MRI of the Temporomandibular Joint

Correlation Between Imaging and Pathology

Tiziana Robba
Carlotta Tanteri
Giulia Tanteri
Editors

Springer

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To our mentors, for teaching us and guiding us
down the path to becoming our best selves
To our families, husbands and to our children
Francesco, Chiara, Benedetta, and Gregorio Oceano
To our patients, for trusting us and for giving us
the possibility to learn something new every day
To our friends and colleagues
To ourselves, because sharing so much made us treasure
each other in a way we had not expected

"Who sees further a dwarf or a giant? Surely a giant for his eyes are situated at a higher level than those of the dwarf. But if the dwarf is placed on the shoulders of the giant who sees further? … So too we are dwarfs astride the shoulders of giants. We master their wisdom and move beyond it. Due to their wisdom we grow wise and are able to say all that we say, but not because we are greater than they."

Isaiah di Trani

Foreword by Ambra Michelotti

This book edited by Tiziana Robba, Carlotta Tanteri, and Giulia Tanteri has the great merit, which is not frequently found, of helping to fill a real gap in the medical–dental literature. The growing knowledge in terms of diagnostic and therapeutic approaches regarding temporomandibular joint pathologies, combined with the incessantly improving technological advances made in the field of diagnostic imaging, have in fact dug a deep groove between the experts of the different disciplines called upon to define the diagnostic and therapeutic path. The project of writing a multidisciplinary book, under the perspective of a dentist, a radiologist, and a maxillofacial surgeon, allows to fill this groove through the union of the clinical and scientific skills of the authors in different fields. The text provides the basic elements needed by the radiologist to understand the different pathologies of the articular tissues and the morphological changes related to them and, at the same time, helps the clinician to interpret the images derived from instrumental investigations. Ultimately, the authors have accomplished an excellent and appreciable work of interdisciplinary linking that will allow all those who will read and study this easily accessible text to face the complex temporomandibular pathologies with greater competence.

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Department of Orthodontics
and Gnathology
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Foreword by Daniele Regge

In this volume, Dr. Tiziana Robba, Dr. Carlotta Tanteri, and Dr. Giulia Tanteri provide a very comprehensive overview of temporomandibular joint (TMJ) disorders and of the role of magnetic resonance imaging (MRI) in their diagnosis. All the chapters of this handbook follow the same structure: after a brief introduction on the epidemiology and etiopathogenesis, the authors elaborate the content adopting a multidisciplinary approach. At first a description of the physiology is given followed by a systematic overview of pathological findings both from a radiological and pathological perspective. The understanding of the text is supported by the superb quality of radiological images. Most importantly, clinical and therapeutic implications of radiological finding are thoroughly discussed.

I found this book extremely inspiring and informative, and I recommend it not only to imaging doctors but also to dentists, gnathologists, and maxillofacial surgeons. I am persuaded that this monograph may greatly add to knowledge by providing adequate and precise description of MRI findings and allow accurate treatment planning in patients with TMJ disorders. I hope it will attain the success it rightly deserves.

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Foreword by Florencio Monje

It is a great honor and privilege to collaborate with this book doing the foreword. The editors form an inspiring team with a clever combination of different specialties involved in the diagnosis and treatment of these pathologies such as radiology, dentistry, and maxillofacial surgery.

The authors indeed make a tour of MRI without ignoring other TMJ imaging modalities. The information of TMJ anatomy applied to MRI, as well as the dynamics of this joint, gives us basic information for the following parts of this book. The key to correct interpretation of TMJ imaging findings lies in a thorough knowledge of the anatomy and an understanding of the function and dysfunction of the TMJs. In other words, the professionals around the pathology of this joint should have enough knowledge about imaging of this area.

The diagnostic process is especially important since an incorrect diagnosis is the most frequent cause of treatment failure. However, radiological findings should never be interpreted in isolation. The decision for any treatment must be based primarily on the combination of clinical and radiological information in conjunction with other factors such as the impact of the disease on the patient and the prognosis in case no treatment is provided. As a maxillofacial surgeon, and someone bewitched by TMJ disease, I truly appreciate this book. It becomes a working tool in TMJ diagnostics, whatever the approach.

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Preface

This book is the result of an enduring cooperation between a radiologist, a maxillofacial surgeon, and a dentist, who became specialized in temporomandibular joint pathology throughout the years. It is from our constant exchange of thoughts, competences, and considerations that the necessity to write this book emerged. The urge to share a common language and the constant need of relying on the reciprocal expertise made us realize that we wanted to bridge the gap, first of all for ourselves.

