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The Evolution of TMD Diagnosis: Past, Present, Future

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Abstract

This review explores the principles and process associated with the diagnosis of temporomandibular disorders (TMDs). TMD diagnosis has evolved substantially over the past 25 y. Previously, diagnosis focused solely on aberrations in oral structures, largely without empirical evidence. The Research Diagnostic Criteria for TMD (RDC/TMD) were developed on core principles of 1) a dual-axis system reflecting the biopsychosocial model, 2) a clear operationalization for reliability, and 3) the allowance of multiple diagnoses. These principles were retained in the subsequent validation research of the RDC/TMD, and the current diagnostic system—the Diagnostic Criteria for TMD (DC/TMD)—has improved on those principles as well as on diagnostic validity and protocols for assessing the psychosocial domain. Further investigations into etiology and its potential contribution to taxonomy revision are described, particularly within the context of complex disease. The review concludes with an outline of major research areas already underway that will support future revisions of the DC/TMD.

Keywords: decision making, diagnostic systems, informatics, pain, psychosocial factors, temporomandibular disorders

Introduction

The present article describes the principles and process underlying the development of diagnostic methods for temporomandibular disorders (TMDs) and highlights the necessary foundations for future taxonomic developments. Key events, as reflected in this review, are depicted in the Figure.

TMDs represent heterogeneous musculoskeletal disorders, while a TMD represents 1 type or 1 aspect, such as TMD pain. TMDs, as a group, are characterized by regional pain in the facial and preauricular areas or by limitation or interference in jaw movement. Frequent examination findings are hyperalgesia—usually revealed via pressure application to the muscles of mastication or temporomandibular joints (TMJs)—and noises in the TMJs. The most common subtypes of TMDs include pain-related disorders, such as myofascial pain and arthralgia, and disorders associated with the TMJ, primarily internal derangements and degenerative joint disease. In addition, the biopsychosocial perspective recognizes the importance of assessing the impact of chronic pain on the person, including psychologic disabilities, such as depression, as well as psychosocial dysfunction, such as inability to perform activities of daily living, susceptibility to medication abuse, and frequency of treatment seeking. These are significant components of clinical presentation of many chronic pain conditions, including TMDs (Dworkin et al. 1990; Dworkin 1994; McLean et al. 2005; Porter-Moffitt et al. 2006; Verkerk et al. 2015).

We begin with the observation that a reliable and valid diagnostic system for many TMD subtypes has evolved from the last 2 decades of TMD diagnostic research. That the definition, characteristics, and biopsychosocial perspective of TMDs are so well known at this time is likely related to the developmental path of TMD diagnosis. Fundamental research has changed the model for TMDs from biomedical, as predominately a pathobiologic condition of the TMJ, to an integrated and multidimensional biopsychosocial model that shares common features with a cluster of prevalent musculoskeletal disorders that include chronic low back pain, chronic headache, and fibromyalgia (Deyo et al. 2014). The central attribute of each condition is persistent pain that drives treatment seeking and becomes debilitating in a significant minority of cases.

The first effort at an evidence-based diagnostic method for TMDs—the Research Diagnostic Criteria for TMD (RDC/TMD)—emerged in 1992 (Dworkin and LeResche 1992) and came from the openly acknowledged need for a diagnostic system that could not only dependably distinguish, for epidemiologic and clinical research purposes, cases from controls but also differentially define and diagnose common subtypes of chronic pain–related TMDs. In the following 2 decades, the RDC/TMD generated much international scientific research responsive to their foundation, built on testable evidence in the context of an iterative process providing the further evidence basis for reliable and valid revisions.

Better diagnostic methods have also led to a better understanding of TMD prevalence, incidence, and other characteristics in populations around the world. Examples include the

