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Editors

Craniofacial Pain

Temporomandibular Disorders and Beyond

Springer

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I dedicate this work to my father Brendan C. Stack, Sr., DDS, MS (1937–2020). My father was a thought leader and private practitioner dedicated to orthodontics and temporomandibular joint (TMJ) dysfunction for over 50 years. His passion for TMJ disease was omnipresent during my upbringing. This was a significant reason I became interested in clinical care and certainly was foundational in my pursuit of a career as an otolaryngologist-head and neck surgeon. Thanks, Dad, for your love and support, your high standards for me, and your professional work for all of its benefits, direct and indirect, it had upon me and my interest in the head and neck and for TMJ/craniofacial pain practitioners and patients worldwide. Also, heartfelt thanks to Ms. Angel Biondi, who managed my father's office for many years, looked out for his best interests, and provided background material for this book.

Brendan C. Stack, Jr., MD, F.A.C.S., F.A.C.E.

Roland, AR, and Springfield, IL

With the deepest gratitude, I wish to thank every being who came into my life and illuminated me through their presence. Lassie and Ruff, thank you for making my life beautiful and meaningful. To my parents, especially my mother, Bhanumathi Shekar, for being an extraordinary woman, my inspiration, voice of reason, and the wind beneath my wings—words do little justice in conveying my gratitude and appreciation. To all my teachers and mentors, across schools and residencies, countries, and continent, thank you for giving me the courage and strength to pursue my dreams—I am forever grateful for that. To my students and residents who brighten my life and motivate me to strive to do better every day. To my patients for

being my best teachers and for making life's journey worthwhile—thank you!

I am grateful to my colleagues and mentors at the SIU School of Dental Medicine and the University of Pittsburgh School of Dental Medicine for their support and guidance. I am obliged to Dr. Bruce E. Rotter, DMD, MS, Dean Emeritus, SIU School of Dental Medicine, for being the reason for my introduction to Dr. Stack 4 years ago. I cannot thank him enough for having faith in me and my abilities as we worked together on this tribute to his father. My thanks are also due to our publisher, Springer Nature, for their patience and perseverance. Lastly, to all those reading our book, thank you for valuing our words and giving us a chance.

Revathi Shekar, BDS, MDS, Dip. ABOM

Pittsburgh, PA

This book aims to do more than assemble much of the vast research on neuroanatomy related to movement disorders. The overall presentation on movement disorders in this book is felt to be unique. Many of the concepts and the information presented have resulted from our continuing goal to understand better the numerous and undeniable results witnessed from the proper knowledge of the stomatognathic system.

I want to thank, with all my heart, my wife Connie for her undaunting love and encouragement throughout our 45 years of marriage. To our children, Anthony II, Calvin, and John, you have been wonderful, and I am proud of all of you. To my grandchildren, I hope to have left a great legacy for you.

Finally, I recognize and give thanks to my teacher and mentor, Brendan C. Stack, Sr., DDS, MS, who passed on his knowledge and wisdom to his padawan.

Anthony B. Sims, DDS, ABCFP, IMD, DHS

Columbia, MD

Foreword

Brendan Stack, Sr., was one of a few dentists in TMJ and orthodontics most admired by my father Harold Gelb, DMD (1925–2022). Shortly after the founding of the American Academy of Craniomandibular Disorders, Brendan founded the rival American Academy of Craniofacial Pain (AACP, www.aacfp.org). In later years, this latter group was where my father felt at home and most welcomed. One of the greatest honors in my father's long life was receiving the **Haden-Stack** Award for his significant contributions to the advancement of knowledge and clinical practice in the diagnosis and treatment of craniofacial pain and temporomandibular joint disorders (TMDs).

Brendan was also well known globally for the Funt–Stack index, which he collaborated with Lawrence A. Funt, D.M.S.D., Bethesda, MD, and was proudly displayed on my father's operatory wall. It helped him to explain how the TMJ could affect the eyes, ears, neck, headaches, jaws, and throat and was well received around the world. It was later adapted and expanded by Bruce H. Kinnie, DDS, who renamed it the K–F–S index.

The Gelb 4/7 jaw and condyle position was the orthodontic finishing position favored by Brendan and the AACP. Harold would put in the Gelb splint, and there was no one better than Brendan to finish the case orthodontically to that position while maintaining orthopedic support. He was an excellent teacher and "professor" who passed this knowledge on to the next generation of TMJ dentists and orthodontists.

I was having lunch one day with these two giants when Brendan candidly said that there was no one that these two would least like to face as expert witnesses than each other. They were both fierce, knowledgeable, and respected experts, admired by their peers, patients, judges, and each other.

Harold and Brendan remained great friends and colleagues for over 50 years.

New York, NY, USA — Michael Gelb

Foreword

I have known Brendan since we matriculated together at Georgetown Dental School in 1958. We were different people; he was single, and I was married. He was an easterner, and I hailed from Arizona. We became acquainted during dental school, and our relationship lasted for over 60 years, which expanded to include our spouses and children. I would see Brendan and his family regularly at meetings of our mutual congregation of the Church of Jesus Christ of Latter-day Saints. After graduation from dental school, I specialized in oral and maxillofacial surgery and set up practices and Brendan specialized in orthodontics and established his practices.

For 50 years, Brendan and I practiced in the same community of Northern Virginia. Brendan was well known for his focus on treating temporomandibular joint dysfunction with occlusal appliances and revision orthodontics. Brendan was well known and highly sought for his treatment success.

I am pleased to see Brendan, Jr., spearhead this book as an update on TMJ/craniofacial pain and its issues as well as a tribute to his father Brendan.

Irvine, CA, USA

N. Ken Coleman

Foreword

"We stand on the shoulders of giants." The statement is well known and frequently used by my colleagues that have dedicated their lives to treating craniofacial/orofacial pain patients. Dr. Brendan Stack was a giant in the field of craniofacial pain diagnosis and management. Dr. Stack literally educated thousands of dentists, but treating patients with complex pain was his passion. Dr. Stack pioneered treatment modalities, which helped countless number of suffering patients.

Dr. Stack was also a founder and inaugural President of the American Academy of Craniofacial Pain. The Academy's most prestigious award bears Dr. Stack's name along with Dr. Jack Haden. The **Haden-Stack** Award is dedicated to individuals who have the unselfish desire to educate others and for their exemplary and extraordinary contributions to the advancement of knowledge and clinical practice in the fields of craniofacial pain and temporomandibular disorders. It was my great honor to receive the Haden-Stack Award in the summer of 2021.

I am proud to say that Dr. Stack was my friend and personal giant in this field. He mentored, educated, and guided me to want to become a better doctor. I received this award because of the assistance and education from this great giant.

