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A proposal for a database of sounds generated by temporomandibular joints and a tool for automated diagnosis based on an RDC/TMD questionnaire

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Abstract: The prevalence of TMD indicates a need to develop new tools that are useful in the case of screening examinations. These methods can support diagnosis at the early stage of the disorder. The purpose of this research was to develop a comprehensive tool that would function as both a database of sounds generated by TMJ and as software which facilitates automated diagnosis. The software would also use the data from the RDC/TMD questionnaire. Such a tool may significantly reduce the time spent by dentists on making manual RDC/TMD diagnoses. Moreover, this solution would enable dentists who do not specialise in TMD to make effective diagnoses. 95 patient took part in the clinical examination: 30 man and 65 females. The mean age of the participants was 33 years. Patients participating in the clinical process were examined according to the Polish version of the RDC/TMD questionnaire (Axis I and Axis II). Subsequently, all subjects were auscultated with an electronic stethoscope. An application has been implemented based on the RDC/TMD diagnostic flow chart. This tool was used for the automated generation of RDC/TMD diagnoses for all patients. As a result of the kind permission and participation of the patients under examination, it was possible to store records of ninety-five people. Each record contains RDC/TMD questionnaire data, auscultation signals and RDC/TMD diagnoses. For the first time, a database was created that has the potential to facilitate further examination. However, the developed system is universal and can therefore be adapted to new DC/TMD criteria.

Keywords: auscultation; TMJ, temporomandibular joints; TMJ sounds database; TMD, temporomandibular disorder; RDC/TMD.

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Introduction

In the literature, there is different data about the prevalence of temporomandibular disorders (TMD) but among general population, the rate is 31% for adults and 11% for children [1]. The substantial number of patients with TMD, both in Poland and worldwide, generates a need to look for a diagnostic tool which could support dentists in the diagnostic process of temporomandibular joints (TMJ) [2–5]. Various questionnaires have been used in the diagnosis of TMD during clinical examination [6–10]. The use of different questionnaires by researchers means that the results are not comparable. To standardise research tools, an international consortium has developed a universal questionnaire Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) to provide a unification of all TMD diagnostic procedures [11]. It was translated into twenty-one languages. The Polish version of the RDC/TMD questionnaire has been available since 2013 and was prepared by Osiewicz *et al.* [12, 13]. The name of the questionnaire translated into Polish translation is "Badawcze Kryteria Diagnostyczne Zaburzeń Czynnościowych Układu Ruchowego Narządu Żucia" (BKD/ZCURNŻ). In the remainder of this article, the short name RDC/TMD of the questionnaire will be used. This survey consists of detailed step-by-step instructions describing how to conduct an examination and also includes verbal phrases that should be used with the patient during diagnosis. The aim of such detailed instruction is to standardise the examination and eliminate the influence of the individual dentist's behaviour and verbal comments on the outcome of the evaluation. Currently, a newer version of the RDC/TMD questionnaire known as DC/TMD (Diagnostic Criteria for Temporomandibular Disorders) [14] is available. At the time of writing this article, the Polish version of RDC/TMD is still available, and a newer version is in final preparation. The Finnish researchers confirmed in their study that the results obtained from the RDC/TMD questionnaire coincide with the results obtained from new questionnaire DC/TMD [15]. Nowadays, one of the additional diagnostic tools commonly used for temporomandibular joints (TMJ) examination is an auscultation [16–21]. Auscultation is the basic diagnostic tool used by clinicians of various specialisations. This is technique that is commonly applied in cardiology and pulmonology but it also supports the diagnosis of conditions relating to joints and intestines. However, this method is also largely dependent on the skills and experience of the medical personnel conducting the examination. It may also be prone to inappropriate pressure forced on the top of measurement head and artefacts caused by facial hair. The solution for the mentioned limitations is an electronic stethoscope which supports the storing of the records in digital format and implements a set of computational techniques to limit the impact of noise and artefacts on the resulting diagnostic signal.