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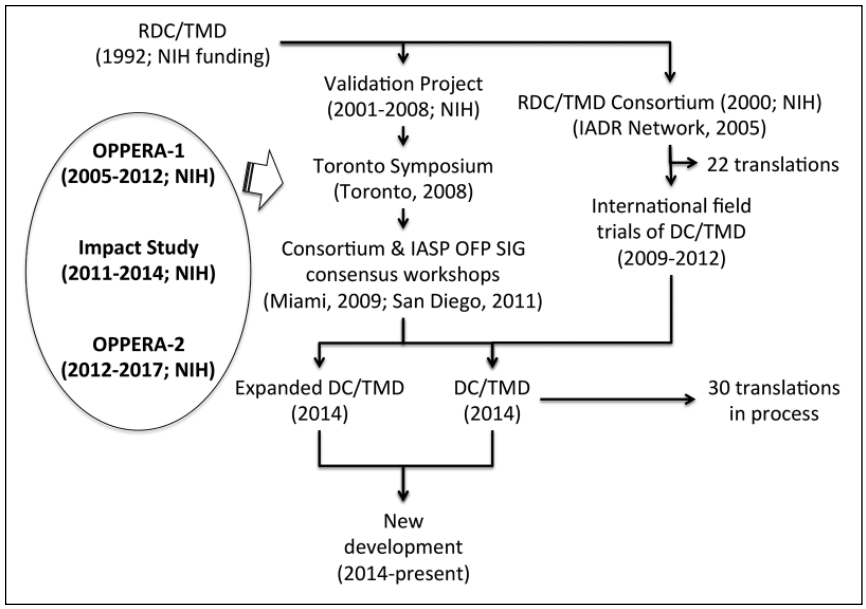

Figure. From the RDC/TMD to the DC/TMD and Expanded DC/TMD. Major steps and funding sources are shown as nodes, with stage-specific products included. DC/TMD, Diagnostic Criteria for Temporomandibular Disorders; IADR Network, International RDC/TMD Consortium Network, within the International Association for Dental Research; IASP OFP SIG, International Association for the Study of Pain Orofacial Pain Special Interest Group; Impact Study, TMJ Intra-articular Disorders, Impact on Pain, Functioning, and Disability; NIH, National Institutes of Health; OPPERA, Orofacial Pain–Prospective Evaluation and Risk Assessment; RDC/TMD, Research Diagnostic Criteria for Temporomandibular Disorders; RDC/TMD Consortium, International RDC/TMD Consortium; Validation Project, Research Diagnostic Criteria–Reliability and Validity.

following: Incidence of TMD pain meriting a diagnosis is 3.9% per annum with an approximately equal male:female ratio (Slade, Bair, et al. 2013). The population prevalence is 10% to 15%, with a sex ratio of approximately 2:1, and clinical populations show a female:male sex distribution ≥4:1 (Drangsholt and LeResche 1999). Pain associated with chronic TMD is poorly explained by relevant physical findings (Ohrbach and Dworkin 1998), and comorbid pains are commonly present (John et al. 2003). Historically, diagnostic efforts focused on etiologic theories of pathobiology focused mainly on single causes, for which the evidence has been insufficient. TMDs are no longer considered a solely local disorder but rather are the outcome of multiple risk determinants (Slade, Fillingim, et al. 2013). An important caveat is that within the heterogeneity of TMDs, our understanding of the disorders revolving around pain as the predominant symptom has improved substantially more than our understanding of disorders revolving around mechanical and degenerative changes in the TMJ.

TMD: Historical Diagnosis, Hysterical Diagnosis

The earliest description of TMD in the medical literature identified mechanical TMJ disc problems (Annandale 1887) with perhaps an unintended consequence of historically associating TMD pain almost exclusively to the TMJ. An early and influential description by Costen (1997; originally published 1934) attributed otologic pain symptoms in the TMJ to insufficient occlusal support of the mandible and established the disorder as TMJ pain arising from forces attributed to certain dental malocclusions. Based on these widely held biomedical theories of TMD etiology, TMDs were primarily diagnosed as TMJ pathology—and "TMJ" became the almost universal name by which the condition was known to dentistry and the lay public, thereby reifying a particular perspective. However, none of these early pathobiologic theories were supported by any available scientifically credible evidence. Yet in spite of their unacceptability by dental scientists, the biomedical model of physical disease as the sole etiologic agent was the dominant model that guided the dental profession in the management of TMDs—the name that eventually replaced TMJ as being more evidence based (American Dental Association 1983)—and, unfortunately, such theories still persist in the field. For example, the more limiting approaches, such as the so-called neuromuscular dentistry, use diagnostic technologies lacking scientific credibility (Lund et al. 1995) while retaining non–evidence based factors as etiologic targets for TMD management, illustrating the importance of using a validated diagnostic system to correctly identify persons with the disorder and to avoid errors in wrong attribution of etiology. Because of the many iatrogenic complications associated with TMJ treatment based on unfounded diagnostic theory, it seemed to many clinical dental researchers and clinicians that the then-prevalent practices reflected an unfortunate move away from the fundamental dictum in medicine to "first, do no harm." In fairness, it must be acknowledged that in some quarters of mainstream medicine, these same inadequacies have been widely reported.

