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CRITICAL COMMENTARY

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"The Ball on the Hill": A new perspective on TMJ functional anatomy

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1 | INTRODUCTION

Much has been written about the anatomy of the temporomandibular joint (TMJ) as well as its associated extra-articular tissues. There is general agreement on the static anatomic features of these structures, as described in a variety of textbooks and scientific papers. However, there is some debate regarding functional anatomy concepts, because these require interpretations and assumptions about how the various structures work during mandibular functions. A prime example is the question of where the mandibular condyle is (or should be) located relative to the skull, when the mouth is fully closed. This debate has implications for clinical practice in orthodontics as well as in several aspects of general dentistry, because it obviously intersects also with the important topic of occlusion. In this paper, a new perspective is offered on these topics by analyzing a set of well-established static and dynamic anatomic facts. Hopefully, this new perspective on condylar position will prove to be helpful to dentists as they deal with the clinical challenges they face every day.

So, let us begin by asking: What kind of a joint is the temporomandibular joint (TMJ)? Is it similar to the shoulder, which is essentially a ball articulating on a flat plate? NO. Is it similar to the knee, which is essentially two balls articulating on two platforms that can bear a lot of weight? NO. Some people seem to think that the TMJ is similar to the hip, which is a ball articulating in a socket. The consequence of this belief is that we see a lot of language describing the TMJ as follows:

1. The mandibular condyle is functionally related to the glenoid fossa when the mouth is fully closed.
2. The condyle-fossa relationship is good/bad; it is centred/not centred (on radiographs); it is ideal or optimal, or not; it is skeletally determined, neuromuscularly determined, occlusally determined, etc.
3. The condyle is (or is not) fully seated in the glenoid fossa.
4. The condyle-fossa relationship is harmonious (or not) with masticatory muscle function.
5. The condyle-fossa relationship is harmonious (or not) with the existing occlusal relationship.

All of these statements and the images that accompany them throughout the dental literature suggest a ball-and-socket relationship. Indeed, one prominent online medical dictionary[1] states that the glenoid fossa is "a deep concavity in the temporal bone at the root of the zygomatic arch that receives the condyle of the mandible", while another[2] defines this fossa as "a deep hollow in the squamous portion of the temporal bone at the root of the zygoma, in which rests the condyle of the mandible." However, even if you accept these definitions, how can you explain all the contradictions within the above list of anatomic concepts? Which version of good or bad relationships, or harmony vs disharmony, should the intelligent clinician accept?

In this paper, the argument will be made (and supported with anatomic facts) that such questions do not really matter, because in fact there is NO functional relationship between the mandibular condyle and the glenoid fossa. While they clearly are anatomic neighbours, they actually have little or no contact with each other either when the mouth is closed or while the mandible is moving. Instead, the functional relationships of the condyle to the skull ALL occur on various parts of the articular eminence, which is a part of the temporal bone on which the condylar head slides during mandibular movements. It is worth noting that about 3/4 of the population can open beyond the crest of that eminence upon yawning or eating, without any problems.[3]

All of these statements lead to the conclusion that the human TMJ is "a ball on a hill" that can operate on both sides of the hill. This assertion is supported by a variety of anatomic and histologic facts, and they imply that a new discussion must be had about condylar positioning when the mouth is closed. In the following paragraphs, these underlying facts will be presented, and the implications for clinical practice will be discussed.

2 | STATIC ANATOMY FACTS

The human TMJ is always loaded, even when the mouth is hanging open in a so-called resting position.[4] Because the mandible is a Class three lever, with the elevator muscles ahead of the joint but behind the dentition, the TMJ cannot be unloaded by any events occurring inside the mouth.[5] For example, biting on a hard foreign object in food by accident will not distract the condyle away from the skull. Similarly, having a balancing-side occlusal interference will not distract the condyle on that side.[6] Biting on an occlusal appliance (OA) that touches only front teeth can increase the TMJ load, but biting only on posterior plastic (including a deliberate pivot) will not decrease loading. As Greene and Menchel[7] point out in their paper about OAs, simply placing a splint over the teeth in a fully dentate person will not in itself reduce TMJ loading.

However, there are other factors that come into play when an OA is worn, and these can alter the quantity and intensity of forces transmitted to the TMJ structures. For example, there may be a reflexive diminishing of muscular clenching and/or bruxing at night, so the total forces will thereby be diminished as well. Another factor to consider is that a less deformable (harder) material placed between the teeth will stimulate an isometric contraction, as opposed to a more deformable (softer) material that allows for shortening of muscle length.[7] In addition, a splint can be designed to bring the mandible forward temporarily in order to shift the TMJ loading from a painful region to a more comfortable one. As Ettlin et al[8] have demonstrated, the insertion of a splint can shift the jaw relationship so that there are new contact areas between joint surfaces.

