Duplex Doppler ultrasound study of the temporomandibular joint

A. Stagnitti ^{a,*}, A. Marini ^a, L. Impara ^b, F.M. Drudi ^a, L. Lo mele ^a,
G. Lillo Odoardi ^a

^a Department of Radiological, Oncological and Patological Sciences, University of Roma "La Sapienza", Italy

^b Università Telematica delle Scienze Umane (UNISU), Niccolò Cusano, Rome, Italy

KEYWORDS

Duplex Doppler;
Ultrasound;
Temporomandibular
joint.

Abstract *Introduction:* The anatomy and physiology of the temporomandibular joint can be studied clinically and by diagnostic imaging. Magnetic resonance imaging (MRI), radiography (X-ray) and computed tomography (CT) have thus for many years contributed to the study of the kinetics in the mandibular condyle. However, also duplex Doppler ultrasound (US) examination is widely used in the study of structures during movement, particularly vascular structures. *Materials and methods:* A total of 30 patients were referred by the Department of Orthodontics to the Department of Radiological, Oncological and Pathological Sciences, University of Rome "La Sapienza". All patients underwent duplex Doppler ultrasound (US) examination of the temporomandibular joint using Toshiba APLIO SSA-770A equipment and duplex Doppler multi-display technique, which allows simultaneous display of US images and color Doppler signals. A linear phased array probe with crystal elements was used operating at a basic frequency of 6 MHz during pulsed Doppler spectral analysis and 7.5 MHz during US imaging.

Results: In normal patients a regular alternation in the spectral Doppler waveforms was obtained, while in patients with temporomandibular joint meniscus dysfunction there was no regularity in the sum of the Fourier series with an unsteady waveform pattern related to irregular movements of the temporomandibular joint.

Conclusions: In all cases duplex Doppler US examination proved able to differentiate between normal and pathological patients and among the latter this technique permitted identification of the most significant aspects of the dysfunctional diseases.

Sommario *Introduzione:* La fisiologia articolare dell'articolazione temporo-mandibolare (ATM) può essere esaminata sia dal punto di vista clinico che strumentale.

La diagnostica per immagini ha da tempo contribuito con la risonanza magnetica (RM) e anche con la radiografia (Rx) e la tomografia computerizzata (TC) all'analisi della morfologia dei capi articolari e della cinetica condilare.

L'esame duplex-ecodoppler è una metodica di largo impiego nello studio delle strutture in movimento in particolar modo a livello delle strutture del sistema vascolare.

* Corresponding author.

E-mail address: a.stagnitti@libero.it (A. Stagnitti).

Materiali e metodi: È stata utilizzata un'apparecchiatura Toshiba APLIO SSA-770A, con l'uso di tecnica duplex-ecodoppler multi display, che consente la visualizzazione contemporanea dell'immagine ecografica e dei segnali Doppler utilizzando una sonda lineare del tipo phased array con cristalli trasduttori funzionanti ad una frequenza fondamentale di 6 MHz per gli spettri Doppler pulsati e 7.5 MHz per l'imaging ecografico. Sono stati esaminati nel Dipartimento di Scienze Radiologiche, Oncologiche e Anatomo-patologiche dell'Università "Sapienza" di Roma, 30 pazienti del reparto di Ortognatodonzia dell'Istituto di Odontoiatria della stessa Università.

Risultati: Nei pazienti normali si è ottenuta un'alternanza regolare degli spettri Doppler, mentre nei soggetti con disfunzioni del complesso condilo-meniscale, si è persa la regolarità della sommatoria degli spettri di Fourier, con altezze incostanti in relazione a spostamenti irregolari del complesso condilo-meniscale.

Conclusioni: L'esame ecodoppler si è dimostrato, in tutti i pazienti, capace di discriminare quelli normali dai patologici e tra questi ultimi ha permesso di identificare gli aspetti più significativi delle patologie disfunzionali.

© 2012 Elsevier Srl. All rights reserved.

Introduction

The temporomandibular joint anatomy and physiology can be studied clinically and by diagnostic imaging, and magnetic resonance imaging (MRI), radiography (x-ray) as well as computed tomography (CT) have therefore for years contributed to the study of joints and kinetics of the mandibular condyle [1–5]. Particularly MRI can accurately depict and characterize the static and dynamic morphology of the meniscus and condyle reaching an elevated sensitivity. The most significant limitations of these diagnostic methods lie in their cost, in the exposure to radiation during x-ray and CT examinations, in their ability to analyze the structures from a morphological rather than a functional point of view and in the inability to provide quantitative data on the kinetics of the condylus and meniscus. A quantitative analysis of the condylus and meniscus is required in order to make appropriate management decisions in patients with temporomandibular joint dysfunctions.