Thus, the TMD field was in considerable disarray, with little agreement and much controversy among academicians, scientists, and clinicians over what constituted the best evidence for deciding on case definition, diagnostic criteria, and rational treatment decisions (Greene 1983). However, researchers in most (but not all) academic dental centers as well as the National Institutes of Health (NIH) displayed increased concern regarding unfounded theories of TMD disease—specifically, the lack of scientific evidence to support etiologic, diagnostic, and treatment practices prevalent in this era.

One arena of promising research implications for TMD diagnosis and management emerged surprisingly from the changing approach that clinical psychiatry was taking to diagnosing psychopathology. The earliest of these notions borrowed from psychoanalytic theory, which, relevant to present concerns, interpreted medically unexplained physical symptoms, such as pain, as manifestations of underlying anxiety

neuroses, such as hysteria. In this context, difficult-to-understand symptoms of persistent pain in the absence of verifiable and objective clinical signs came to be thought of as "psychosomatic"—physical symptoms denoting underlying psychopathology; the overall theoretical term for this process of conversion of neurotic symptoms into physical complaints was labeled "somatization" by psychoanalytic theory. However, with the emergence and increasing acceptance of a biopsychosocial integrative view of physical disease and psychiatric illness, it became clear that psychoanalytic theory offered little scientific evidence to explain the etiology of signs and symptoms associated with chronic pain.

With successive iterations of the *Diagnostic and Statistical Manual for Mental Disorders* (*DSM*) for diagnosing psychopathology, less and less reliance was placed on interpretations of patient behavior based on as-yet-unsubstantiated theories of psychopathology. Instead, efforts were directed to developing an iterative process of defining mental disorders on a descriptive basis as the best compromise to aid clinical research and treatment. Successive generations of the *DSM*, from the *DSM-IIIR* to the *DSM-V* (American Psychiatric Association 1980, 2000, 2013), now rely almost exclusively on continual revisions of the currently best available evidence for psychiatric diagnoses and case definitions for such common mental disorders as anxiety, depression, and clinical symptoms such as pain presenting without objectively measurable physical findings. Terms such as "hysterical conversion" disappeared and were replaced by descriptions consistent with patient presentations, including the impact on the person of presenting signs and symptoms of psychiatric disability. This move to develop descriptive versus etiologic hypotheses for disorders where no underlying etiologic theory could be scientifically supported is universally viewed as a critical step forward toward the more rational diagnosis and management of mental illness.

RDC/TMD: Rationale, Early Beginnings, and Shortcomings

The experience gained in psychiatry of emphasizing, given the limited etiologic evidence, descriptive diagnoses as a more useful approach to studying self-reported subjective states and behaviors was imported to the TMD field. NIH funding (S.F.D., principal investigator) supported a workgroup of expert TMD clinical researchers to develop an evidence-based descriptive diagnostic system regarding common TMD subtypes, one that was divorced from any of the then-prevailing (and highly contentious) theories about presumed etiology. This effort, labeled the RDC/TMD, had modest goals based on the little that was known scientifically, and it limited the initial effort to common TMD patient presentations prevalent enough to study within a reasonable time frame.

The core principles underlying this diagnostic approach included 1) a biopsychosocial model to assess and classify disease and illness; 2) epidemiologic data for discerning distribution of signs and symptoms by sex and age and for identifying population norms from which disease could be better defined; 3) a dual-axis system composed of physical diagnoses (axis I) and psychosocial profiles (axis II); 4) strict operational definitions of terms, including precise specifications for the clinical examination as well as the classification of findings, and protocols for required reliability and validity studies; and 5) recognition that the initial effort required future data to be generated as the evidence basis for inevitable revisions. Parameters for assessing the sufficiency of diagnostic systems encompassed sampling methods, research suitability, sensitivity and specificity, interrater reliability, and clinical considerations, such as biological correlates, multiple diagnoses, and support of clinical decision making, as developed elsewhere (Fenton et al. 1981). Based on these parameters, critical review of existing diagnostic systems revealed their considerable deficiencies and substantiated data in support of developing RDC/TMD research standards (Ohrbach and Stohler 1992).

Upon publication of the resultant RDC/TMD (Dworkin and LeResche 1992), immediate interest warranted translations, grant proposals, and data-based publications. Because "research" was the purposefully identified initial objective and was part of the title, the clinical field largely ignored the RDC/TMD and its potential to bring clarity and evidence-based diagnoses and clinical treatment decisions. The research field, by contrast, raised specific and welcome criticisms focused on pragmatic issues as well as stage-specific growth issues (Clark et al. 1993; Steenks and de Wijer 2009b). For example, the RDC/TMD exhibited important omissions from the then-nascent fields of genetics, epigenetics, brain neuroscience, and diagnostic testing instrumentation to quantify relationships between subjective pain report and physiologic findings (e.g., quantitative sensory testing).

