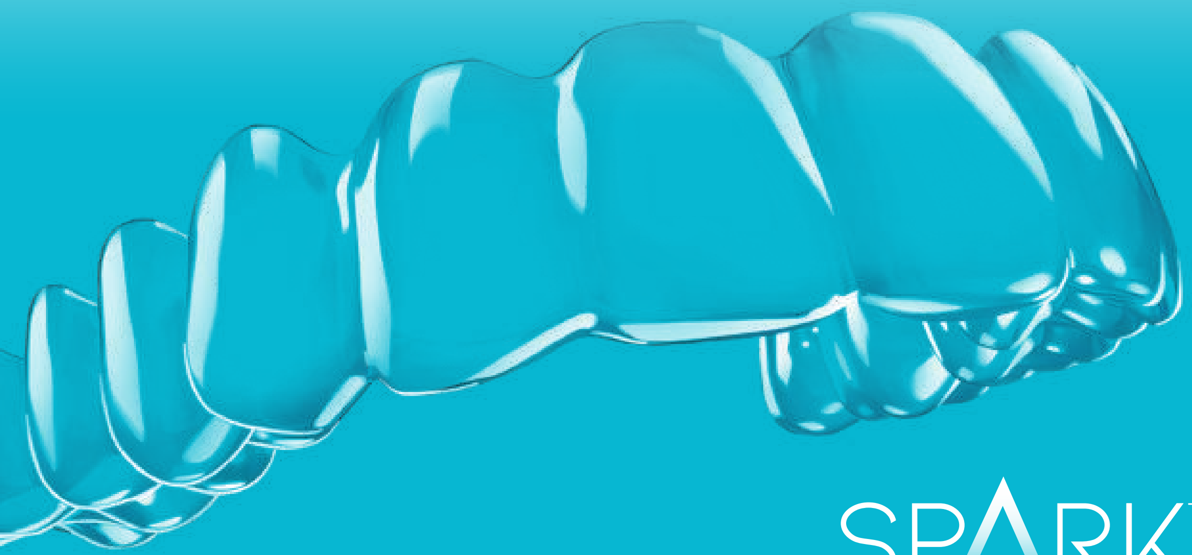

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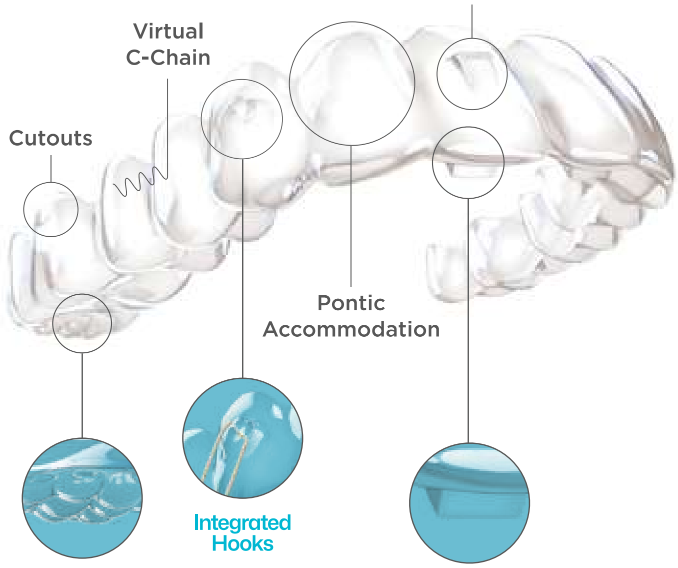

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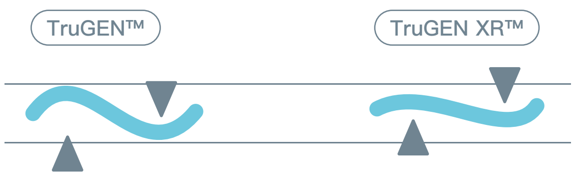

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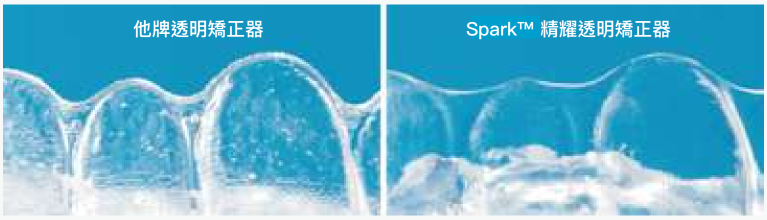

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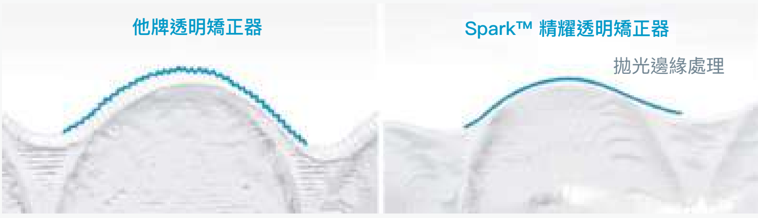