This book aims at providing an easy-to-consult format with the essential knowledge to address TMJ magnetic resonance interpretation. The focus of our work was on presenting TMJ conditions that gnathologists and dental practitioners encounter in their daily practice. Clinicians, in fact, often lack the technical-radiological familiarity with the exams they prescribe and seldom know how to interpret the images they receive. For this reason, we gave plenty of room to the description of MRI TMJ anatomy, to the radiological correlation with the most common disorders, and to technical considerations which lie behind high-quality MR images. At the same time, we wanted to let radiologists understand the clinical presentation which precedes the request to perform radiological examinations for the TMJ, so as to allow them to better appreciate which details should be taken into account while performing the investigation and evaluating the images.

The collaboration between our three disciplines provided insight into each other's difficulties and allowed us to include pieces of information which make this book valuable to all colleagues that deal with temporomandibular disorder patients. The illustrations and the clarifying terminology aim at simplifying concepts which usually create confusion.

Clinicians deal with signs and symptoms, but at times rely too much on their clinical confidence alone. Our approach to TMJ conditions should be consequential, based on shared diagnostic criteria and supported by instrumental analyses. Magnetic resonance shows what is concealed behind signs and symptoms, supporting diagnostics and therapeutic choices.

We sincerely hope that our work will help radiologists to better grasp the clinical reasoning behind TMJ imaging and that it will help clinicians realize how MRI is becoming a fundamental part of everybody's practice.

Tiziana Robba
Carlotta Tanteri
Giulia Tanteri

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We would like to thank the contributing authors of this book for their commitment and effort and for the high-quality material they provided.

Thank you Dr. Gino Carnazza and Dr. Eugenio Tanteri, our mentors. Thanks for giving us the possibility of writing this book. You selflessly moved one step back and allowed us to do this by ourselves. Thank you for teaching us, inspiring us, and sharing your knowledge and thank you for your constant support.

Thank you Prof. Gregor Slavicek for giving us the possibility to learn, study and grow up with you.

Thank you to the colleagues who helped up with illustrations and imaging. Thank you Dr. Angelo Bracco and Dr. Nicolò Margolo for the remarkable anatomical drawings.

We would like to thank our mothers and fathers for giving us the necessary peace of mind to go through these hard times and for always having our backs.

Thank you to our husbands and children because we have been blessed by your presence in our lives. Thank you from the bottom of our hearts for your support and your patience.

One final thank you to the doctors, technicians, staff, nurses, and good friends who work with us daily. Thank you for the constant exchange of knowledge, for questioning us and spending your lives with us.

Contents

1 TMJ Magnetic Resonance: Technical Considerations 1
Valeria Clementi and Tiziana Robba

2 Other TMJ Imaging Modalities 25
Luca Luberto, Sara Garberoglio, and Gino Carnazza

3 TMJ and MRI Anatomy 37
Giulia Tanteri, Roberto Prandi, Paolo Lodo, Nicolò Margolo, and Gino Carnazza

4 TMJ Dynamics 57
Giulia Tanteri, Eugenio Tanteri, Carlotta Tanteri, and Gregor Slavicek

5 Developmental Disorders 91
Giovanni Gerbino, Vito Chianca, and Guglielmo Ramieri

6 TMJ Trauma 105
Claudio Caldarelli, Paolo Busolli, and Giacomo Paolo Vaudano

7 Joint Disorders 125
Carlotta Tanteri, Tiziana Robba, Roberta Cimino, and Giulia Tanteri

8 Joint Diseases 175
Tiziana Robba, Paolo Tosco, Simone Parisi, Guglielmo Ramieri, Enrico Fusaro, Riccardo Faletti, and Giulia Tanteri

