, as the paths in algorithms are clear and fixed and in cases with several different types of trauma, the software only recognizes one of the problems. There were three cases of non-compliance in the "lateral luxation" trauma; the reason for this discrepancy was that the software recognition algorithm was designed according to the definition of lateral luxation by Andreasen JO. Software evaluation was performed in the trauma department of Shiraz School of Dentistry, where endodontics professors and residents are present, and the reference which they

Table 1. Frequency of consistency between the diagnosis of the professor and the resident and the diagnosis of the software

Type of injury	Consistency between the diagnosis of the professor and the resident and the diagnosis of the software			Total
	Mismatch	Partial compliance	Full compliance	
Crown fracture	0	0	20	20
Crown-root fracture	0	0	7	7
Root fracture	0	0	5	5
Concussion	0	0	4	4
Subluxation	0	0	8	8
Lateral luxation	3	0	4	7
Extrusion	0	0	7	7
Intrusion	0	0	5	5
Avulsion	0	0	7	7
Alveolar fracture	0	0	3	3
Primary dentition	0	0	1	1
Several traumas	0	3	0	3
Total	3	3	71	77

Table 2. Frequency of consistency between the diagnosis of the professor and the resident and the diagnosis of the software

		Frequency	Percent
Diagnosis of the professor and the resident and the diagnosis of the software	Full compliance	71	92.2
	Partial compliance	3	3.9
	No compliance	3	3.9
	Total	77	100.0

Table 3. Frequency of consistency between the treatment plan of the professor and the resident and the treatment plan of the software

		Frequency	Percent
Compliance between treatment plan of the professor and the resident and the treatment plan of the software	Full compliance	51	66.2
	Partial compliance	22	28.6
	No compliance	4	5.2
	Total	77	100.0

Table 4. Frequency of consistency between the treatment plan of the professor and the resident and the treatment plan of the software

Type of Injury	Consistency between the treatment plan of the professor and the resident and the treatment plan of the software			Total
	Full compliance	Partial compliance	Mismatch	
Crown fracture	18	0	2	20
Crown-root fracture	3	4	0	7
Root fracture	4	1	0	5
Concussion	4	0	0	4
Subluxation	2	5	1	8
Lateral luxation	3	3	1	7
Extrusion	5	2	0	7
Intrusion	4	1	0	5
Avulsion	3	4	0	7
Alveolar fracture	3	0	0	3
Primary dentition	1	0	0	1
Several trauma	1	2	0	3
Total	51	22	4	77

use is mainly the *Pathways* book, and the definition of lateral displacement in these two references is different. Based on Andreasen JO's definition, a tooth that has a lateral luxation does not loosen. On the contrary, any damage that moves the teeth to the side, even if teeth are avulsed or show great mobility, is considered to have lateral luxation in the *Pathways* book. Considering the evaluation of the software's proposed treatment plan, of the 77 cases, 51 cases of complete compliance, 22 cases of relative compliance, and 4 cases of non-compliance were observed. In many cases of software-proposed treatments, the treatment plan provided by the software was based on the reference books and was, therefore, more comprehensive, accurate, and more detailed than the treatment plan provided by the resident and the professor; these cases were identified as "relative compliance." In some cases, the software proposed treatment options such as reconstructive or prosthetic treatment, the need for forced eruption, crown lengthening surgery, antibiotics prescription, etc. Generally, only pulp-related therapies are performed in the trauma department, and the patient is referred for further treatment (the Trauma Department of Shiraz School of Dentistry is associated with the Department of Root Canal Treatment). As a result, concerning the treatment plan, in most cases, the relative compliance was in favor of the software; in some cases, the relative compliance was due to differences in the follow-up time provided by the software (based on the reference) and the follow-up time suggested by the professor; due to the specific circumstances of a patient and at the discretion of the professor, the patient was advised to return sooner. This implies one of the weaknesses of computer programs, i.e., experts consider all the aspects of a case more comprehensively. The inconsistencies of the treatment plan proposed by the software were due to some weaknesses. First, in case of lateral luxation trauma, the amount of displacement was undefined in the software. In some cases, when the displacement is very low (about 1 mm), teeth may not loosen after repositioning and therefore do not require splinting. This was not programmed into the software as it was not mentioned in the book. Second, the patient's visit time has not been included in the software for some traumas, i.e., in some cases the treatment plan that the software proposed suited a patient who was referred shortly after an injury. However, the professor also considered the patient's visit time, and if several weeks had passed since the trauma to the tooth, depending on the condition of the tooth and the results of the tests, his treatment plan would be quite different from the software. The other two cases of inconsistency were when the patient had referred 1 month after a complicated crown-root fracture, but following the clinical examination and dental radiography and based on the signs of pulp vitality, the professor suggested MTA pulpotomy instead of the apexification treatment suggested by the software based on references, which showed good response of the tooth and favorable results in follow-up sessions. Therefore, it can be concluded that due to the less comprehensive approach of computer programs, they cannot replace an expert and their use should be accompanied by a professional's opinion as in some special or complex cases, one has to make decisions based on the specific circumstances. For the treatment plan, in many cases of partial compliance, the treatment plan provided by the software was more complete, accurate, and more detailed than the one provided by the resident and the professor, i.e., not only did the software propose the same treatment plan, but it also considered aspects not mentioned by the professor but discussed in reference books. The sum of full compliance and partial compliance (94%) was considered the criterion for software efficiency in the presentation of the treatment plan.