The development of a TMJ sounds database will support auscultation training by providing reference signals to inexperienced dentists. The storing of signals also offers the prospect of computer-aided diagnosis and the automatic classification of biomedical signals. In addition, computer-assisted auscultation also enables the visualisation of signals, which significantly improves the effectiveness of the teaching of diagnosis based on the auscultation of the patient. In the case of heart sounds, the PhysioNet online public library provides many reference signals which are commonly used by researchers. Despite the high prevalence of TMD, no similar database has thus far been published for TMJ sounds. Considering the increasing numbers of patients suffering from TMD and after analysing the available literature and reviewing RDC/TMD diagnostic diagrams, we have found it feasible to develop a solution for storing RDC/TMD patient records and automatically calculating correlated TMJ diagnosis. Such an approach would shorten the time dentists spend on tedious manual RDC/TMD diagnosis on a daily basis. However, above all, our solution would enable patients to be diagnosed by dentists who in their daily practice work with procedures other than TMD treatment. It would help to direct patients to specialists more quickly in order to determine and deliver treatment.

The purpose of the research was to create and develop a database of acoustic signals of the TMJ which will be available for download after tests.

Another objective of the study was to create a computer system that would enable the automation of diagnostics of the masticatory system based on standard clinical procedures.

Combining these two aims, the overall goal was to create a comprehensive tool that would be both a database for sounds generated by TMJ and an application for automating RDC/TMD diagnoses, which would significantly reduce the time spent on making diagnoses according to the guidelines and allow dentists to appropriately instruct the patient.

Materials and Methods

The study was performed on a group of patients of the University Dental Clinic in Krakow who suffered from disorders of the masticatory system.

Ninety-five patient took part in the clinical examination. There were 30 man and 65 females. The mean age of the participants was 33 years. Every participant was informed about the aim of the study and gave written consent to participate in the examination which was officially approved by the Jagiellonian University Bioethics Committee (consent number 1072.6120.71.2019). The inclusion criteria were to accept all adults in the age 18 to 52 years who volunteered to participate in the study. The exclusion criteria were the occurrence of general diseases that make it impossible to continue in the research, withdrawal of consent to participate in the project and signals that were recorded from TMJ incorrectly.

Examination

Patients were examined according to the polish version of the RDC/TMD questionnaire (BKD/ZCURNŻ) [13] Axis I and Axis II. The diagnosis was made according to specific and detailed decision-making diagrams separately for the left and right joints according to the RDC/TMD Diagnostic Algorithms. Part of the patients diagnosed with TMD decided to begin treatment in the clinic.

For the purposes of this article, manual diagnosis was defined as the "standard method". Each patient could obtain up to five different types of diagnoses, which is significantly time consuming. As a result of the implementation of the logic defined by the algorithms from the article written by Osiewicz *et al.* [12, 13] the diagnosis is automatically made by the software.

To determine the time gain in automating diagnosis, the time needed to make diagnoses at the same 10 patients was compared in a standard way — manually and using the application.

The designed application provides a graphic user interface that allows the user to add, delete and edit patient records containing all the data necessary to issue a diagnosis based on the RDC/TMD form. The experimental approach is shown in Figure 1, which depicts a simplified flowchart of the examination procedure.

Entering test data into the application enables a fast diagnosis of the patient and if necessary a referral to a specialist for treatment. In addition, the software has a built-in module for calculating and visualising histograms of various diagnoses, as well as sex and age statistics of patients registered in the database as shown in Figure 2. The designed software was developed in the Python 3.8 programming language using the PyQt5 application framework and the Matplotlib data visualisation library. The SQLite database engine was used for storing the structured patient data in the non-volatile memory of the computer. The code of the application is available as an open-source project under the GNU General Public License v3.0 on the GitHub server at https://github.com/marcinkajor/TMJ-RDC-Diagnoser.

Auscultation

A vital stage of this study was the auscultation of TMJ on the left and right sides of the body. Each joint was considered separately. Patients were examined by a dentist through the application of the head of a Littmann 3200(3M™) electronic stethoscope to the preauricular area during jaw opening and closing movements.