Therefore, the TMJ must be built anatomically to sustain loads at all times, and especially during functions like chewing and clenching. So let us look at which structures are designed to fulfil that task when the mouth is fully closed, and also as it is opening:

1. The glenoid fossa has a very thin roof. Indeed, holding a skull up to the light, it is possible to see light through that structure; therefore, it is obviously not designed for sustaining heavy functional loads. But the articular eminence is very thick and easily capable of sustaining loads.
2. The post-glenoid tubercle looks like a rear wall for the glenoid fossa, but it is not a functional element of the TMJ.
3. The articular surfaces of both the mandibular condyle and the eminence are covered with fibrocartilage—a tissue that is designed to sustain loading—but the glenoid fossa has no cartilage covering (Figure 1).
4. The articular disc is avascular in its middle section, because that is where maximum force is occurring between the articulating surfaces (see where F meets F' in Figure 1). While the disc also helps to distribute force more broadly on the eminence, most of that force goes towards the anterior band due to the anteriomedial forces produced by the elevator muscles (see where f meets f' in Figure 1).

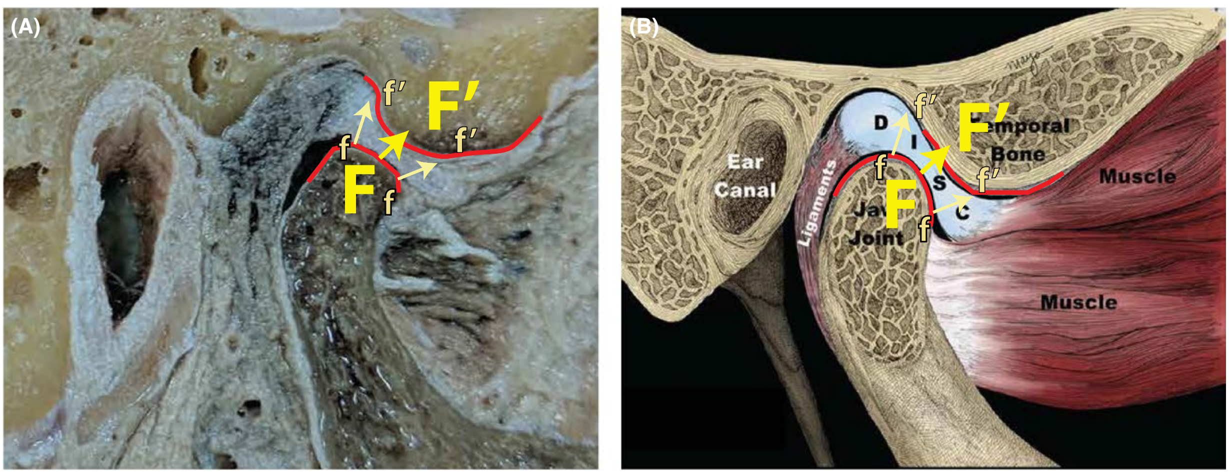

FIGURE 1 Anatomy of the temporomandibular joint (TMJ) with the mouth closed. A, is an anatomic specimen that has been preserved by a process of freezing skulls and then slicing them into 3 mm thick sections, and then storing them in ethyl alcohol; B, is an anatomic illustration. Note that the articular disc is divided into 3 zones: PB = posterior band; IZ = intermediate zone; AB = anterior band. The red lines represent fibrocartilage that covers the functional surfaces of the condyle and the skull. Note that there is no fibrocartilage inside the glenoid fossa; instead, on the skull it begins at Point A and ends at Point C (see Figure 2). The arrow F-F' represents the main force loading area between the condyle and the articular eminence, with the IZ zone of the disc in between them. This portion of the disc is avascular and aneural, so it can sustain heavy loading forces. Because the disc does help to distribute forces to some degree, the two arrows f-f" represent the lesser forces that are transmitted through that tissue to AB and PB; the force vector is stronger towards AB due to the mesio-superior orientation of the mandible's elevator muscles

5. Therefore, ALL functions of the TMJ must take place between surfaces of the mandibular condyle and the skull where fibrocartilage is present. As shown in both Figures 1 and 2, the only skull surfaces that are covered with this material are the posterior and anterior slopes of the articular eminence.