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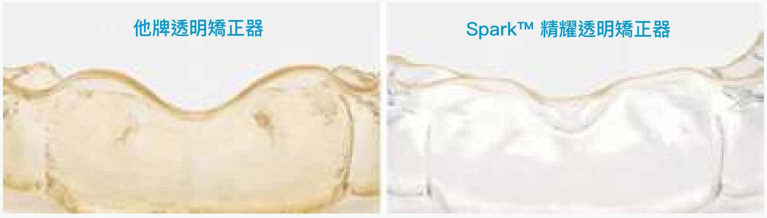

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Center of Resistance: Critical Factor in Expression of Tooth Movement

Abstract

The concept for a tooth's center of resistance (C_{Res}) was introduced about 100 years ago. It is fundamental to the physics of orthodontic biomechanics. The C_{Res} defines the response of a naturally restrained tooth (PDL and alveolar bone) to applied loads. It is typically specified near the center of the bone-supported root. This report describes the dynamic change in the position of the C_{Res} during treatment with fixed appliances (FA) to achieve precise tooth movement with applied force (F) for tipping the tooth and a couple for rotating the root in the plane of the force. The limitation for removable appliances, including clear aligners (CA), is they only readily achieve tipping. A specific set of aligners rarely exceed a treatment efficiency greater than 50% of a programmed clinical simulation like ClinCheck® (Align Technology, Tempe AZ). Removable appliances fail to efficiently control the location of the C_{Res}. (J Digital Orthod 2025;77:46-54)

Introduction

The center of resistance (C_{Res}) for a tooth root restrained by periodontium is the reference point for calculating and understanding tooth movement during orthodontic treatment.[1] The C_{Res} resembles, but not equal, to the center of mass (C_M) for free bodies in physics. Tooth movement is defined by the relationship between the vector(s) applied to the tooth and the position of its C_{Res}. This process is how forces act on a free body relative to its C_M. However, C_{Res} is more complex concept in physics because the "body" (tooth/teeth) is restrained. Unlike the C_M which is a fixed point unless there is a change in the properties of the body. The position of the C_{Res} can change with a decrease in the restrained bone and PDL support, e.g. periodontitis, as well as the position and nature of a load applied to a tooth or segment of teeth, namely a couple at the bracket level.

The C_{Res} controversary in orthodontics has a long history. In 1917, Fish[2] defined the C_{Res} as the three dimensional (3D) point through which a force vector would result in neither tipping nor rotation of the tooth. This pioneering definition was essentially impossible to demonstrate clinically (in-vivo) or in vitro. In 2013, Viecilli, Budiman and Burstone[3] assessed tooth movement in 3D with finite element analysis (FEA). Each plane (X, Y, & Z) had a couple-generated axes of rotation that did not intersect at a 3D C_{Res} as previously postulated. Translation for a given plane is achieved by projecting the intersection of the two axes of resistance perpendicular to the direction of the force.[3]

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Private Practice - Tel-Aviv, Israel (Center left)
Agate N. Krausz,
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W. Eugene Roberts,
Editor-in-Chief, Journal of Digital Orthodontics (Right)




For the past century, most orthodontic literature suggests the C_{Res} for single-rooted teeth is somewhere between the gingival margin and the mid-root area of the restrained root. C_{Res} is commonly thought to be within the coronal third or apical two-thirds of the root.[4,5] For a multirooted tooth, it is at or near the furcation. The C_{Res} concept applies to all treated and untreated teeth. Physiologic and therapeutic loads are subject to the same restraints. They typically interact to achieve a specific orthodontic outcome.

Objectives of this Report

Analyze current biomechanics literature to elucidate the overall spectrum for tooth movement based on physical principles.[4,5]

Investigate C_{Res} position during orthodontic treatment. Does it change in a manner that influences the tooth movement response?

Determine why CAs only achieve about 50% of programmed tooth movement with a specific set of aligners.[6]

Assess the finishing challenges for CAs compared to fixed appliances.

Center of Mass

The C_M of a free body defines its movement relative to the line of force and/or an applied moment. C_M is amenable to precise mathematical analysis as a behavior due to an applied load. According to physical laws, a force on a tooth if it was a free body in three ways:[3-5]

1. **Through the C_M:** Linear tooth movement (translation) occurs in the direction of the force, and all body parts move respectively.

2. **Offset to the C_M:** Generates combined angular (rotational) and linear (translation) movement when the body rotates around its C_M while moving in the direction of the force.

3. **Applied Couple:** Two equal, but opposite forces, whose lines of action do not coincide produce a moment for pure angular rotation around the C_M.