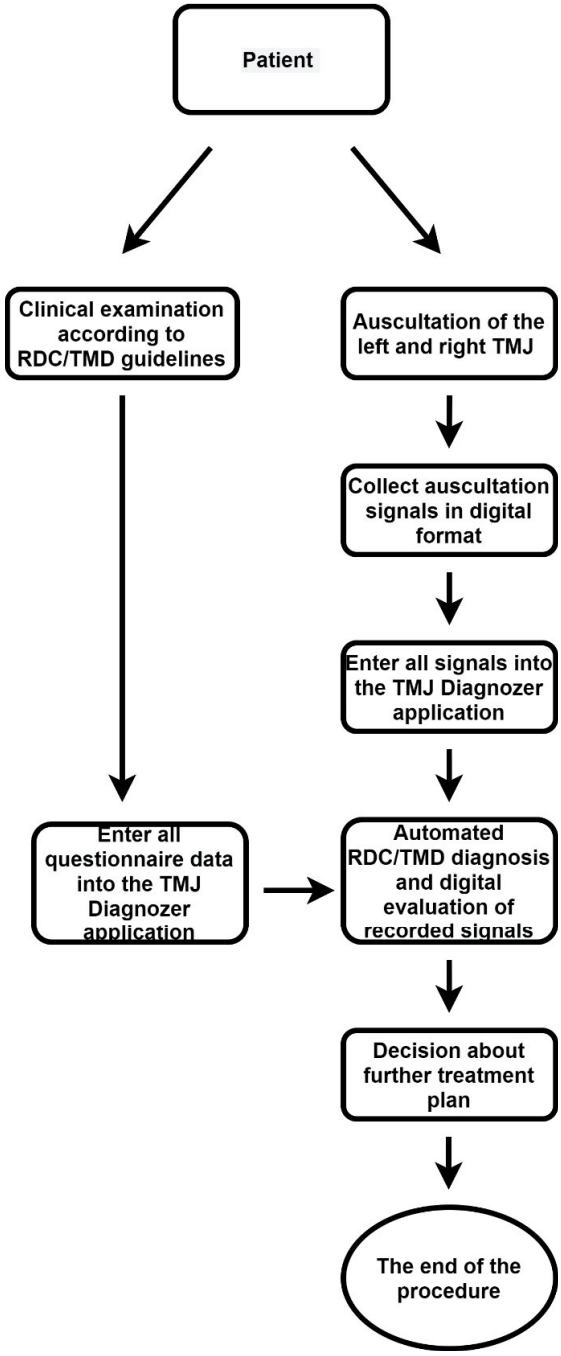

Fig. 1. Flowchart of the examination procedure including the application of the RDC/TMD questionnaire and auscultation with an electronic stethoscope.

Fig. 2. Application screenshots: **a)** database view, **b)** new patient record, **c)** recorded sound from joint, **d)** "File" tab with available options, **e)** general statistic based on patients records, **f)** statistic window with histogram.

Data storing

The application enables users to register patient records along with digital auscultation signals collected during a dental examination. The database supports storage of up to eight audio files (uncompressed WAV format) recorded during auscultation at a sampling rate of 4000 Hz. This is the sampling frequency at which the electronic stethoscope works. The system enables the digital recording of signals of frequencies up to 2000 Hz. This feature corresponds to the specificity of auscultation signals for which the main components are in the low frequency range. Therefore, the auscultatory signal of the joints collected by this device is diagnostically useful. The entire database can be imported and exported into a single file with the '.rdc' extension or into a zip archive containing structured measurement files from each patient and correlated RDC/TMD diagnoses in text format.

The program is also equipped with a module that allows the dentist to segment each auscultation signal by extracting a section of diagnostic importance into a '.csv' file. This functionality was used to generate reference data for the training and validation of the algorithms for the automatic segmentation of sounds generated by TMJ.

Results

The database contains ninety-five patient and 321 TMJ acoustic signals recorded from both the left and right joints as a result of multiple auscultation of the patients undergoing TMD treatment. During every visit for undergoing treatment patients were auscultated with a stethoscope and the recordings were attached to the sound database.

Our application enabled us to significantly reduce the time needed for a single diagnosis made according to the guidelines from the RDC/TMD questionnaire. Table 1 presents a comparison of the time needed for a single diagnosis in the case of a standard (manual) method and the automated procedure made by application. Measurements were performed on ten patient records which were used to made a diagnosis by one author (JG) with the use of RDC/TMD diagrams and the delivered software.

Our results showed that an average decrease of time needed for a single diagnosis was almost twenty-seven minutes.

All data was collected during clinical examination and includes digital auscultation measurements combined with diagnostic information from the RDC/TMD questionnaire.

The significance of this achievement can be emphasised by the fact that no similar database of TMJ acoustic signals has been reported in literature. This can facilitate the learning process of dentistry students and may become a reference for further research related to the signal processing of TMJ sounds.