Hurricane, WV, USA — Jeanne K. Bailey

Past Presidents of the AACP

Dr. Brendan C. Stack, Sr., was a founder of the American Academy of Craniofacial Pain. This organization began in 1985. More information can be found at https://www.aacfp.org/page/About. The list of the past AACP presidential leadership is below:

Dr. Brendan Stack, DDS, MS 1985–1990	*Dr. Robert Talley, DDS* 2006–2008
Dr. Robert Talley, DDS 1990–1992	*Dr. Donald Warren, DDS* 2008–2010
Dr. Jack Haden, DDS 1992–1994	*Dr. Jamison Spencer, DMD, MS* 2010–2012
Dr. Gerald Murphy, DDS 1994–1996	*Dr. Terry Bennett, DMD* 2012–2014
Dr. Charles Holt, DDS 1996–1998	*Dr. Jeffrey McCarty, DDS* 2014–2016
Dr. Wesley Shankland, DDS, MS 1998–2000	*Dr. Steven R. Olmos, DDS* 2016–2018
Dr. Clifton Simmons, DDS 2000–2002	*Dr. Jeanne K. Bailey, DDS* 2018–2020
Dr. Larry Tilley, DMD 2002–2004	*Dr. Jeffrey McCarty, DDS* 2020–2022
Dr. Steven Kilpatrick, DDS 2004–2006	

Contributions of Brendan C. Stack, Sr., to the Dental/Medical Literature

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Professional Recollections of Brendan C. Stack, Sr., DDS, MS

Brendan was a gifted teacher, mentor, and the finest TMJ clinician. I studied with him for over 25 years with annual visits to Old Courthouse Road (office) and Oberon Way (home). I owe him a huge debt of gratitude and think of him often. He had a wicked sense of humor and the heart of a lion, an extraordinary man who pursued learning in order to provide his patients with care par excellence!

Patrick Grossmann, BDS, LDS, D.Orth, RCS
London, England, UK

I had reached the oral examination stage in my quest for AACP honors. Along with other nervous AACP members who had passed rigorous written test and were facing this last hurdle to lifelong recognition, I was ushered into a large room. Tables, with three chairs at each, dotted the room. I was directed to the remaining chair at a table where my two examiners awaited, Brendan Stack and someone else who paled into insignificance alongside the great man.

A few introductory questions were easily answered. Then came the big one. "Can you give us causes associated with TMJ problems in young women?" inquired Brendan. I mentioned the usual: trauma, mandibular displacement from thumb sucking, and estrogen. Then I added, "at this first consultation it is probably not appropriate to suggest to the mother of a 14-year-old girl that ethinyl estradiol in oral contraceptives is linked to TMJ dysfunction."

"Don't worry about it," Brendan snorted. "The 14-year-old girls are all out there, mating (sic) like bunny rabbits."

One of my fellow candidates remarked to me later, "I knew you had passed when I heard your roar of laughter in that uninviting room."

John Burford, BDS, DFAACP
Auckland, New Zealand

After discussing the care of a mutual patient with Dr. Stack, he invited me to come to his office to learn more about how he treats his patients. I was not sure what this experience was going to entail, but I was certain that it was going to be life-changing after watching how he interacted with people in ways that I had never experienced before in my career. He reminded me of the M&M candy: a hard shell on the outside was required to protect the soft inside that could melt under certain conditions. His sometimes gruff exterior could be easily misunderstood as aggressive, but I quickly realized that to be the leader that he needed to be for all that followed him, this toughness was

necessary. The soft, caring inside was easy to see as he gave his all in caring for his patients.

As we came near to the end of our time together during that particular office visit, he took me aside, looked me straight in the eyes, and told me that our profession needed people like me to continue pushing this field forward. He told me that you can always tell the leaders by the arrows that they have stuck in their backs. I quickly realized the challenge that I had been asked to rise to and decided to show my mentor that I was able to gain the respect of the man that had just thrown down a gauntlet that I had no choice but to pick up.

When he and I reconnected several years later at an AACP conference, when his memory had started to falter, I reminded him of our previous meeting, and it brought back every detail and conversation that we had ever discussed. I have done my best to follow in his footsteps, and I have gathered the quiver of the arrows in my back. I am constantly grateful for his leadership, wisdom, and friendship.

Angie Tenholder DMD, FAACP, DABCDSM, FAGD

President, American Board of Craniofacial Dental Sleep Medicine

Education Committee Co-chairperson, American Academy of Craniofacial Pain

Fellow, American Academy of Craniofacial Pain and Academy of General Dentistry

Board Certified, American Board of Craniofacial Dental Sleep Medicine

Columbia, IL, USA

I have been a member of the American Academy of Craniomandibular Pain (AACP) since 2004, but I first heard Dr. Stack in the early 1990s at a meeting of the American Equilibration Society in Chicago, where he lectured and participated in a round table with the other two most prominent orthodontists of that time regarding our specialty and orthodontics. It was memorable.

I again met Dr. Stack while we were both lecturing in Argentina in 2004, for what was then the Latin American chapter of the AACP, and I invited him to lecture in my country for the 2006 chapter meeting, and he immediately accepted. As always, we learned so much from him, and we even lost him during the social events, because he visited more parts of the country than planned. Later, I learned that his two dental assistants were originally from Panama, and he went and bought them many souvenirs.

During a meeting of the AACP and some years before Dr. Stack retired, I mentioned to him that I was going to spend some time in Washington, DC, and asked him if I could stay a day in his office. Of course, he accepted, and I still help my patients with what I learned that day and remember him every time.

The last time I saw Dr. Stack was in an AACP meeting in Orlando in 2017, and unfortunately, he was already in a wheelchair. He was by himself waiting to be called to be given one of the many honors he deserved, and I asked him if I could accompany and escort him. He was very happy, and I was honored but sad at the same time to see him not well.

Dr. Stack always treated me like family, student, and colleague, and he will always be in my heart and mind.

Dr. Fernando R. Jaén, Odontólogo

Panama City, Panama

I was attending an IAO meeting in VA in the 1980s where Brendan was speaking, and I asked so many questions that a doc in the front turned around and yelled, "You need to take his training!" Brendan was not teaching anything in the United States, and I could not go to the UK or Europe, so I called his office and signed in as a patient. That began our relationship, with me driving down from northeastern PA and arriving before my appointment, staying until the end of his day, and learning from him as he treated my TMD and he saw his other patients. I completed the multi-year program he gave with Jay Gerber and Dick Greenan later on. We trained together with Gerald Smith to learn about Darick Nordstrom's ALF appliance. We collaborated on some movement disorder cases.

Brendan was my savior and became my close friend and professional and personal mentor for decades. I loved him and miss him frequently. When I have a tough case, I still ask, "What would Brendan do?" and the answer always comes.

Rebecca L. Griffiths, DMD

Phoenix, AZ, USA

As the retired founder and owner of Rideau Orthodontic Mfg. Ltd., a Canadian orthopedic/orthodontic laboratory, I met Dr. Brendan Stack 40 years early on in his orthodontic career. Dr. Stack, a true pioneer for "treating the cause not the symptoms" of cranial facial pain and TMJD, provided opportunities to organize dental seminars in Canada for several thousand Canadian dentists whose patients benefited from Dr. Stack's teachings and that of other leaders as well. Brendan seldom took holidays, although following a couple of Ontario lectures, he visited my family home on the Big Rideau Lake for fishing.