9 Tumors and Tumor-Like Lesions 219
Paolo Tosco, Vito Chianca, and Guglielmo Ramieri

Index 235

1 TMJ Magnetic Resonance: Technical Considerations

Valeria Clementi and Tiziana Robba

Key Points

- MR is a multiparametric imaging technique based on absorption of energy by the atomic nuclei of tissues and the subsequent return of the system to its initial state. In order to be performed, the patient has to be inserted into specially generated magnetic fields and non-ionizing electromagnetic radiation is used.
- The main contrast parameters used for image generation are: proton density, T_1, and T_2. These last two are intrinsic parameters of any tissue, related to its microscopic structure, which influence the way the system returns to equilibrium after absorption of the radio frequency (RF) energy. Parameters combination can provide for a great variability of the contrast between tissues, and it is selected on the basis of the clinical question.
- Images are generated by sequences of radio frequency pulses and variable magnetic fields. There are two main types of sequences: spin echo and gradient echo. Spin echo sequences are the most commonly used as they provide fine anatomical details, thanks to their SNR. Gradient echo sequences are used to decrease acquisition times, are more sensitive to changes of magnetic susceptibility of tissues, and may provide information regarding deposits such as calcium or hemosiderin.
- MRI is a tomographic imaging technique: it represents anatomical region volumes through 2D images. MR, unlike other imaging techniques, can directly acquire along oblique planes. 3D acquisitions are also possible, allowing isotropic 3D reconstructions of the volume.
- Over the years, clinical MR systems have offered an increasing number of sequences and techniques, many of which are intended to reduce acquisition times through different modalities of data acquisition (fast acquisition techniques) and to suppress fat signal (fat signal suppression techniques).
- MR does not use ionizing radiation and can therefore be considered a low-risk technique. However, MR may still involve risks for operators and patients, and these can be limited by site design and safety procedures applied in the daily practice.

Electronic supplementary material The online version of this chapter (https://doi.org/10.1007/978-3-030-25421-6_1) contains supplementary material, which is available to authorized users.

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1.1 Introduction

Imaging of the temporomandibular joint (TMJ) has been continuously evolving along with the advancement of imaging technologies. Even though many imaging modalities are currently used to evaluate the TMJ (i.e., cone beam computed tomography—CBCT—and multi-detector computed tomography—MDCT), the use of magnetic resonance imaging has increased due to its great contrast resolution, its strength in highlighting soft tissue structures and signs of inflammation, and its capability in acquiring dynamic imaging for demonstration of the functionality of the joint (Bag et al. 2014). Furthermore, MRI does not involve ionizing radiations and this helps in limiting the overall history of patient exposure (Niraj et al. 2016). On the other hand, the relative disadvantages of MRI compared to CT include a more complex scanning technique and a longer acquisition time. The advantages of CT over MRI are enhanced bone details and 3D assessment of congenital, developmental, and traumatic conditions (Bag et al. 2014; Niraj et al. 2016). In this chapter, the reader will be given the essential and basic information to understand the principles of physics that underlie the creation of MR images.

1.2 Principles of Physics of Magnetic Resonance Imaging

1.2.1 Nucleus and Spin

The MR imaging technique is based on absorption of energy by atomic nuclei and the following return of the system to the initial state. In particular, the majority of MR clinical applications are based on hydrogen nuclei, in fact, this is one of the most common elements in nature and very abundant in the human body.

Atoms consist of three main particles: protons, which have a positive charge, neutrons, which have no charge, and electrons, which have a negative charge.

The atomic nucleus is positively charged due to the presence of protons and neutrons. Electrons are displaced in orbitals surrounding the nucleus. Each element is defined by a typical number of protons and electrons, while the nucleus can contain a variable number of neutrons, thus characterizing different isotopes of the same element. The hydrogen nucleus contains a single proton and no neutron (Fig. 1.1).

The complete comprehension of the MR phenomenon is based on the quantum mechanics theory, the most complete model to interpret the microscopic world. However, quantum mechanics is usually very far from our intuitive interpretation, which is based on the macroscopic world experience and described by the classical physics models. For this reason, it is common to use quantum mechanics concepts, together with some classical mechanics models, to explain and better understand some aspects of MR.

The atomic nucleus has the intrinsic property of rotating about its axis, like a spinning top. The physical quantity that describes this feature is a vector called *spin angular momentum*, also called *spin* (Fig. 1.2a). From the physics of electromagnetism, it is also known that a moving charge creates a magnetic field. The magnetic field source can be represented in physics by a dipole, that can be imagined as a little magnet, with a north pole and a south pole. Then a nucleus can be represented as a spinning top because of its rotation about its axis, as well as a little magnet because of its little magnetic field (Fig. 1.2b). The little dipoles, generated by the spinning charged atomic nuclei, are at the origin of the MR signal.