Table 1. Comparison of the time needed for a single diagnosis made by the automated method and with the use of a standard manual method.

		Time taken for a single diagnosis (minutes)	
		Standard method	**Automated method (TMJ RDC Diagnoser application)**
Dentist (JG) who made diagnosis according to the guidelines from the RDC/TMD questionnaire	patient 1	32	6
	patient 2	33	5
	patient 3	36.5	5
	patient 4	28	5.5
	patient 5	40	6
	patient 6	30	6
	patient 7	30	5
	patient 8	32.5	5
	patient 9	25	4.5
	patient 10	35	5
Mean		32.2	5.3
Average time reduction		26.9	

Discussion

Dentists are currently noticing an increase in the number of patients with symptoms like tension in the muscles of the head and neck area, bruxism, clicking and crepitations in TMJs because of the pandemic situation of the recent past [22, 23]. COVID-19 positive patients have demonstrated an increased risk of developing TMD [24, 25].

Moreover, stress, psychological and emotional disturbances, the work environment and the emotional tensions can also have an effect on TMD [26–28].

Patients with acoustic symptoms within TMJs, limitation or difficulty of the jaws movements are a large group of TMD patients [29].These problems concern patients of every age. Such disorders affect the general condition of the health and decrease the quality of life [30, 31]. Adolescents diagnosed with TMD showed an increase inclination towards depression and somnolence, as well as a deterioration in the quality of sleep [32].

As previously mentioned, the TMD screening test is the RDC/TMD questionnaire. Unfortunately, it requires manual analysis of collected data based on documented decision diagrams which is time consuming and prone to errors in its execution.

According to the conducted study, the developed computer application which supports automated RDC/TMD diagnosis reduces the diagnosis process by an average of almost twenty-seven minutes. This is the time which can be utilised to diagnose more patients.

The benefit of the application is the ability to screen patients by dentists not involved in TMD treatment and, if necessary, to refer patients to a specialist. This process makes it is easier to make diagnoses.

A database of TMJ sounds can also function as a source of knowledge for other dentists. Due to the fact that a database containing acoustic signals from TMJ has not been reported so far, there has been no reference for signals obtained on a daily basis during TMJ diagnosis. However, as a result of our application, the dentist can auscultate, record data and compare the results obtained throughout the patient's entire clinical trial. This supports the more effective monitoring of ongoing therapy. The digitalisation of the data also supports the telemedical approach in which severe and complex medical cases may be consulted remotely by sharing patient data among different medical facilities.

In order to meet the expectations of the scientists, including dentists who face the challenge of encountering patients with TMD on a daily basis, the software tool was proposed by our team. Moreover, it enables a degree of automation to be introduced into the diagnostic procedure and stores records of the obtained signals and these can be used for further analysis as well as for education. The proposed method may also provide a motivational function for patients in the treatment process through ongoing verification of its progress. If the patient can notice that the sounds are weakening during periodic measurements, this will be a motivating factor. This approach will allow for the objectification of patients' subjective feelings about the loudness of sounds. They are usually perceived as louder due to the bone conduction of acoustic waves. Thanks to this, the patient will be able to see that they are not so loud objectively, and that they are gradually reduced.

Conclusions

In this research, we have presented a software solution which addresses two major problems related to the diagnosis of TMD. Firstly, it enables a reduction in the time required for a single diagnosis to be made according to the RDC/TMD questionnaire as a result of the automated diagnosis. Secondly, the designed application facilitates the anonymous storage of patient data including RDC/TMD form and digital acoustic signals which can be recorded with an electronic stethoscope during the TMJ diagnostic procedure. The software enabled the creation of a TMJ sounds database in which each signal is correlated with all diagnostic patient data. This repository can be extracted to a single, structured archive file and distributed across both medical and scientific institutions as a reference for research related to the field of TMJ.

Future research will involve extending the signal repository with further patient records and adding support for the newer version of the DC/TMD questionnaire as soon as it is officially translated into Polish.

Authors contribution statement

Research concept: J.G., M.K., J.E.L.; Methodology: J.G., M.K., J.E.L.; software: M.K.; Carrying out the project (treating patients): J.G.; Manuscript preparation: J.G., M.K.; Supervision: J.E.L., M.P., Preparing the article for printing: J.G.; Submission of the article for publication: J.G.

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Conflict of interest

None declared.

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