3 | FUNCTIONAL ANATOMY FACTS

Based on the above static anatomy facts, we can better understand the following facts about how the TMJ functions[9,10]:

1. The range of motion for the human TMJ includes moving beyond the crest of the articular eminence in about 75% of the normal population. This occurs without subluxation or dislocation. By using cephalometric laminography (tomography) almost 70 years ago to measure all sorts of TMJ structures and relationships, Ricketts[3] found that in 55 patients, 35 could open 1-5 mm past the crest of the evidence and five could open more than 5 mm past it! This fact is now generally recognized by all anatomists.
2. The fibrocartilage covering the mandibular condyle extends pretty far down the posterior slope of that structure (see Figure 1A). This enable the condyle to move past the crest of the eminence with that posterior slope being in contact with the anterior slope of the eminence (see Figure 2A).
3. Therefore, the mandibular condyle is operating as a "ball on a hill", which begins from Point A and moves to Point C. It is not functionally related to the glenoid fossa when the mouth is closed, but instead is resting at a high zone on the hill (see where F meets F' in Figure 1A and B).

This obviously leads to the question of what determines where each person's condyle will end up on the hill when the mouth is closed. Clearly, it has to be the occlusion of that person's teeth in maximum interdigitation (MI). It turns out that this is a unique feature of the temporomandibular joint, because it is the only joint(s) in the human body with a definite stopping point. No other joint has an extra-articular determinant of where it has to go; all movements are permitted or limited by the anatomy of each joint.

So this means that when you close your mouth, the mandibular condyle must stop at Point F-F' on the hill because your teeth have reached MI. But is that an absolute point for your whole life, or does it change? Since the human body does not remain static over time, for the masticatory system we know that the following events are always occurring[9]:

1. Teeth—cannot metabolize, but they can wear occlusally and proximally
2. Muscles—undergo constant addition and subtraction of cells in response to functional demands
3. TM joints—constant remodelling is taking place in all the hard and soft tissues comprising that joint. This of course includes the bony articulating surfaces as well as the fibrocartilage covering them.

These three facts are the basis for HOMOEOSTASIS of the TMJ—dental complex, and as a result the loading zone F-F' changes a tiny amount every day in healthy dentate people. You might think at this point that everybody would be satisfied with this explanation for how the TMJ is built, how it works, and why it is positioned where it is for each person. But unfortunately, some dentists believe that there are ideal or optimal TMJ relationships, and that the MI of your teeth is somehow preventing you from achieving those positions. Therefore, it is time to analyze how MI dental relationships are

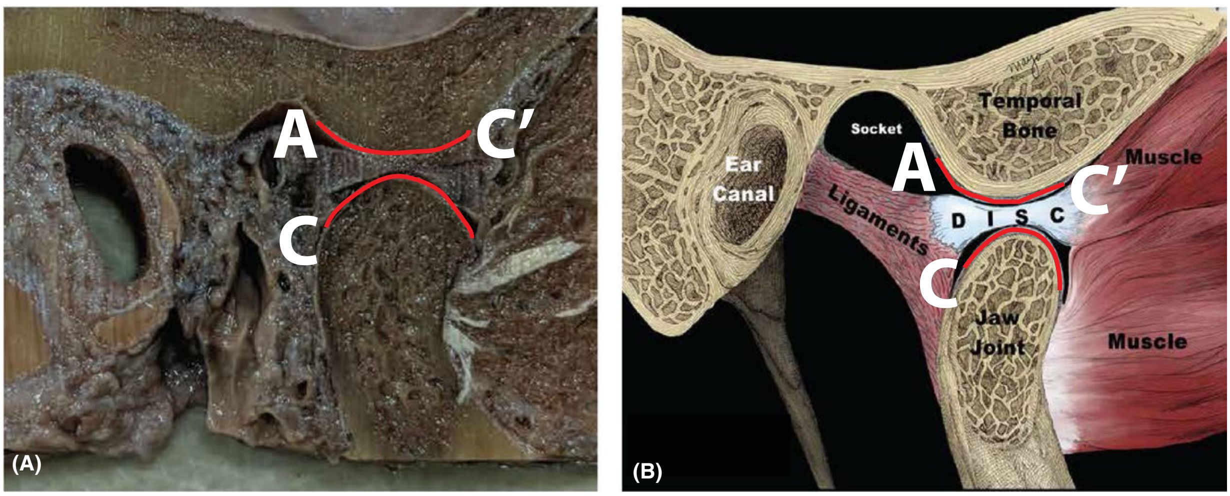

FIGURE 2 Anatomy of the TMJ with the mouth open to the crest of the articular eminence, again showing an anatomic slice (A) and an illustration (B). Note that the posterior surface of the condyle is rotating forward as the mandible is being depressed. While not shown in these pictures, when the condyle goes past the crest and onto the anterior slope of the eminence, Point C will meet Point C'. Note that the fibrocartilage tissue is covering these functional surfaces, with the skull (eminence) portion beginning at Point A and ending at Point C'. (See text for discussion of this wide-opening phenomenon)

determined, so we can consider why they are generally biologically acceptable.