Rideau Orthodontic fabricated the **A**lternative **L**ightwire **F**unctional (ALF), lower splint devices, upper four way sagittal to "explode the maxilla," in addition to Brendan's luted upper/lower Hawley-style retainers to maintain orthodontic alignment while supporting AP/TMJ correction throughout sleep. I was blessed to have Dr. Brendan Stack as a mentor and dear friend for so many years.

It is a wonderful tribute for his final textbook to be published by his loving namesake son, which also compliments Brendan's extensive video series entitled "Stack of Knowledge."

Emmett Griffiths

Smith Falls, Ontario, Canada

I knew Dr. Stack well. He was more than a friend; he was like my brother. When I could not get paid by the motor vehicle insurance companies for TMJ injuries, I began to sue them. I needed to have experts I could rely on to testify on the patient's behalf and he did that. Dr. Brendan Stack came out to Denver and testified at least four times. The opposing lawyers knew that they were in for it when he testified. I won those cases. He helped put TMJ on the map with respect to whiplash injuries.

I took each of his classes two or three times because I wanted to learn as much as I could. At one class, he called me out and said, "Is this correct, you took this same class last month and my office informs me that you're registered in the same class two months from now?" I answered yes and he asked why. I showed him my notes from the previous class and how I was now taking the notes that I missed from that last class. At a break later on in the day, he asked if there were any questions, and most of the participants had already left the room when I asked my question. I asked my question, and he answered it, but one doctor came forward and asked him to explain it. So, he explained his answer. The doctor then said, "No, I don't understand the question, can you explain the question?" The point of this is to show how deeply Dr. Stack went into the topic when he was teaching it. It was necessary to take the same class several times to get the full depth of the instruction because he was giving out so much information. Dr. Stack was a brilliant man and a great teacher and clinician.

To this day, there are times that I wish I could still ask him questions about a patient's treatment. I have three fellowships in TMJ and am a diplomate from the American Academy of Integrative Medicine. I have been treating TMJ patients for 46 years and for a total of almost 5000 patients, and I still do not know as much as Dr. Stack. He was a great man, a great teacher, and a great friend. I really miss him.

Roger Druckman DDS
Denver, CO, USA

Dr. Brendan Stack pioneered patient-centered, comprehensive collaborative therapies long before others in our profession followed his lead. He consistently challenged orthodoxies in orthodontics with upgraded and advanced craniofacial-cervical chronic pain management for orthodontic and facial orthopedic patients.

General Patton said: "When everyone is thinking alike, no-one is doing much thinking." Brendan thought outside the box without getting lost out there. He shined light on facial pain/TMD co-management and provided higher levels of whole body/system optimization, with truly comprehensive orthodontic treatments. However, he was often challenged by colleagues who did not yet know.

All truth passes through three stages: First, it is ridiculed. Second, it is vehemently opposed. Third, it is accepted as being self-evident (Arthur Schopenhauer). As Winston Churchill pointed out, you can see adversity in every opportunity, or you can see the opportunity in every adversity. Dr. Stack's chapter in the Orthodontics for the TMJ-TMD Patient textbook (Grummons) stands apart from the writings by others of us who had the privilege to advance the message and methods of interdisciplinary therapeutics.

Countless patients live better lives, and doctors treat as thinkers because of Dr. Stack's contributions and influences. Worthy thanks have been earned by him from professional and patient communities.

Respectfully shared,

Duane Grummons, DDS, MSD, ABO
American Board Certified in Facial Orthopedics and Orthodontics
Spokane, WA, USA

Some Additional History on TMD and Movement Disorders, Recollections from Dr. Stack …

"I have difficulty remembering my first Tourette's patient, but the successful treatment of that patient resulted in word spreading throughout the Tourette's (community) sic, and more Tourette's patients began to knock on my door. I have enjoyed success, as well as personal satisfaction, in treating these children without having to use medications, behavior modification, etc.", Brendan C. Stack, DDS, MS published (reference below).

"For a century and a half, Tourette's syndrome has been a mystery to the medical profession, with physicians first believing that it was a psychological disorder, then a neurological/brain disorder, and then an infectious disease caused by streptococcus. What was never considered was that this disorder was due to a structural abnormality, which would manifest itself as a neurological problem. What has since been discovered is that Tourette's syndrome is neither psychological, infectious, genetic, nor environmental in origin, but is what we have termed a structural-reflex disorder. It has been shown in a pilot study of multiple cases how and why Tourette's, and its multiple comorbid disorders, can be discontinued with an intraoral orthotic device that requires no medicine or surgery."

"Tourette's syndrome is defined as an inherited neurological disorder that is a chronic idiopathic syndrome, characterized by the presence of multiple motor tics and vocal tics that have their beginning before adulthood (usually with an onset in childhood between ages 5 and 8). Tics are repetitive, stereotypical movements or phonetic events, which are nonrhythmic and involuntary (motor tics), such as blinking, coughing, sniffing, shoulder shrugging, neck stretching, throat clearing, etc."

"Tourette's syndrome was originally thought to be a rare and severely bizarre disorder, most often associated with coprolalia, which occurs in approximately 10% of those with Tourette's. Now T.S. is understood to be less rare and is often classified as a condition having a wide range of severity. It is currently treated with medications that seem to incapacitate the patient or by frequent psychological counseling that teaches behavior modification when a promontory urge is felt immediately prior to the tic(s)."

"Tourette's patients seem to have normal intelligence and a normal life expectancy. The most common disability is within a social setting, and those with T.S. find it embarrassing when severe movements or vocalizations occur. People with Tourette's can achieve success in all walks of life, from athletics to professional careers. Prejudice or ostracizing is very common at school or at work."

"In February of (sic 2012), Dr. Anthony B. Sims and I made a presentation explaining my technique to the Board of Directors of the National Tourette's Association in New York City. We were well-received. They were interested because of the many phone calls received from parents of patients asking why they were still being treated with medications and/or psychological counseling when they had personally experienced the results of my treatment techniques. These calls originated not only from the United States, but also from Europe as a result of my having lectured there. The Tourette's Association of America is currently in the process of formulating grant proposals to test my methodology, which will probably be funded in the near future."

"As word of my treatment successes spread, other people approached me with different types of movement disorders. These were older patients, many of whom had been diagnosed with Parkinson's or pre-Parkinson's type tremors or had not yet received an official diagnosis by a neurologist, or who were trying to avoid being labeled as Parkinsonian. Their thinking was that if I could treat someone's head from shaking back and forth, then I should be able to treat their arms from flailing up and down. I then began to think about the treatment of Parkinson's movement disorder patients. Applying these same principles, I successfully treated a number of Parkinson's patients."