Duplex Doppler ultrasound (US) examination is a widely used technique in the study of movable structures, particularly the vascular system [6]. The equipment associates real-time B-mode US with pulsed Doppler technique which permits evaluation of the differences in frequency and therefore calculation of blood flow velocity in the selected vessel [7]. Some studies of the temporomandibular joint have used Doppler sound analysis techniques [8] and recently also two-dimensional Doppler velocimetry techniques [9].

The aim of this study was to evaluate morphology and dynamics of the sum of spectral components of the structures involved in the biomechanics of normal and dysfunctional temporomandibular joints.

Materials and methods

A total of 30 patients were referred by the Department of Orthodontics to the Department of Radiological, Oncological and Pathological Sciences, University of Rome "La Sapienza". Of these patients, 10 were asymptomatic while

20 presented symptoms of temporomandibular joint disorder. All patients underwent duplex Doppler US examination of the temporomandibular joint. Findings were correlated with the symptoms and possible biomechanical abnormalities. Written informed consent was obtained from all patients.

Examinations were performed on Toshiba APLIO SSA-770A equipment using duplex Doppler multi-display technique, which allows simultaneous display of US images and Doppler signals. A linear phased array probe with crystal elements was used operating at a basic frequency of 6 MHz during pulsed Doppler spectral analysis and 7.5 MHz during B-mode US imaging.

The sample volume can be positioned at varying depth and width and be represented in real-time US image overlays (Fig. 1). Using a similar electronic mechanism it is also possible to determine the change in the direction of the propagation of emitted US pulses and Doppler pulsar revelation.

Using a different electronic driver, the angle α between the direction of propagation of emitted US pulses and the

Figure 1 Sample volume of the mandibular condyle and analysis of condylar movements using Doppler US.

direction of motion of the condyle and meniscus is accurately identified.

This system can sample large ranges of Doppler frequency Δf_d depending on the velocity v of motion of the object under examination (in this case the condyle and meniscus), according to the formula [9].

$$\Delta f_d = \frac{2vc\cos\alpha}{\lambda}$$

where λ is the wave length of the US perturbation in the soft tissues of the temporomandibular region linked to the velocity of US propagation c and to the US frequency f by the relationship

$$\lambda = c/f$$

Selection of the electronic sampling volume corresponds to the selection of a particular portion of the reflected echo of which the fast Fourier transform (FFT) is calculated in order to determine the Fourier amplitude $A(f)$ related to the individual frequencies which make up the spectrum signal $a(t)$, given by:

$$A(f) = \sum_{-\infty}^{+\infty} \sin(2\pi ft) a(t)$$

This last operation, the FFT, permits visualization of the distribution of Doppler frequencies and therefore the velocities related to the examined volume. This whole elaboration is performed using a period which is proportional to the pulse repetition frequency (PRF) and allows evaluation in the very moment in which the measurement of the frequency corresponding to the maximum Fourier is carried out.

All these calculations are shown in a timing diagram of Δf_d as a function of time. Distribution of velocity at any moment is indicated by a gray scale proportional to the Fourier amplitudes [10].

For a correct standardization of the pulsed duplex Doppler US analysis procedure of the condyle and meniscus, it is necessary to use a high pass filter which eliminates the spurious Doppler frequencies caused by random fluctuations of the signal or changes in the thickness of the subcutaneous soft tissues due to movements outside the joint. These movements are presumably slower than the motion of the condyle and are easily removed by filtration. An indication of the correct use of the filter is provided by the presence in the Doppler diagram of a good representation of the inversion phase in the phase of transition between opening and closing. From Shannon's sampling theorem it can be derived that the maximum signal frequency to be measured must be less than half the sampling frequency (Nyquist's limit), in this case at half of the pulse duration of PRF. This permits elimination of aliasing phenomena, which consist of the apparent reversal of Δf_d in the components presenting a frequency above this limit [10].

In order to be able to evaluate high velocities of the motion under examination, high values of PRF have to be used, although this results in a suboptimal visualization of the low spectral frequency components. In the present case

Figure 2 A 40-year-old male patient: pulsed Doppler US shows a regular profile and spectral symmetry.

pulse repetition frequency was set close to the lower limit of the allowed range.