4 | BIOLOGIC BASIS FOR ESTABLISHMENT OF DENTAL AND JAW RELATIONSHIPS

All orthodontists and others interested in growth and development of the masticatory system should be concerned about the scientific answers to this question: What determines how MI is established in each person? Early in life, when there are no teeth, the mandibular positions on the hill are determined by whatever feeding and speaking activities are occurring. As the teeth erupt into occlusion (especially deciduous molars), a more definite stopping point for the condyle is determined by those teeth. However, due to growth and development of all the anatomic components, there is constant change in the stopping point until sometime in adolescence, when the permanent dentition relationship is established.[10,11]

Assuming growth has essentially stopped, your daily MI relationship is determined by a neuromuscular program known as an ENGRAM, which is defined as "a presumed encoding in neural tissue that provides a physical basis for the persistence of memory".[12] This explains how repeated physical activities can be done without conscious thought, including handwriting, gait, throwing a ball, swimming, AND closing your mouth 100 times into MI occlusion! The engram related to the human jaw controls the activity of the mandible as it opens, closes, chews food and all other functions. The neurological components of this engram include a combination of muscle position sensors, TMJ position sensors and thousands of PDL proprioceptors that surround all the teeth. Therefore, your current MI relationship is controlled by a program, but as we know, dentists can change that program in various ways—and indeed some dentists have developed concepts (and procedures) for DE-PROGRAMMING the current mandibular relationship.

Once again, we are in a territory where only dentists can tread; no orthopaedic physicians can offer to permanently change the position of any other joint in the human body—nor have they suggested that such changes could "optimize" the relationship of your hip, knee or shoulder. But somehow certain dentists have come to believe that a jaw relationship could be "bad" because they do not like the existing MI occlusion. And since they possess the means to change jaw position permanently by changing MI, various procedures have been developed to accomplish that. Most of those procedures include the use of an oral appliance to "de-program" the current occlusion (eg, Kois deprogrammer[13]).

5 | ORAL APPLIANCES (SPLINTS) AND DE-PROGRAMMING

In order to discuss this issue, it is important to begin by recognizing that ALL splints become de-programmers as soon as they are inserted, because they prevent MI from occurring. The plastic surface of the appliance (which is usually flat by design) is occluding with opposing teeth, so the original engram is no longer operative, and the mandible will be free to wander in one direction or another. If a specific occlusal index or ramp is built into the splint, then the mandible must go to that particular position. But—is this de-programming a good thing or a bad thing to do to our patients? The answer to that question depends on your INTENT:

If your intention is to disrupt the program 24 hours a day by prescribing constant use of the OA because you want to:

1. "Relax" the muscles in order to manipulate the mandible more easily
2. Find the "ideal" or "optimal" jaw position
3. Inform the patient that he/she has a discrepancy between MI and some other position (centric relation, neuromuscular centric, correct vertical dimension, etc.)
4. Permanently alter the occlusal relationships using equilibration, orthodontics[*], orthognathic surgery, or full-mouth reconstruction.

Then you are disrupting HOMOEOSTASIS, and you need to justify that intrusion. Many dentists who use these de-programming appliances are indeed trying to accomplish one or more of the above goals.

On the other hand, if your intention is to use an oral appliance (mostly at night) to:

1. Protect occlusal surfaces of teeth from bruxism wear
2. Diminish quantity of nocturnal bruxism activities
3. Avoid morning pain and stiffness from bruxism
4. Relax sore masticatory muscles
5. Diminish intracapsular TMJ pain

Then, you can ignore the deprogramming feature, because it is temporary and the normal daytime program will resume when you wake up and remove the appliance. A properly designed OA will not cause or allow any tooth movement to occur, so your normal jaw position is easily re-established in the morning. However, poorly designed appliances can cause dental and even skeletal changes that may have profound consequences.[7]

6 | FINAL THOUGHTS ABOUT THE BALL ON THE HILL

By recognizing that the temporomandibular joint is operating as a ball on a hill, capable of travelling on both slopes of that hill, we can stop wondering whether a healthy dentate person has a biologically acceptable jaw relationship. As for patients with TM disorders, there is enough literature out there by now to realize that occlusion and jaw positions are not the important factors in determining who gets sick, or what needs to be done to help such patients.[14] So which dental patients are still in need of having some treatment that involves consideration of their jaw relationships?