Efforts to use artificial intelligence in medicine were initiated in the early 1970s.[10] Many expert systems are currently used in medicine, including the PUFF expert system for diagnosing lung diseases, the BlueBox expert system for diagnosing and treatment of depression, and the MYCIN expert system for diagnosing and treatment of microbial diseases.[8] To the best of our knowledge, there is no software for diagnosing and treating trauma to the mouth and teeth; therefore, there is no oral trauma software in the field that can be compared with our software, but in some respects, this software can be compared with other diagnostic and therapeutic software discussed in the review section of this article.

Khoramian Tusi and Zeynali[8] presented an expert system for determining the treatment plan for dental caries in children; in this system, the input variables were the patient's symptoms and the output was the proposed treatments. In this respect, it is to some extent similar to our software. The accuracy of the output in this system was 95%, which was almost identical to the present study. In contrast to the present study, Khoramian Tusi and Zeynali used a Bayesian Network. A Bayesian Network is a computational technique for creating information structures and arriving at logical inferences from information using statistical and probabilistic methods.

Azizi and Mohammadi Khorasani[2]designed and evaluated the efficiency of a decision support system to detect soft tissue lesions; utilization of the software was proven to be reliable and useful by statistical analysis. The efficiency of this system was 100% when used by oral medicine specialists, 75% for general dentists, and 83% for senior dental students. In the present study, the patient's information was entered into the software by senior dental students. As a result, Azizi and Mohammadi Khorasani's study[2] can be compared with the present study considering the results achieved by the final year dental students (83%), which makes the present software more efficient. Azizi and Mohammadi Khorasani's study[2] had a better and more accurate assessment method compared to the present study; in their study, the effectiveness of the software was determined by lesions whose definitive diagnosis was made by bone marrow biopsy and laboratory tests, which is a gold standard, while the use of the diagnosis and treatment plan suggested by the professor as the gold standard, as used in the present study, is less accurate due to human error. This evaluation method was unavoidable due to the nature of trauma injuries, which cannot be confirmed by histopathology.

Savabi et al[9] designed a smart software to present a treatment plan for removable partial prostheses. The efficiency of this software was 90%, which was almost similar to our software. The study concluded that the software could be a good guide for educating students and retraining dentists, as well as facilitating and increasing the accuracy and speed of choosing treatment plans, which is also true for the present software.

The advantage of our software over the two mentioned software is that it is web-based and can be used on all operating systems, including Android, IOS, Windows, etc. It is easy to modify and update. In addition to the "Diagnosis" and "Treatment Plan" sections, this software also has a section called "Basic Principles" which explains the important tips on how to deal with a trauma patient and the necessary clinical examinations and radiographs. In addition, when the dentist makes a final diagnosis, they can view the schematic image of the lesion in the software and use a feature called "further study." If they select the feature they can read the explanatory material about the characteristics of the lesion, which could help the dentist remember what they may have forgotten, and always have a summary of the reference book available.

The limitations of this study were related to the evaluation of the software; in this study, the diagnosis and treatment plan of the professor and the resident were considered the gold standard and were compared with the diagnosis and treatment plan of the software, which was programmed based on the reference books. Due to the circumstances that may cause human error, such as fatigue, forgetting some information, unfavorable mental condition, rushing, etc., the diagnosis and treatment plan of the professor and the resident may not be 100% correct. However, the use of this evaluation method was unavoidable due to the nature of trauma injuries, which cannot be confirmed by histopathology. In software for the diagnosis of jaw bone lesions or soft tissue lesions, as the lesions can be sampled after the diagnosis and sent to a laboratory for final diagnosis, the evaluation of the software is very simple and accurate. However, this was not possible with different types of trauma.

Another limitation of this study was that among the samples used, there was no case of soft tissue damage; there was only one case of deciduous tooth trauma, which is not enough to evaluate the effectiveness of the software. The reason for the absence of this type of trauma in our samples was that the evaluation was performed in the Trauma Department of Shiraz School of Dentistry, which is related to the Root Canal Treatment Department. Usually, the treatments related to permanent tooth pulp are performed in this department, and for further treatment, such as soft tissue injuries or trauma to the primary teeth, the patient is referred to the other department.

It is recommended that a prospective study be performed to complete the software evaluation. In this study, patients can be treated based on the software's response, and the results can be recorded through follow-up examinations. Also, considering that the software is made based on a reference, a study can measure the error rate of dentists and the level of deviation from the reference.

In addition to these studies, it is recommended that further research be performed on "soft tissue injuries" and "deciduous teeth" in surgery and pediatrics departments.

Strengths and Limitations

Based on the results of this study, which confirmed 92% of the diagnoses and 94% of the treatment plans, this program functions with favorable adequacy, but the remaining 8% and 6% indicate the need to upgrade this program in the future. Changes can also be made to the same version of the software to achieve higher adequacy; it can also be concluded that due to the more limited scope of computer programs, the software cannot replace a specialist in some special or complex cases in which decisions should be made based on specific circumstances, in which case, the program's suggestion should be accompanied by an expert's opinion.

Conclusion

The comprehensive information provided by this software and the step-by-step diagnosis and treatment plan can facilitate and increase the accuracy and speed of diagnosis and treatment plan selection for all types of oral and dental trauma.

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Writing–review & editing: Maryam Bakhtiar.

Competing Interests

The authors have declared that no conflict of interest exists.

Data Availability Statement

All data are available.

Ethical Approval

The study was approved by the Ethics Committee of Shiraz University of Medical Sciences (Approval ID: IR.SUMS.REC.1398.553).

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