Results

In the normal patients enrolled in this study, a regular Doppler spectrum alternation was obtained with negative frequency values compared to the baseline in movements of anterior displacement of the condyle and meniscus (moving away) and a spectrum of positive Doppler waveforms during the closing movement of the mouth. The temporal height and width of the sum of Doppler spectra appeared linked to the velocity and intensity of the movements of opening and closing the mouth. In these normal patients, the sum of Fourier spectra showed a symmetrical pattern, and the peak was regular or only with some small irregularities (only one peak both in the opening and closing of the mouth) (Fig. 2).

Figure 3 A 45-year-old female patient with joint dysfunction; note the evident irregularities in the spectral profile.

Figure 4 A 50-year-old male patient presenting temporomandibular joint dysfunction with jaw clicking and evident irregularities in the spectral profile.

In patients with dysfunctions of the condyle and meniscus, the sum of Fourier spectra was irregular, and there were multiple peaks (opening and/or closing) of irregular heights due to incorrect movements of the meniscus and condyle (Figs. 3 and 4). The pattern representing the mean velocity extrapolated from the Doppler frequency variations provided an immediate interpretation of the Fourier spectra which was required for a correct diagnosis [11].

Discussion

In all cases Doppler US examination proved able to differentiate normal from pathological patients, and among the latter this method permitted identification of the most significant aspects of dysfunctional diseases. However, the correct outcome of the examination seems to depend on operator experience as it is possible to generate many artifacts which are sometimes linked to minor methodological variations especially in the positioning and inclination of the transducer. The examination proved particularly useful in the planning of management and follow-up because it permitted quantification of the kinetic moment of the pathological movement including temporal and spatial relationship. The examination is easy to perform

and the high diagnostic reliability of the method justifies its insertion into diagnostic and therapeutic protocols of dysfunctional disorders of the temporomandibular joint.

Conflict of interest

The authors have no conflict of interest to disclose.

Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.jus.2012.02.005](https://doi.org/10.1016/j.jus.2012.02.005).

References

- [1] Arvidsson LZ, Smith HJ, Flatø B, Larheim TA. Temporomandibular joint findings in adults with long-standing juvenile idiopathic arthritis: CT and MR imaging assessment. *Radiology* 2010 Jul;256(1):191–200.
- [2] Badel T, Marotti M, Keros J, Kern J, Krolo I. Magnetic resonance imaging study on temporomandibular joint morphology. *Coll Antropol* 2009 Jun;33(2):455–60.
- [3] Burnett KR, Davis CL, Read J. Dynamic display of the temporomandibular joint meniscus by using “fast-scan” MR imaging. *AJR Am J Roentgenol* 1987 Nov;149(5):959–62.
- [4] Conway WF, Hayes CW, Campbell RL, Laskin DM. Temporomandibular joint motion: efficacy of fast low-angle shot MR imaging. *Radiology* 1989 Sep;172(3):821–6.
- [5] Roberts D, Schenck J, Joseph P, Foster T, Hart H, Pettigrew J, et al. Temporomandibular joint: magnetic resonance imaging. *Radiology* 1985 Mar;154(3):829–30.
- [6] Zwiebel WJ. Duplex sonography of the cerebral arteries: efficacy, limitations, and indications. *AJR Am J Roentgenol* 1992 Jan;158(1):29–36.
- [7] Bastos CC, Fish PJ, Vaz F. Spectrum of doppler ultrasound signals from nonstationary blood flow. *IEEE Trans Ultrason Ferroelectr Freq Control* 1999;46(5):1201–17.
- [8] Davidson SI. Doppler auscultation an aid in temporomandibular joint diagnosis. *Cranio-mandibular Disord* 1988;2(3).
- [9] Festa F, Mandolesi S, Bonadonna R. Valutazione preliminare del ruolo del Doppler nella diagnosi delle disfunzioni dell’articolazione temporo-mandibolare. *Quaderni di Odontostomatologia* anno V n.4; 1988.
- [10] Burns PN. The physical principles of Doppler and spectral analysis. *J Clin Ultrasound* 1987 Nov-Dec;15(9):567–90.
- [11] Marini M, Lillo Odoardi G, Tartaglia P. Duplex-doppler and cine-Bmode echography of the temporal-mandibular joint. Clinical validation. *Comput Med Imaging Graph* 1995 Nov-Dec;19(6):457–63.