Stack BC. My journey from orthodontics to craniofacial pain and TMJ to movement disorders. Cranio. 2012;30(3):156–8. https://doi.org/10.1179/crn.2012.023.

Preface

The concept of this book started about 10 years ago, preceding my father's passing in 2020. The core concept of the book was to describe the arc of evolution and understanding about TMJ dysfunction over the past 50 years and my father's role in it. The book would cover the current state of basic knowledge (diagnosis, imaging, and therapeutics). It would then proceed to advanced concepts and the leading edge of TMJ therapeutics.

Unfortunately, these discussions initiated after my father's health had started to decline. We worked on outlines and a list of possible contributors, valued professional colleagues of my father, but progress was slow. Many people who my father had wanted to include as authors in the book had retired from clinical practice and/or were otherwise occupied from engaging in the book opportunity. My father's energy in the last years of his life was quite limited. Other distractions to the project presented themselves. Then came the COVID-19 pandemic and intercurrent illness of my father. My father passed away on July 24, 2020. This obviously put a pause on this book project.

In honor of my father's career and memory, I decided to resume the project. At this time, I was the Chairman of Otolaryngology-Head and Neck Surgery at the Southern Illinois University (SIU) School of Medicine, Springfield, IL. I reached out to the SIU Dental School on our sister campus (Edwardsville, IL) and was put in contact with Dr. Revathi Shekar who was faculty there at the time and has ably orchestrated the recruitment of and submissions from various members of the SIU Dental School of core concept chapters (Part I). She has now moved on to be faculty at the University of Pittsburgh School of Dentistry and contributed her own chapter. Dr. Anthony B. Sims, a practicing colleague of my father in the Washington, DC, area (Columbia, MD) and protegee, who collaborated extensively with my father and knew of the evolution of my father's practice and thinking, was able to contribute and recruit authors in a significant way to add advanced materials to this text (Part II). Thank you to Drs. Shekar and Sims for your support of this project.

This book has a broad application to the dental and medical professions. The book covers material related to patients presenting with craniofacial pain. The information contained within is of value to the frontline generalist (dentist or physician) as well as the specialist and even the academic/researcher. There has been much progress made in the understanding of the TMJ, its dysfunction, and its implications on overall health and well-being. It

is hoped that this compilation will facilitate ongoing progress in areas of TMJ craniofacial pain and TMJ-related movement disorders. With the addition of online videos, readers will be able to see significant clinical demonstrations of TMJ therapeutics and its impact upon patients afflicted with movement disorders.

Springfield, IL, USA Brendan C. Stack Jr.

Contents

Part I

Fundamentals

The Temporomandibular Joint: Form and Function

Anita R. Joy-Thomas and Robert D. Spears

1 Introduction

The temporomandibular joint (TMJ) is a specialized synovial joint that is essential for the full range of function of the mammalian jaw. It is a complex joint made up of various tissue types, including bone, cartilage, connective tissues, as well as associated muscles and tendons. The TMJ is described as a bilateral, diarthrodial, synovial joint that is located between the mandibular condyles and the temporal bones. Each TMJ is made up of the condylar head of the mandible, the glenoid fossa and articular eminence of the temporal bone, an articular disc, and a synovial membrane-lined fibrous capsule that encloses the entire joint (Fig. 1). The articulating surfaces of the joint are lined by fibrocartilage, rather than hyaline cartilage, in adults. The articular disc is another unique feature of the TMJ, which by its location divides the joint space into two chambers—superior and inferior (Fig. 2). This particular anatomical feature of the TMJ allows the joint to function as a unit in both hinge/axial/rotational (ginglymus) and gliding/translational (arthrodial) movements, thus also being described as a ginglymoarthrodial joint [1, 2].

As with any joint in the human body, the TMJ not only allows for a full range of motion associated with mastication, but it also reduces forces acting on the associated bones by dissipation or distribution of load-bearing from the associated bones to the surrounding soft tissues. TMJ dysfunction therefore affects not only the bony components of the joint, but also the soft tissue components. Therefore, from a functional standpoint and to better manage TMJ dysfunction, a thorough understanding of TMJ anatomy, both of the hard and soft tissue components, is essential.

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Fig. 3 Some studies linked the unilateral posterior crossbite (UPCB) to TMD, especially if they were associated with a functional shift. (**a**) Photos are taken in maximum intercuspation position. Note the unilateral crossbite on the left side and the midline deviation. (**b**) Photos of the same patient taken in centric relation. Note the premature interference between the upper and lower premolars on the left side causing the mandible to shift to the left upon full closure

The association between masticatory muscle pain and UPCB has also been investigated. To evaluate if the occlusal alteration results in an asymmetrical muscle function and overloading of the muscles, muscular activity was assessed in children with and without UPCB using a standardized electromyographic protocol. The results showed that UPCB did not contribute to an asymmetric activation of the temporalis and masseter muscles during their function. These findings were different in the adults where individuals with severe malocclusions presented asymmetrical muscular activity [22], unlike the group with normal occlusion who presented more symmetrical and balanced muscular activation [23]. These findings suggest that in growing subjects, an asymmetrical muscular activity is commonly experienced without signs and symptoms of TMD. Adults with asymmetric masticatory muscle activity might be related to the presence of muscular pain and chronic myalgia [10, 24].

2.1.2 Sagittal and Vertical Malocclusions

In a recent systemic review, Manfredini et al. [25] tried to assess the association between TMD and the features of dental occlusion including the vertical and sagittal malocclusions. They found no cause-effect relation between the TMD and dental malocclusion. Thus, they encouraged all clinicians to abandon the gnathological paradigm in their TMD practice. However, in their other systemic review, they tried to link the facial morphology to the TMDs. They found an association between the skeletal class II profile and hyperdivergent growth pattern with the development of disc displacements and degenerative TMD [26]. This might be due to the joint's instability in these individuals and the potential risk of developing disc position abnormalities. This instability can be caused by the poor reciprocal fitting of the articular surfaces (small condyle and wide glenoid fossa) [27].

On the other hand, the development of an anterior open bite or a unilateral posterior open bite can be a sign of an idiopathic resorption of the condyle or a bilateral or unilateral condylar degenerative osteoarthritis [28, 29]. In such case, malocclusion is the sign of the development of the TMD rather than being the cause (Fig. 4).

2.2 A Sudden Change in the Occlusion

Adaptation within the masticatory system is possible within certain biological limits whenever the occlusion is altered for most individuals. However,

Fig. 1 A class II malocclusion is clinically associated with increased overjet due to either excessive maxillary growth or deficient mandibular growth. Functional appliances reposition the mandible anteriorly in an effort to redirect mandibular growth

most of these findings pointed towards a skeletal class II division 1 malocclusion with insufficient mandibular growth [3]. Posterior and superior displacement of the mandibular condyle in the glenoid fossa was assumed to be responsible for the malocclusion-related TMD symptoms [4]. Subsequently, various designs of oral appliances that raised the vertical dimension were proposed to address both TMJ and ear symptoms [5, 6]. Based on the early clinical evidence, orthodontic and dental educators advocated a detailed examination of TMJ function as an integral part of orthodontic clinical diagnosis.