Responses to critics were incorporated or explained more completely, as they reflected the major basic premises and objectives underlying the RDC/TMD approach to developing 1) a diagnostic system reliant on the presence of self-reported pain (Turk and Flor 1987), 2) a physical examination sufficient to yield reliable case definitions and diagnoses suitable for validation research (John et al. 2005), and 3) sufficient data by which the limitations identified in the first stage of development of the diagnostic system could be addressed. Because the initial goal for the RDC/TMD was to allow it to start the process of data collection that would be responsive to its inherent limitations, the potential was enhanced for maximizing the likelihood that further research would yield data-based revisions to the diagnostic system. The joint publication of critiques and responses (Goulet 2009; Greene 2009; Steenks and de Wijer 2009a, 2009b; Svensson 2009), supported largely by the body of RDC/TMD research, illustrated that important growth in scientific TMD research had occurred and that increasing demand for evidence-based research had replaced a great deal of divergent (and often untestable) theories as the road to progress in the contentious arenas of clinical TMD diagnosis and management.

A Consortium Emerges

The National Institute of Dental and Craniofacial Research (NIDCR) requested proposals to support international research, and funding was awarded (S.F.D., principal investigator) for

the development of an international RDC/TMD research consortium, with an initial informal affiliation with the International Association for Dental Research (IADR) to support RDC/TMD use in international scientific TMD research. The consortium grew to become a formal network within the IADR, which better allowed it to sponsor symposia and workshops that proved to be invaluable in revising the RDC/TMD. As of 2015, the Science Citation Index reported 1,695 citations to the RDC/TMD and Google Scholar, 2,947 citations. In addition, the RDC/TMD had been translated into 22 languages, many according to an evolving set of state-of-the-art translation standards (Ohrbach et al. 2013). These many language translations have in turn contributed to a knowledge base about TMDs that cuts across sociocultural, financial, health care, and theoretical domains, further fulfilling the initially stated goals underlying RDC/TMD development.

Validation of the RDC/TMD

By the late 1990s, the RDC/TMD were the dominant if not required diagnostic system for NIH-funded research applications and most TMD peer-reviewed scientific publications. As implied above, the need for critical assessment of the RDC/TMD was recognized by the NIDCR, which funded the multisite Validation Project (E.L. Schiffman, principal investigator) for assessing the reliability and validity of the RDC/TMD in the service of ideally providing a basis for the first RDC/TMD revision. The Validation Project not only retained all operational principles foundational to the RDC/TMD but also improved on them when possible (e.g., more clearly operationalized clinical examination procedures). In one sense, the Validation Project served as proof of concept of the underlying premise of the RDC/TMD: a descriptive approach to diagnosis has heuristic value. The Validation Project produced new standards for TMJ imaging diagnosis (Ahmad et al. 2009) as well as core findings (Anderson et al. 2010; Look et al. 2010; Ohrbach, Turner, et al. 2010; Schiffman, Ohrbach, et al. 2010; Schiffman, Truelove, et al. 2010; Truelove et al. 2010). The significance of this project cannot be overstated: NIDCR-supported resources further advanced the science of diagnosis, which was immediately applicable to TMDs and readily generalizable to serve as a template for systematic chronic pain research in other fields (Fillingim et al. 2014).

Development of the DC/TMD

In parallel with the publications from the Validation Project and other researchers, the International RDC/TMD Consortium Network sponsored a series of public and invited symposia that coincided with annual IADR meetings. These meetings and workshops comprised recognized clinical researchers and research-oriented clinicians whose lengthy deliberations led to consensus recommendations (Ohrbach, List, et al. 2010a, 2010b) for the first revision of the RDC/TMD.

Parallel with those workshops, 3 other NIH-funded projects occurred in timely sequence: OPPERA-1 (W. Maixner, principal investigator), Impact Study (E.L. Schiffman, principal investigator), and OPPERA-2 (W. Maixner and G.D. Slade, co–principal investigators). These separate research investments fostered further improvements in TMD diagnosis by peer-reviewed research designs that allowed refinement and better operationalization of research methods initially pioneered by the RDC/TMD and the evidence-based refinements derived from the Validation Project (Ohrbach 2014).