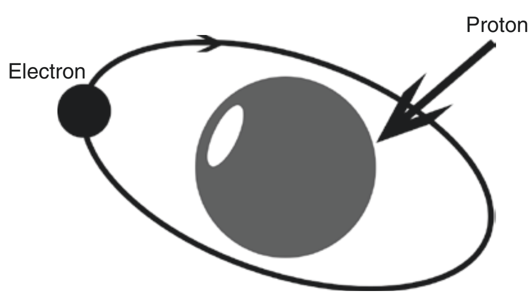

Fig. 1.1 Hydrogen atom. Its nucleus is made up of one proton only. Its electron cloud also consists of only one electron

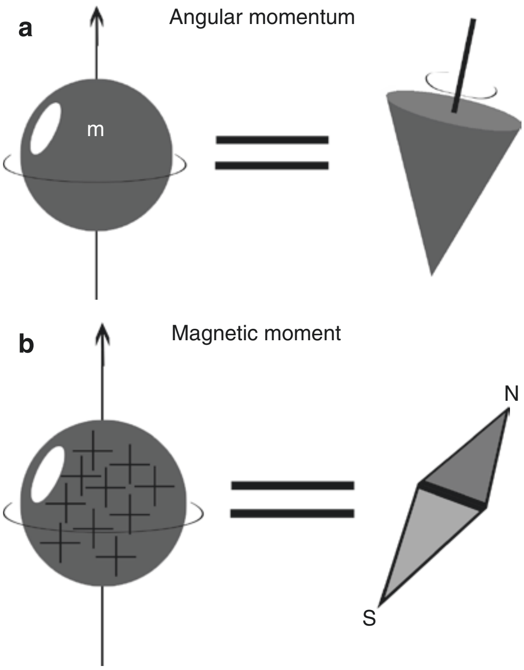

Fig. 1.2 (**a**, **b**) The atomic nucleus of hydrogen rotates about its own axis, like a spinning top. The physical quantity that describes this feature is a vector called *spin angular momentum* (**a**). The positively charged hydrogen nucleus rotates about its own axis like a spinning top and it generates a small magnetic field. It can be represented as a small magnet, with a north and a south pole (**b**)

Based on what has just been described, a volume of patient tissue can be imagined as a pool of little magnets, all hydrogen nuclei (or spins), each of them rotating about their own axis and generating a little microscopic magnet. In normal conditions, out of a strong magnetic field, all spin orientations are possible, the magnetic fields generated from the nuclei cancel each other out and the overall effect is that there is no macroscopic magnetization on the tissue (Fig. 1.3).

1.2.2 Resonance Phenomena and Larmor Precession

When the patient is introduced into a uniform and constant high-intensity magnetic field, specifically created inside the MR scanner, called $\mathbf{B_0}$, the hydrogen spins, which were randomly oriented up to that point, move to align along the main magnetic field $\mathbf{B_0}$ in a parallel or anti-parallel orientation (Fig. 1.4). The anti-parallel alignment implies a higher energy than the parallel one and the latter is more frequent. In classical physics models, if a spinning top is moved from its axis while it rotates about itself, it also begins to rotate around the direction of gravity. Again, the spin can be considered as a spinning top, and when the spin is exposed to the magnetic field $\mathbf{B_0}$ it behaves like a spinning top on the gravitational field, and it starts to rotate around the axis of $\mathbf{B_0}$ with a typical motion called *precession* (Fig. 1.5).

The Larmor equation describes the relationship between the intensity of the magnetic field $\mathbf{B_0}$ and the rotation frequency of the spin precession:

$$\omega_0 = \gamma B_0 \quad (1.1)$$

where ω_0 is known as the Larmor precession frequency or resonance frequency and it is expressed in MHz, γ is the gyromagnetic ratio (unique to every atom), expressed in MHz/T, and B_0 is the magnetic field strength in Tesla.

Protons have a gyromagnetic ratio of 42.58 MHz/T, and the corresponding Larmor frequency at 1.5 T is 63.87 MHz. This value can be roughly compared to about 1 KHz, which is the Larmor frequency corresponding to the magnetic field intensity of the Earth.

As a consequence of what has been described, whenever a patient is brought into an external magnetic field, the overall effect is the appearance of a macroscopic magnetization that can be represented as a vector **M**, with the same direction and orientation of the external magnetic field $\mathbf{B_0}$ (Fig. 1.6). There is no magnetization vector when a tissue is not placed in an external magnetic field.