Gnathology, defined as the study of the masticatory system, is closely related to understanding TMJ function during health and disease. The Gnathological Society, founded in 1926, stressed the importance of jaw kinematics and intraoral telemetry to achieve both a balanced and harmonious occlusion as well as optimum TMJ function [7]. Establishment of canine-guided occlusion and ensuring coincidence of maximum intercuspation with centric relation of the mandible were believed to be important for preventing and treating TMDs [8–10]. In situations where these gnathologic "goals" were not achieved with orthodontic treatment, custom-fabricated oral appliances were prescribed for TMDs. Various designs of these occlusal splints to treat TMDs have been proposed over the years, but scientific evidence for their efficacy is lacking [11].

In the 1970s, a gnathologic-prosthodontic concept of occlusion was introduced to the specialty of orthodontics by Ronald Roth. He believed that orthodontic treatment could modify the occlusion similar to full-mouth prosthodontic rehabilitation [12, 13]. This was consistent with the preexisting view that occlusal disharmonies and improper condyle position caused TMD [14]. According to Roth, the attainment of tooth and condyle positions recommended by the Gnathological Society was crucial for a stable orthodontic outcome as well as to prevent and/or cure TMD. Further, he stated that by ignoring gnathologic concepts, orthodontists could contribute to the development of TMDs. Although there was no evidence to support these claims, they sought to establish a relationship between orthodontic treatment and TMDs by placing the onus on orthodontists.

In the 1980s, the specialty of orthodontics witnessed another conflict in the ongoing debate about TMDs. This decade saw increasing numbers of "functional" orthodontic appliances being introduced to correct skeletal class II malocclusions (Fig. 1). Although their designs vary, most of these appliances aim to redirect growth by repositioning it more anteriorly. A group of orthodontists promoted functional appliances as more effective and less likely to cause TMDs compared to traditional orthodontic appliances such as elastics, headgears, chin cups, and treatment plans that required extraction of teeth. Unfortunately, these claims were not backed by scientific evidence either until the landmark lawsuit mentioned previously in this chapter changed all that [1].

3 Evidence-Based Perspective

3.1 Malocclusion and TMD

The term "malocclusion" in orthodontics is a rather broad categorization that encompasses both skeletal and dental discrepancies between

the maxilla and mandible. Additionally, the relationship between the jaws may be affected in the sagittal, transverse, or vertical planes [15], thus further complicating a direct analysis between TMD and malocclusion.

3.2 Malocclusions in the Transverse Plane

In the transverse dimension, posterior crossbites of skeletal or dental origin are the primary concerns. A bilateral posterior crossbite results from a small maxilla or a large mandible and may be associated with TMD symptoms such as headache, muscle pain, and clicking [16]. As these are mostly attributable to an aberrant path of closure of the mandible, orthodontic correction of the crossbite can alleviate some of the TMD symptoms.

A unilateral posterior crossbite, on the other hand, is more challenging to treat orthodontically (Fig. 2). This is due to the underlying asymmetric muscular activity and the resulting altered condyle position in the glenoid fossa between the crossbite and non-crossbite sides. Unilateral posterior crossbites are prevalent in young individuals and directly affect the masticatory system, leading to abnormal occlusal contacts [17, 18] and overloading the masticatory muscles asymmetrically [19] (Fig. 2). These in turn have been implicated in causing myofascial pain and TMJ clicking.

A 10-year follow-up study was conducted to analyze the relationship between unilateral posterior crossbite and TMJ clicking [20]. During the initial observation period of adolescents, there was no association between the crossbite and joint clicking [17]. However, this changed after 10 years when an association was seen and the study participants self-reported joint clicking [20]. Orthodontic treatment in these subjects did not decrease the likelihood of self-reporting TMJ clicking, suggesting that occlusal factors are not the primary determinants of the reported symptoms. Instead, anatomic factors such as asymmetries in the glenoid fossa and/or mandibular condyle could be related to joint symptoms either concomitant to or resulting from a unilateral posterior crossbite.

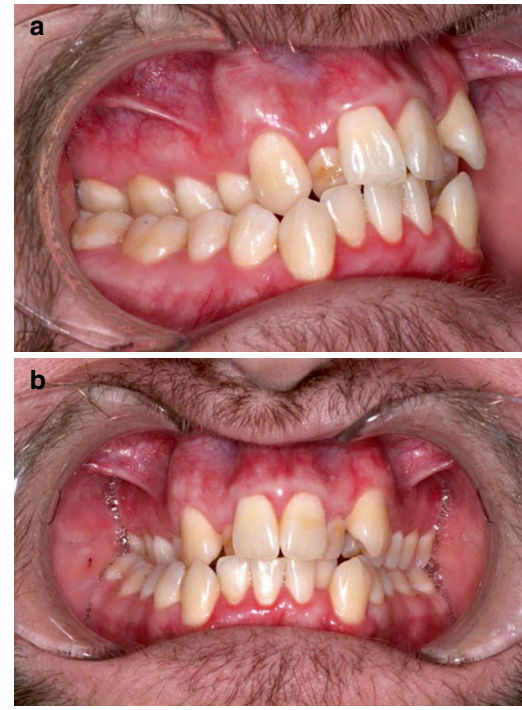

Fig. 2 (**a**) A unilateral posterior crossbite seen on the patient's right side. This transverse malocclusion is associated with deviation of the mandible to one side during jaw closure. (**b**) A common clinical finding is premature contact (during jaw closure) on a tooth or a group of teeth that are out of alignment compared to the other teeth

A prospective study evaluated the association (if any) between malocclusion characteristics during adolescence and TMJ clicking later in life [21]. Posterior crossbite, overbite, and overjet measured in subjects at age 15 years were compared against self-reported TMJ clicking at age 45 years. Results showed that neither the malocclusion variables that were analyzed nor a history of orthodontic treatment was associated with TMJ clicking. Overall, there is insufficient scientific evidence to establish a direct link between posterior crossbite and TMJ clicking.

The activity of the masticatory muscles has been investigated in relation to posterior crossbite and TMD. A systematic review concluded that there is no evidence to establish a relationship between posterior crossbite, masticatory muscle pain, and TMJ disc displacement [18]. Specifically, with a unilateral posterior crossbite, it could be speculated that unbalanced activation

anterior disc displacement and eventually TMD. However, studies using magnetic resonance imaging (MRI) to analyze the condyle-disc-fossa relationship after the application of controlled forces with a chin cup have concluded that the appliance does not increase the risk for TMD [31, 32].