1. Patients who need complete U/L dentures. Since these individuals have no occlusally driven engram, the dentist must establish both a vertical relationship between the arches and a horizontal position of the condyle resting on the hill. No matter what terminology is used to describe that position, it is clear that the condyle will need to be resting high up on the hill when the teeth meet.
2. Patients who need full-mouth dental rehabilitation, with or without implants. Again, such patients will need the same consideration as totally edentulous patients in order to establish their new jaw relationships.
3. Patients undergoing full orthodontic treatment will need a finishing position that is stable both orthopaedically and dentally, as recommended by Okeson.[15] While many methods have been advocated for achieving that goal, it appears that the orthodontic profession as a whole has succeeded in achieving stable results for almost all of their patients over a period of many decades. The very diversity of so many approaches to orthodontic and orthognathic finishing speaks volumes about the ability of the human body to adapt to massive occlusal change when necessary. It should be emphasized that orthodontic treatment is unique in that it could last 2-3 years, during which the occlusal engram is completely disrupted and changing daily. Nevertheless, orthodontists know that eventually they can establish a new condylar position once the teeth have been aligned and stabilized, and this new position will almost always be biologically acceptable.

But except for these three special groups of patients, it is important for all dentists to recognize that their typical dentate patients are likely to have a healthy, well-adapted jaw position that does not need to be analyzed or changed. Furthermore, that jaw position meets the standard advocated by Okeson[15] when he speaks about a musculoskeletally stable orthopaedic position. As Greene and Obrez[11] point out, there is no scientifically credible medical necessity argument for mandibular repositioning as a therapeutic or preventative procedure. So let's conclude by accepting every individual's "ball on the hill" as being a normal anatomic feature of their TMJ, and then we can focus on the real challenges of providing good orthodontic and dental care.

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ENDNOTE

***NOTE: the normal practice of using orthodontics to change occlusion in patients who are appropriately classified and treated is not being criticized here.**

REFERENCES

1. https://www.medilexicon.com/dictionary/35056. Accessed August 21, 2018.
2. https://www.thefreedictionary.com/glenoid+fossa. Accessed August 21, 2018.
3. Ricketts RM. Variations of the temporomandibular joint as revealed by cephalometric laminography. *Am J Orthod*. 1950;12:877-898.
4. Clemente CD. *Anatomy: A Regional Atlas of the Human Body*, 6th edn. Philadelphia: Lippincott, Williams and Wilkins; 2011.
5. Hylander WL. The human mandible: lever or link? *Am J Phys Anthropol*. 1975;43:227-242.
6. Hylander WL. An experimental analysis of temporomandibular joint reaction force in Macaques. *Am J Phys Anthropol*. 1979;51:433-456.
7. Greene CS, Menchel HE. The use of oral appliances in the management of temporomandibular disorders. *Oral Maxillofac Surg Clin North Am*. 2018;30:265-277.
8. Ettlin DA, Mang H, Colombo V, Palla S, Gallo LM. Stereometric assessment of TMJ space variation by occlusal splints. *J Dent Res*. 2008;87:877-881.
9. DuBrul EL. *Sicher's Oral Anatomy*, 7th edn. St. Louis, MO: Mosby Inc.; 1980.
10. Obrez A, Gallo L. Anatomy and function of the TMJ. In: Laskin DM, Greene CS, Hylander WL, eds. *TMDs – An Evidence-Based Approach to Diagnosis and Treatment*. Chicago: Quintessence Publishing Co; 2006:35-52.
11. Greene CS, Obrez A. Treating temporomandibular disorders with permanent mandibular repositioning: is it medically necessary? *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2015;119:489-498.
12. https://www.dictionary.com/browse/engram. Accessed August 21, 2018.
13. https://www.koiscenter.com/kois-deprogrammer. Accessed August 29, 2018.
14. Manfredini D, Lombardo L, Siciliani G. Temporomandibular disorders and dental occlusion. A systematic review of association studies: end of an era? *J Oral Rehabil*. 2017;44:908-923.
15. Okeson J. Evolution of occlusion and temporomandibular disorder in orthodontics: past, present, and future. *J Orthod Dentofacial Orthop*. 2015;147:S216-S223.

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