Publications resulting from this dynamic longitudinal process of research and data analyses included 1) the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD; Schiffman et al. 2014) providing reliable and valid criteria for the common TMDs for clinical and research settings; 2) the expanded DC/TMD (Peck et al. 2014) as operationalizable criteria for the uncommon TMDs; 3) joint publication of the DC/TMD and the expanded DC/TMD by the American Academy of Orofacial Pain (de Leeuw and Klasser 2013), thereby removing the artificial barrier between research and clinical diagnostic methods; and 4) an executive summary of the DC/TMD (Schiffman and Ohrbach 2016) to better disseminate the diagnostic standards to the general clinical field. In summary, as compared with the RDC/TMD, the DC/TMD have advanced to an evidence-based system with greater validity for clinical use. Tables 1 and 2 highlight that progression.

Is There a TMD Phenotype?

OPPERA (Orofacial Pain: Prospective Evaluation and Risk Assessment) has investigated etiologic factors underlying the development of acute TMD pain and its transition to a chronic pain condition. OPPERA created a specific TMD case definition, sufficient to clearly identify those without lifetime TMDs as based on pain and pain-related limitations as well as for acute or chronic TMD pain, using modified RDC/TMD (Slade et al. 2011).

As illustrated by Slade and colleagues (2016), abundant variables were identified distinguishing chronic TMDs from non-TMDs as well as predicting first onset of TMD as a pain disorder, thereby supporting the extent to which case classification made with these simple markers of disease accurately captures a fundamental quality of "TMD." The results from approximately 35 published OPPERA studies revolve around the simple phenotype identified by the TMD case definition, indicating that it may be a sufficient marker for underlying complexity as well as suggesting that other diagnostic resources should be allocated to more refined assessment of the appreciable variability reflected as individual differences in how TMDs are expressed. While the OPPERA studies have been limited to subjects 18 to 44 y old characterized on the basis of masticatory system pain, patient characteristics are largely similar across the major RDC/TMD subtypes (Kino et al. 2005), and treatment models suggest that the same principles successful for managing pain conditions apply to TMJ impairments (Schiffman et al. 2007). Consequently, the OPPERA evidence suggestive of a TMD pain phenotype identified by the core diagnostic variables contained within, for example, the DC/TMD may be generalizable to other types of TMDs but this awaits confirmation.

Table 1. Validity Statistics of the RDC/TMD and DC/TMD Organized by Diagnoses within Each System.

	RDC/TMD		DC/TMD	
Diagnosis	Sensitivity	Specificity	Sensitivity	Specificity
Myalgia			0.90	0.99
With limitation	0.65	0.92		
Without limitation	0.79	0.92		
Myofascial pain with referral			0.86	0.98
Arthralgia	0.53	0.86	0.89	0.98
Disk displacement				
With reduction	0.38	0.88	0.34	0.92
With reduction, with locking			0.38	0.98
Without reduction, with limitation	0.22	0.99	0.80	0.97
Without reduction, without limitation	0.03	0.99	0.54	0.79
Osteoarthrosis	0.15	0.99		
Osteoarthritis	0.10	0.99		
Degenerative joint disease			0.55	0.61
Subluxation			0.98	1.00

Statistics adapted from Truelove et al. (2010) and Schiffman, Ohrbach, et al. (2010).
DC/TMD, Diagnostic Criteria for Temporomandibular Disorders; RDC/TMD, Research Diagnostic Criteria for Temporomandibular Disorders.

Table 2. Comparison of Axis II Assessments in the RDC/TMD and DC/TMD.

Domain	RDC/TMD	DC/TMD
Pain intensity	Graded Chronic Pain Scale	Graded Chronic Pain Scale version 2
Pain locations		Pain manikin
Pain-related disability (physical function)	Graded Chronic Pain Scale	Graded Chronic Pain Scale version 2
Functional limitation of jaw	Checklist	Jaw Functional Limitation Scale
Distress		
Depression	Modified SCL-90 subscales	PHQ-9
Anxiety		GAD-7
Physical symptoms	SCL-90 subscale	PHQ-15
Parafunction		Oral Behaviors Checklist

Information is from Dworkin and LeResche (1992) and Schiffman et al. (2014). All instruments are available at www.rdc-tmdinternational.org.
DC/TMD, Diagnostic Criteria for Temporomandibular Disorders; GAD-7, Generalized Anxiety Disorder 7; PHQ-9, Patient Health Questionnaire 9; PHQ-15, Patient Health Questionnaire 15; RDC/TMD, Research Diagnostic Criteria for Temporomandibular Disorders; SCL-90, Symptom Checklist–90.