A hyperdivergent growth pattern of the mandible is associated with increased lower facial height, steep mandibular plane angle, and a tendency for an anterior open bite. On the other hand, a hypodivergent growth pattern is clinically associated with a deep overbite (Fig. 5). Both of these malocclusions in the vertical plane have a direct impact on the TMJ and the surrounding musculature. A systematic review reported an association between anterior open bite and TMJ disc displacement subsequently leading to degenerative TMJ disorders [33]. As mandibular growth and condyle position are closely interrelated, this is to be expected. The authors did, however, caution that their conclusion was based on low-quality evidence from heterogenous studies.

3.4 Condylar Position and Dental Occlusion

The relationship between the positions of the condyles in the glenoid fossa and the teeth in the dental arches has long been debated in dental literature. Consequently, definitions of often-used terms such as centric relation (CR) and maximum intercuspation (MI) have been repeatedly modified. For instance, over the past five decades, the definition of CR (the position of the condyles independent of tooth contact) has evolved from describing the condylar position in the glenoid fossa as being the most posterior to posterior-superior to the currently accepted anterior-superior [34].

The importance of accurately defining, as well as clinically finding, CR in dentistry lies in the assumption that this condylar position refers to the ideal and reproducible relationship between the mandible and cranium [35]. This forms the basis of the gnathological view that in order to prevent TMD after any dental procedure such as orthodontic treatment, CR and MI must coincide [36]. Thus, proponents of this theory have used various CR bite registration procedures and occlusal deprogramming oral appliances to obtain centric relation records [37, 38]. However, evaluation of condylar position in the glenoid fossa using magnetic resonance imaging (MRI) showed that chair-side manipulation of the jaw into a centric relation position is not reliable and cannot be used to prevent TMDs [39].

Based on the contemporary scientific evidence, there is no rationale for mounting orthodontic patients' maxillary and mandibular casts on a dental articulator to determine and treat a malocclusion to an arbitrary CR [40]. Additionally, TMD signs and symptoms are not related to a particular position of the mandibular condyle in the glenoid fossa, whether it be posterior, superior, or anterior [41, 42]. Not surprisingly, authors of a recent review on the clinical implications of centric relation recommended that the term "CR" should not be used at all. To maintain TMJ health, each orthodontic patient should instead be treated to establish a unique TMJ position that is determined by maximum intercuspation of the teeth [43].

Fig. 5 Both anterior open bite and deep overbite malocclusions in the vertical plane can predispose to the development of TMD

Fig. 1 Patient lying in supine position

Fig. 2 Patient with closed mouth and aligned teeth in the natural biting position

For patients who are unable to maintain their mouths open and stable throughout the scanning process, a prefabricated mouth prop can be used

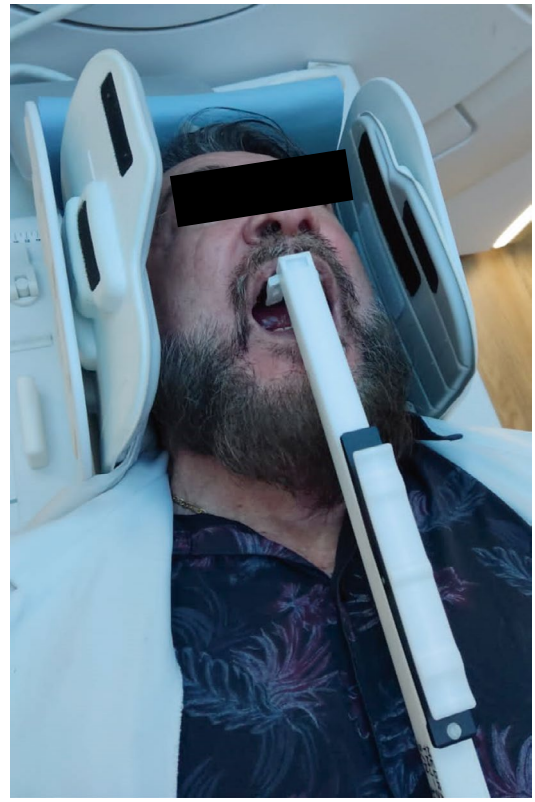

Fig. 3 Mouth prop device to evaluate the TMJ in the open mouth position

(Fig. 3). This device is designed to mimic and sustain the patient's maximum mouth opening, effectively stabilizing it during imaging. In some cases, a third scan may be requested with a splint inserted between the teeth. This splint, created by a dentist, alters the relationship between the condyle and the fossa (the concave depression in the temporal bone). It helps evaluate the impact of the splint on the position of the condyle and the surrounding soft tissues [5, 6].

Dual-surface coils are small bilateral coils used to provide excellent detail of the joint with a small field of view, high signal-to-noise ratio, and simultaneous bilateral acquisition (Fig. 4). Modern multichannel head coils and flexible coils with great parameters can also be used with satisfactory results (Fig. 5) [5].

The specific protocol for conducting an MR study of the temporomandibular joint (TMJ) can vary among different institutions. However, there are some key sequences that are com-

ing, and sleepy after a meal or while watching television are some of the indicators. OSA might induce bruxism. Use Epworth Sleepiness Scale or STOP-BANG questionnaire. Continuous positive airway pressure (CPAP) is the gold standard and most efficacious for treating OSA. Mandibular advancement device (MAD, oral sleep appliance) can be used if a patient is intolerant to CPAP [12, 13]. When you identify a patient with OSA using the questionnaires listed above, refer the patient for a sleep study. MAD is an option for OSA, but make sure to educate patients about its possible side effects [14, 15]. Be aware that it is common for some patients to request for MAD after a short and inadequate trial of CPAP usage.

6 Examination

A thorough examination will tell you whether the pain is primarily from the muscles (Fig. 2) or the temporomandibular joint (Fig. 3). Tenderness to palpation of the preauricular region indicates joint inflammation. Consider imaging in these cases. A panoramic radiograph is a good place to start. A CBCT is ideal to see a three-dimensional image. If there is painful click or lock with difficulty opening mouth, an MRI with TMJ protocol (closed mouth and open mouth) should be considered to confirm the historical and clinical diagnosis.