On a quantum mechanics point of view, when the spin component is measured along an axis (the *z*-axis, for instance) it is only possible to obtain a finite number of values (quantized values), related to a number which describe the spin angular momentum: the spin quantum number *I*. This number is different from nucleus to nucleus. Nuclei with a spin quantum number $I = 0$ cannot be used for MR. The hydrogen nucleus has the spin quantum number $I = ½$, which makes it suitable for the creation of MR signal. Other nuclei,

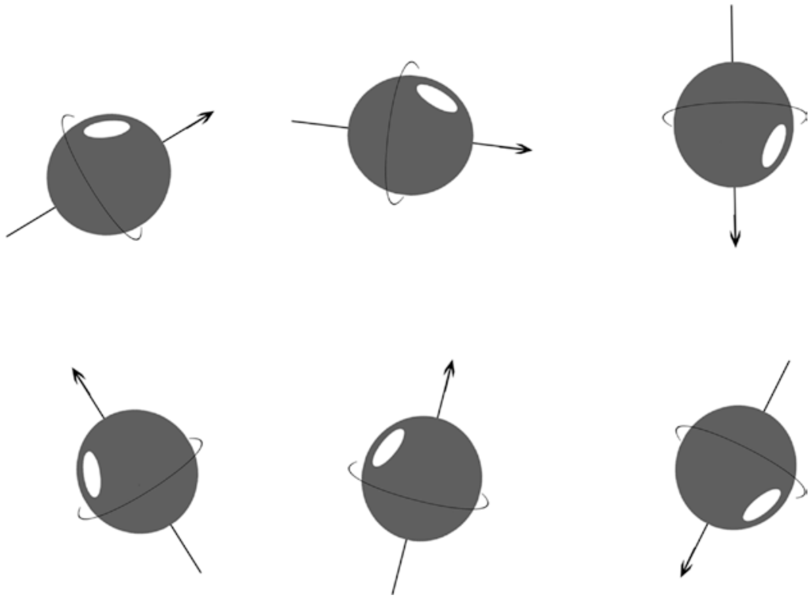

Fig. 1.3 Under normal conditions, rotating axes of spins within a tissue all have different directions and they cancel each other out. The overall effect is that there is no macroscopic magnetization within that tissue

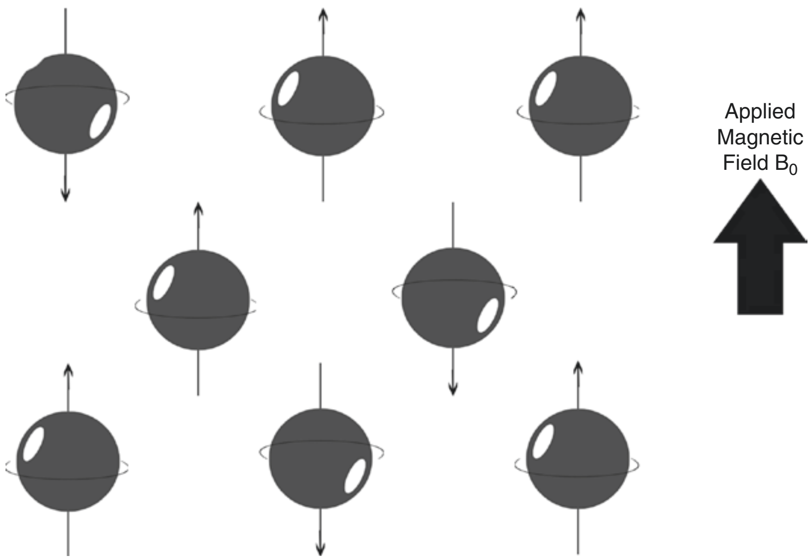

Fig. 1.4 The hydrogen spins move to align along the main magnetic field $\mathbf{B_0}$ in a parallel or anti-parallel orientation when the patient is introduced into the high-intensity magnetic field $\mathbf{B_0}$ inside the MR scanner. The anti-parallel alignment implies a higher energy than the parallel one and the latter is more frequent

for example carbon-13, nitrogen-14, fluorine-19, phosphorus-31, and sodium-23, are characterized by an $I \neq 0$ and could potentially generate MR signal. However, these elements are less abundant in biological tissues compared to hydrogen; therefore, their use in MRI is not standard and is limited to specific research applications.

Out of the $\mathbf{B_0}$ field, when measuring the hydrogen nucleus spin component along the z-axis, the only possible results are two values, corresponding to spin states UP and DOWN, both having the same energy. The number of spins UP is equivalent to the number of spins DOWN and there is no macroscopic effect. On the contrary, when a patient is placed into the main magnetic field $\mathbf{B_0}$, the two possible hydrogen spins configurations—with respect to the $\mathbf{B_0}$ axis, UP (anti-parallel) or DOWN (parallel)—become energetically different, with UP alignment corresponding to the upper energy state (Fig. 1.7). The distribution of the spins population, between up and down energy states, is no longer equal and it is related to the