Causation and Complex Disease

Findings from OPPERA and other published studies have supported identification of TMDs as a complex disorder within a biopsychosocial illness model, confirming that for almost all cases, TMDs are not a condition localized to pathology in orofacial structures. That is, while TMDs can occur as a condition localized to just masticatory structures (e.g., isolated myalgia disorder of the masseter or TMJ arthralgia, secondary to local injury), the evidence indicates that when these initially local symptoms, such as masseter or TMJ pain, persist (perhaps beyond the time of usual healing) and become a diagnosable pain disorder, a different process begins to unfold (Wall 1979). Consequently, chronic TMDs are most usefully conceived and understood in their complexity: multisystem problems with overlapping comorbidities of physical signs and symptoms as well as changes in behaviors, emotional status, and social interactions as manifestations of general central nervous system dysregulation (Diatchenko et al. 2006; Tracey and Mantyh 2007; Slade, Fillingim, et al. 2013).

Complex diseases in general rarely have single factors sufficient for "causing" the disorder. Rather, the etiology of a complex disease, TMD included, is best explained as multiple risk determinants acting together in what has been referred to as component causes acting within a web (Rothman and Greenland 2005). For example, many genes contribute to pain perception, and mutations in ≥1 pain-related genes account for some of the variability of each individual's pain experiences (Mogil 2012), and while these pain experiences may be initiated by nociception from injury to the TMJ, pain processing invokes many subsystems (Craig 2003). The implications of this complex web of causation for a diagnostic system based on scientific evidence supports the notion that specific clinical phenotypes, even if simply identified, may represent the spectrum of multidetermined expressions of chronic TMDs, which evolve over time (Dworkin et al. 1992).

Taxonomies Are Dynamic: Future Directions

The path forward for improving TMD diagnosis and its utility will, per force, be multifaceted (Michelotti et al. 2016). In this final section, pathways are suggested for future research that will ideally yield increasingly precise and useful TMD phenotypes,

which will in turn allow the criteria-based diagnostic system to advance, comprising the best available standards for the emergence of a true taxonomy of TMDs. The pathways below denote particular content areas of research; we call attention here to the significance of the conceptual basis underlying a pathway. The history of the RDC/TMD leading to the successful DC/TMD illustrates the importance of strong conceptual principles and their adherence as the necessary foundation for establishing taxonomic tools that can progress.

As an example of maintaining principles, an axis III (described below) is envisioned as a parallel construction to axes I and II. Axis III would present conceptual issues embedded in the "bio" part of the term "biopsychosocial" other than those biologic aspects present in axis I. While axis I alone would continue to carry the physical diagnoses of TMD, axis III would represent the underlying pathobiologic processes contributing to the TMD phenotype, currently absent from the RDC/TMD and its successor, DC/TMD. Thus, axis III could contribute diagnostic findings from such diverse biologic considerations as genetics, epigenetics, and neuroscience. Clinical pain researchers over many years have suggested that a physical diagnosis will not be needed for chronic pain disorders once mechanisms based on axis III factors are established. Framed differently, axis I is a special case of the "bio" in biopsychosocial, and it is likely that treatment targeted to that "bio" level will be revealed by further conceptual breakthroughs in formulating phenotypes from the axis II domain while perhaps enabling etiology to emerge from an axis III domain.

Known directions of research to realize these ambitious objectives include the following. While some can quickly lead to progress, others necessarily require a long-range perspective.

Sociocultural translations. The DC/TMD is being translated into 30 languages, with 6 completed. These formally conducted translations (Ohrbach et al. 2013) allow comparable data across settings and will facilitate the same process of international revision of the DC/TMD as it occurred for the RDC/TMD.

Headache and referred pain. The Validation Project challenged the ICHD-2 definition of headache secondary to TMJ (International Headache Society 2004), resulting in the incorporation of a revised disorder, headache secondary to TMD (Schiffman et al. 2012), into the DC/TMD as well as ICHD-3 (International Headache Society 2013). The referred pain diagnoses in the DC/TMD provide an inclusive set of categories for subtyping muscle pain. Collectively, these aspects of the DC/TMD can shape future research on primary versus secondary headache and the role of referred pain (Svensson 2007; Ballegaard et al. 2008).

Expanded DC/TMD. The expanded DC/TMD (Peck et al. 2014) were based on consensus and revisions of the prior American Academy of Orofacial Pain taxonomy (de Leeuw 2008), itself a product of many years of work by member contributors. The goal of the expanded DC/TMD was to create a set of uncommon nonoverlapping TMDs with operationalizable criteria to achieve high interexaminer reliability and, therefore, diagnostic validity, thereby a sufficient framework for further development.