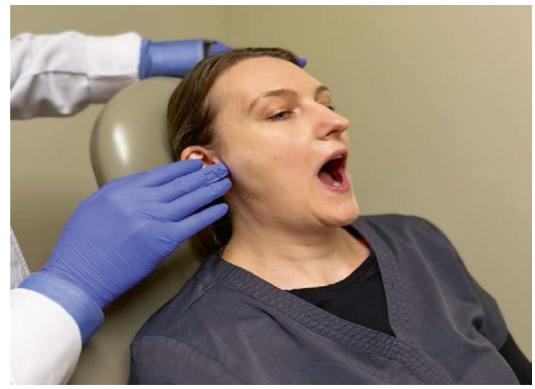

Fig. 3 Examination of temporomandibular joint at the preauricular region

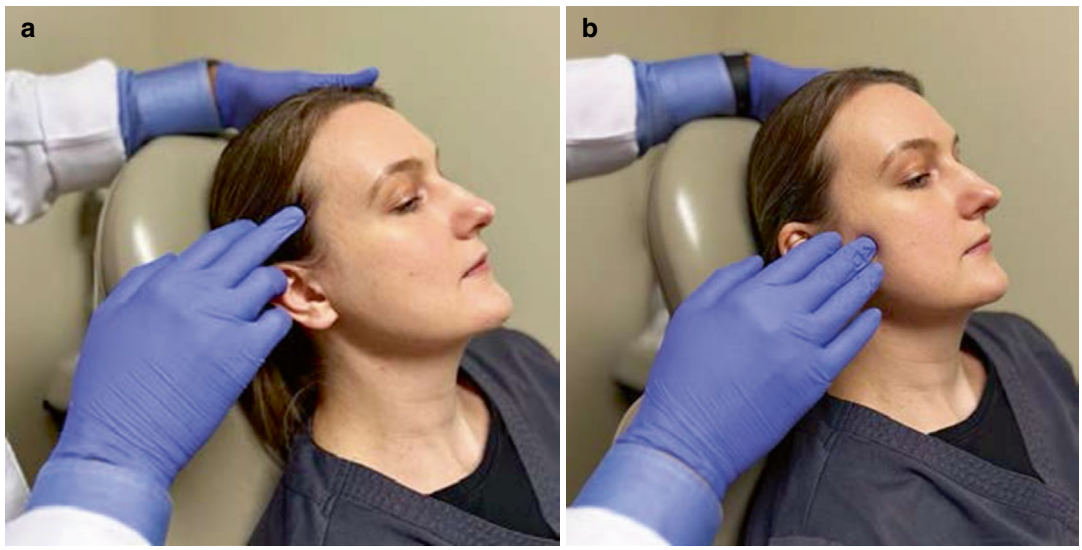

Fig. 2 Examination of (**a**) masseter and (**b**) temporalis muscle

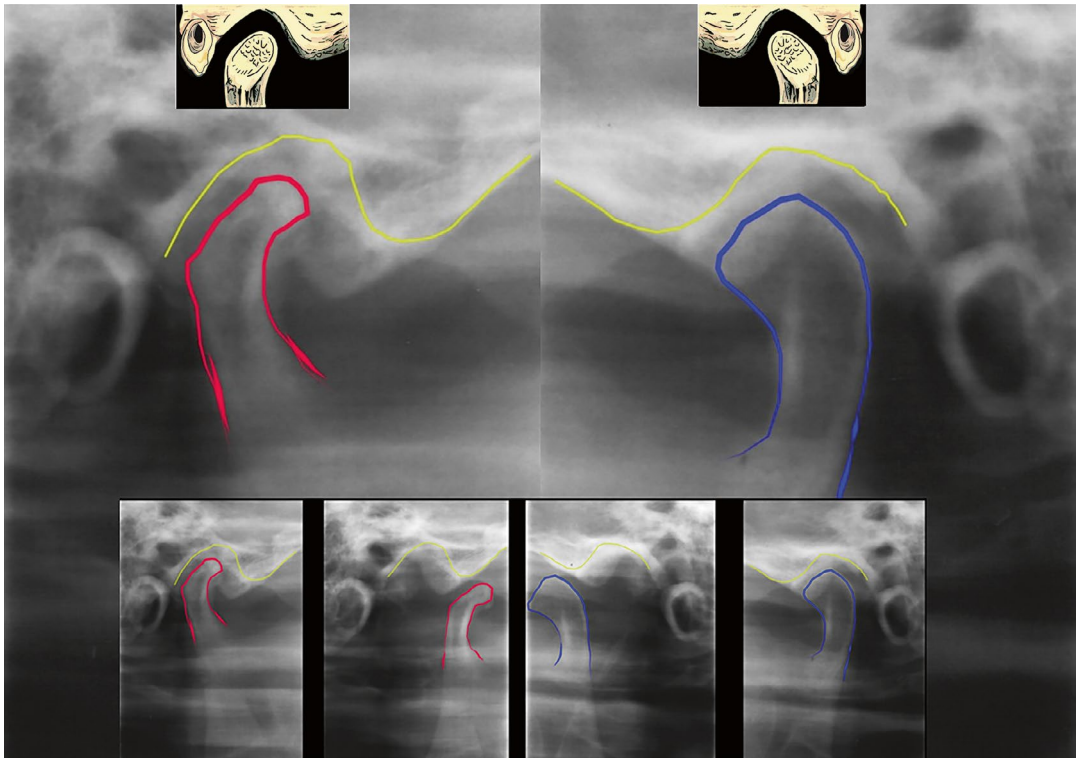

Fig. 8 Image showing an illustration of the heads of the mandibles (windows) and plain films of a patient where the structures bear no resemblance to the healthy physical structure of the illustration

Fig. 9 **Whole-body** postural photos: front, back, right, and left profile and front smiling