Axis III. Genetics, epigenetics, and neuroscience will inevitably be incorporated into comprehensive phenotypes of chronic pain, including TMDs. Obvious candidates include biomarkers broadly conceived (Ceusters et al. 2015) and changes in glial cells associated with persistence of pain (Watkins and Maier 2002) for specifying standardized diagnostic categories pathognomonic of chronic (TMD) pain. The interaction of genetics and epigenetics with advances in brain neurosciences permits the study of the brain-behavior interface (Nielsen et al. 2009). Rapidly emerging findings from interdisciplinary research will probably revolutionize how disease and illness diagnoses are eventually determined. TMDs as a chronic pain condition warrant being included, perhaps even leading such future research.

Taxonometric methods. A major Validation Project accomplishment involved the diagnostic reference standard. TMJ-based diagnoses (internal derangements, degenerative joint disease) use imaging-based classifications as the reference standard. For pain disorders, however, there is no external method of determining who has pain. The Validation Project's reference standard for pain diagnoses was built on multiple calibrated examiners and a priori classification rules from which deviation was permitted if necessary, and a statistical learning method identified findings for the respective criterion (Schiffman, Ohrbach, et al. 2010; Schiffman, Truelove, et al. 2010). Many such methods need to be explored as we move to higher-dimensional diagnostic approaches.

Etiologic studies. Etiologic research will require clean separation of putative etiologic factors from variables embedded in the case definition. With further research, an etiology-qualified diagnosis may emerge (e.g., stress-related myalgia vs. injury-related myalgia).

Incorporate biomedical ontology. Just as a case definition represents an instantiated clarity (even if only temporarily) into a disorder, biomedical ontology seeks to assist disease experts by, for example, creating clearer concepts, providing computational tools for data manipulation, developing heuristics, and better linking highly dimensional data sets (Ceusters and Smith 2010; Smith and Ceusters 2010). The traditional flat-plane approach of signs_i and symptoms_j, which maps to disease_{ij}, may reach a dead end.

Revise axis II instruments. Many perspectives (e.g., Bellamy et al. 1997; Dworkin et al. 2005; Cella et al. 2010) exist and compete regarding which person-level constructs, based on which measures, in which disease or person should be evaluated. Moving a standard forward while remaining responsive to individual needs becomes, paradoxically, evermore complex as the standard succeeds.

Guidelines for axis II interpretation. Multidimensional interpretation of axis II measures, as related to brain-based

responses to pain and contributions to pain, for the individual patient remains a goal.

Utility. A given patient's problem list—stemming from chief complaint, history, and examination—will contain entries from multiple domains: Does a better axis I diagnosis or a better axis II assessment better guide treatment decisions?

Revision of the DC/TMD. All of the above individual initiatives will contribute substantially and critically to any revision of the DC/TMD. Mechanisms for formal taxonomic revision will need to be developed and are being considered by the Consortium Network.

Conclusion

The above developmental history depicting stages in the history of TMD diagnosis leads to several intersecting themes. One is that TMD classification, per the RDC/TMD → DC/TMD evolution in its present stage of development, has been gratifyingly successful in the accomplishment of many of its stated aims and is the only evidence-based TMD diagnostic system that has been submitted to rigorous scientific investigation. Full clinical implementation of the protocol in its present state would benefit the population, for consistency of diagnostic methods and clinical terms that allow standardization in reporting of measurements and criteria for diagnostic decision making. Another theme is that diagnostic systems will not remain static: criticisms will and must emerge in relation to the need for both the center and the boundaries of the diagnosis system to be tested, better understood, and modified. A third theme focuses on 1) whether a complex disease can be adequately represented by a phenotype that yields to simple clinical assessment and 2) the degree to which the heterogeneity of TMD can be reduced to such phenotypes. This theme also highlights the relative sufficiency of a descriptive taxonomy awaiting more comprehensive development in parallel with better understanding of the complex disease. A final theme is that our understanding of disorders specific to the TMJ lags behind that for pain disorders. The collective implication of these themes is that further research and development will benefit from a programmatic approach inclusive of the multiple directions described here as well as countless others existing outside the current consortium framework.

Author Contributions

R. Ohrbach, contributed to conception and design, drafted and critically revised the manuscript; S. Dworkin, contributed to conception and design, critically revised the manuscript. Both authors gave final approval and agree to be accountable for all aspects of the work.

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Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) Workgroup (1990–1992)

Samuel Dworkin, James Fricton, Lars Hollender, Kimberly Huggins, Linda LeResche, James Lund, Norman Mohl, Richard Ohrbach, Sandro Palla, Earl Sommers, Christian Stohler, Edmond Truelove, Michael von Korff, Charles Widmer

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International RDC/TMD Consortium (2000–2002)

Mark Drangsholt, Samuel Dworkin, James Fricton, Jean-Paul Goulet, Kimberly Huggins, Mike John, Iven Klineberg, Linda LeResche, Thomas List, Richard Ohrbach, Octavia Plesh, Eric Schiffman, Christian Stohler, Keson Beng-Choon Tan, Edmond Truelove, Adrian Yap, Efraim Winocur

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Research Diagnostic Criteria: Reliability and Validity (2001–2007)

University of Minnesota: Mansur Ahmad, Gary Anderson, Quintin Anderson, John Look, Wei Pan, Eric Schiffman, Feng Tai

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NIDCR (U01-DE017018)

Miami Consensus Workshop (2009)

Workgroup 1: Gary Anderson, Yoly Gonzalez, Jean-Paul Goulet, Rigmor Jensen, Bill Maixner, Ambra Michelotti, Greg Murray, Corine Visscher

Workgroup 2: Sharon Brooks, Lars Hollender, Frank Lobbezoo, John Look, Sandro Palla, Arne Petersson, Eric Schiffman

Workgroup 3: Werner Ceusters, Antoon deLaat, Reny deLeeuw, Mark Drangsholt, Dominic Ettlin, Charly Gaul, Thomas List, Don Nixdorf, Joanna Zakrzewska

Workgroup 4: Sam Dworkin, Louis Goldberg, Jennifer Haythornthwaite, Mike John, Richard Ohrbach, Paul Pionchon, Marylee van der Meulen

At large: Terri Cowley, Don Denucci, John Kusiak, Barry Smith, Peter Svensson

International RDC/TMD Consortium Network and IADR

Orofacial Pain Special Interest Group of the International Association for the Study of Pain
Canadian Institute for Health Research
National Center for Biomedical Ontology
Medtech

JOR-CORE Disability Workgroup (2009)

Justin Durham, Anat Gavish, Jordi Martinez-Gomis, Richard Ohrbach, Yoshihiro Tsukiyama, Wataru Tachida
Wiley-Blackwell

San Diego Consensus Workshop (2011)

Workgroup 1: Gary Anderson, Reny deLeeuw, Jean-Paul Goulet, Rigmor Jensen, Frank Lobbezoo, Chris Peck, Arne Petersson, Eric Schiffman
Workgroup 2: Justin Durham, Dominic Ettlin, Ambra Michelotti, Richard Ohrbach, Sandro Palla, Karen Raphael, Yoshihiro Tsukiyama, Corine Visscher
Workgroup 3: Raphael Benoliel, Brian Cairns, Mark Drangsholt, Malin Ernberg, Lou Goldberg, Bill Maixner, Don Nixdorf, Doreen Pfau, Peter Svensson
International RDC/TMD Consortium Network and IADR
International Association for the Study of Pain Orofacial Pain Special Interest Group
Canadian Institute for Health Research

Iguacu Falls (Brazil) Workshop (2012)

Workgroup 1: Reny deLeeuw, Jean-Paul Goulet, Frank Lobbezoo, Chris Peck, Eric Schiffman, Thomas List
Workgroup 2: Justin Durham, Dominik Ettlin, Richard Ohrbach
International RDC/TMD Consortium Network and IADR

Temporomandibular Joint Intra-articular Disorders: Impact on Pain, Functioning, and Disability (2011–2014)

Mansur Ahmad, Gary Anderson, Yoly Gonzalez, Lars Hollender, John Look, Krishnan Kartha, Richard Ohrbach, Eric Schiffman, Earl Sommers, Edmond Truelove
NIDCR (U01-DE019784)

OPPERA 2 (2012–2017)

Luda Diatchenko, Roger Fillingim, Yoly Gonzalez, Joel Greenspan, Christopher Lyu, Bill Maixner, Richard Ohrbach, Gary Slade, Bruce Weir
NIDCR (U01-DE017018)

Seattle Symposium (2013)

Raphael Benoliel, Brian Cairns, Werner Ceusters, Justin Durham, Eli Eliav, Ambra Michelotti, Richard Ohrbach, Karen Raphael
International RDC/TMD Consortium Network and IADR

Cape Town Symposium (2014)

Per Alstergren, Jean-Paul Goulet, Frank Lobbezoo, Ambra Michelotti, Richard Ohrbach, Chris Peck, Eric Schiffman
International RDC/TMD Consortium Network and IADR

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