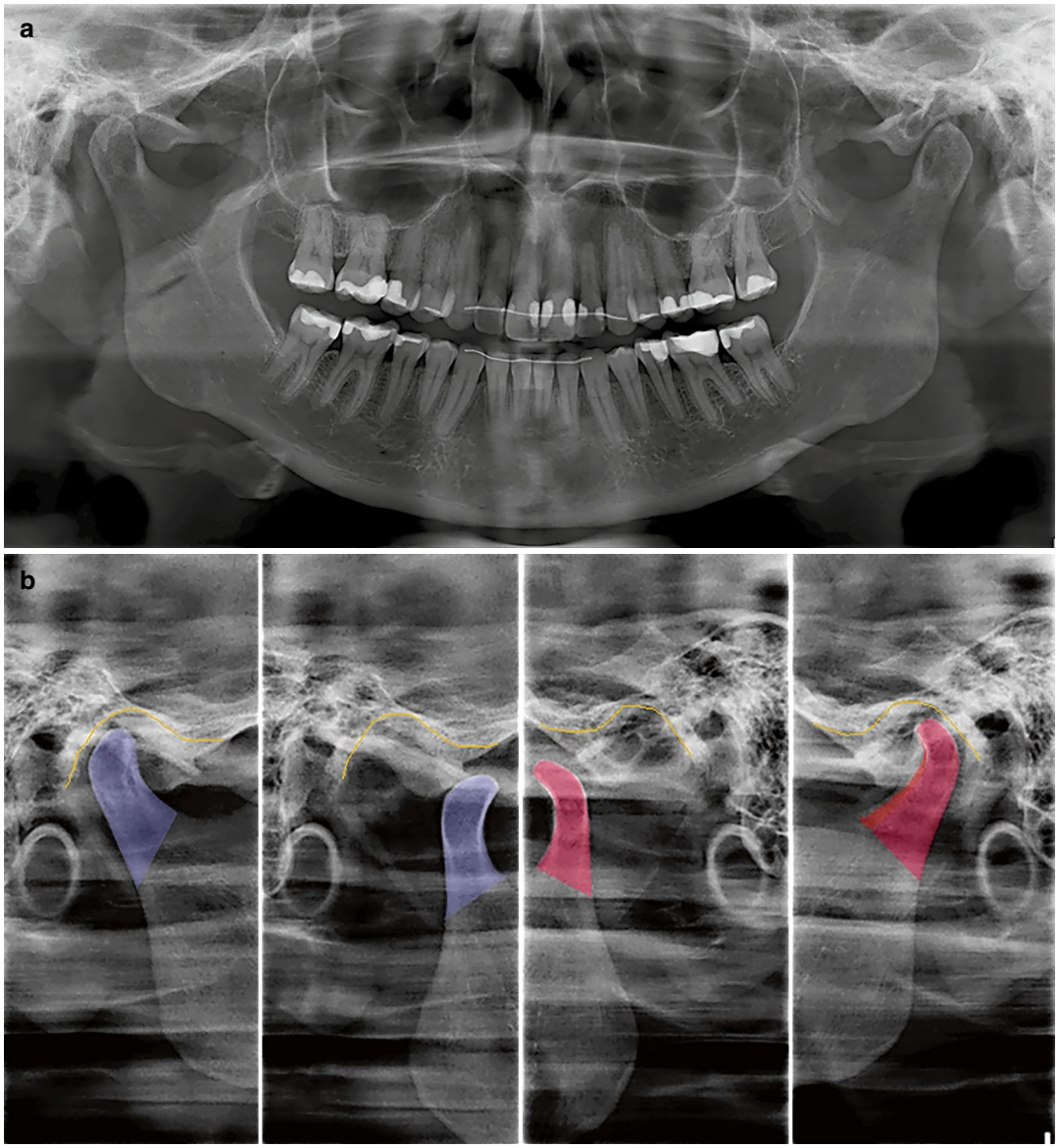

Fig. 11 (**a**) Panoramic and (**b**) TMJ plain films of the patient with condyle color highlights

4.5 Structural Misalignment Related to Temporomandibular Joint Pathology

A 17-year-old patient who had already been treated orthodontically returned to the clinic complaining of headache, ear pain, shoulder pain, and bilateral joint clicks. She had pain in her TMJs and a stronger ache when retrodiscal palpation was performed, an indication of condyle retro-position. The patient showed an "ideal occlusion" without relapses from the orthodontic treatment, which was finished 5 years previously (Fig. 14). She exhibited no interference in jaw protrusion nor lateral translation. A surface electromyography was performed to measure the right and left anterior temporalis muscle and right and left masseter muscle activity in maximum intercuspation and clenching. The masseter muscles, the most powerful of the

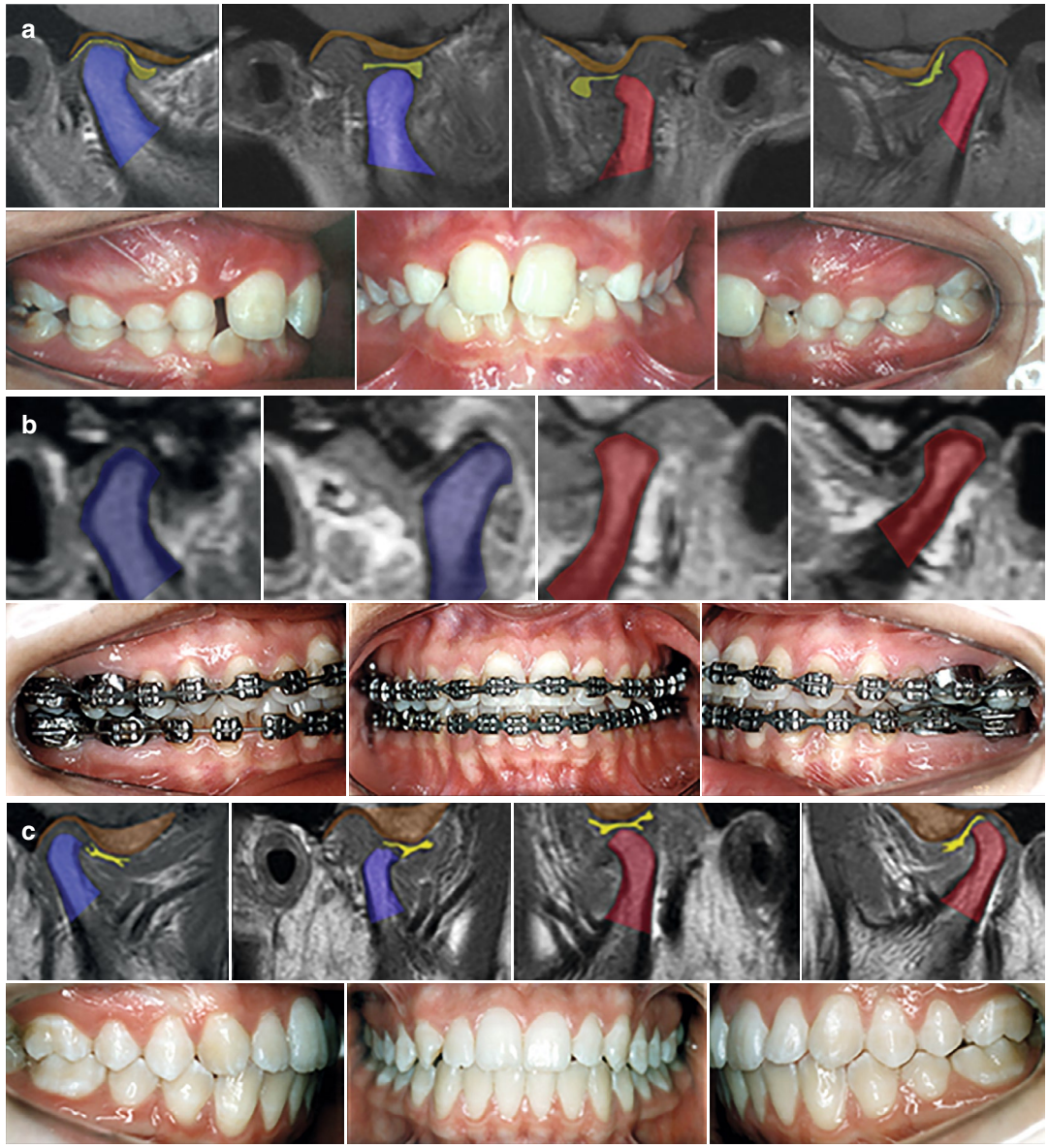

Fig. 7 Different images of occlusions of patients with the respective MRI images in closed and open mouth with color highlights

itant ones, which modifies the degree of complexity of the disease.

How is a better relationship between muscles, jaws, teeth, and temporomandibular joints achieved when several components of the stomatognathic system may be injured with different types and degrees of lesions? In the section, ***TMJ Pathology Treatment (Chap. 13)***, four clinical cases are presented with the therapeutic resources utilized. Even though the importance of full-body photographs has been emphasized heretofore, for brevity and convenience, they are not included. The focus in the third section is TMJ structural and functional changes.