Contrary to free bodies, teeth are restrained objects.[2-5] Their roots are anchored by the periodontal ligament (PDL) to the supporting alveolar bone.[3,4] Collectively, the periodontium is an organ of reactive tissues responding to repetitive loads with relative high rates of turnover. The PDL is a dynamic tissue about 250 μm thick that turns over very rapidly (in days).[7] Alveolar bone has a high turnover rate compared to basilar bone.[8] Dynamic turnover properties for periodontium, especially under sustained orthodontic loading, respond to the failure of materials due to the therapeutic load(s) superimposed on the high magnitude, transient loads of mastication. This dynamic natural restraint, dictates tooth movement relative to the C_{Res} position.[3,9]

Numerous *in vivo* and *in vitro* studies of single-rooted teeth in untreated, restrained conditions found C_{Res} at about the middle of the apical two-thirds of the root.[3-5,10] As gingival recession exposes more of the root in the oral cavity, the C_{Res} shifts apically. However, due to variations in biological and physical effects on the surrounding tissues, the precise C_{Res} position varies. Studies on multi-rooted teeth place the C_{Res} near the root furcation.[3,4]

During orthodontic treatment, the variable physical properties of the PDL and alveolar bone make it essentially impossible to pinpoint the C_{Res} at any given moment. Furthermore, unlike free bodies, restrained teeth cannot respond with rotation and translation to force vectors applied to the root. A force applied to the crown results in tipping due to the moment of the force acting on the root. Tipping is the default movement for restrained bodies exposed to a complex environment such as aligners applying forces on all aspects of tooth surfaces. Thus, rotation occurs by tipping.[10]

Biomechanical implications[11-13] of the tooth's natural restraint limit the potential loads acting on it to two types:

1. **Tipping:** Force vectors not passing through the C_{Res} rotate the tooth around the the C_{Res} and not around the center of rotation.[4,5]

2. **Couples:** Generate pure rotation around the C_{Res}.[4,5]

These orthodontic loads differ in application due to the lever arm required for rotation. The further the C_{Res} is from the crown, where loads are applied, the easier it is to achieve tipping from a clinical perspective. Tipping magnitude is directly related to lever arm length. As mentioned above, orthodontic tipping, commonly achieved with removable or fixed appliances, rotates the tooth around its C_{Res}.

When the requirement for apical movement is significantly greater than coronal movement, orthodontic torque (moment applied at the

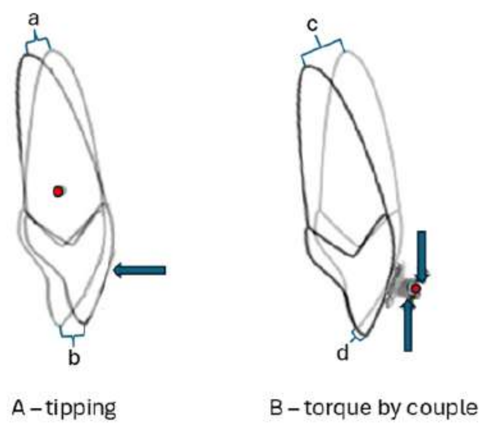

Fig. 1:
The differences between tipping and torque are in tipping, the apex and the crown's edge move about the same (a~b) in opposite directions, while in torque, the apex moves much more than the crown's edge (c>>d), in opposite directions. The red dots marks the C_{Res} during movement, which is equal to the tooth's center of rotation. Note for torque, it corresponds to the bracket where the moment is applied.

bracket) is required. The axis of rotation in the plane of tooth movement shifts from the root to the bracket (Fig. 1). Achieving this important step in the mechanics response is easily facilitated only with fixed appliances. Removable appliances do not change the position the C_{Res} from root to crown for such movements. No aligner or other removable appliance can generate couples in the plane of tooth movement capable of shifting the C_{Res} to the crown of the tooth.

Historical Perspectives

C.S. Case in 1895,[14] achieved the crown tip-based rotation (root torque) by restraining adjacent teeth. The root movement machines achieved root retraction by rotation at the tooth crown level. The necessity for fixed appliances to achieve such precise movement was deemed obvious (Fig. 2).

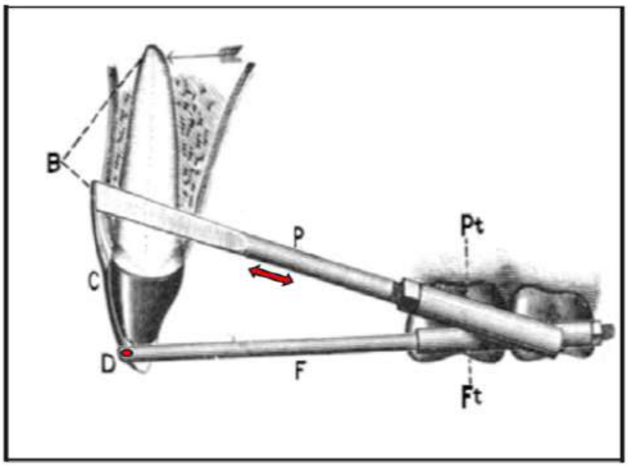

Fig. 2:
The root movement machine built by C.S Case (1895)
Changing the P-arm length rotated the tooth around point D, delivering torque as should be defined: the apex moves more than the crown's edge in different directions. The B-C lever elongates the B-D arm to decrease the needed force for the tipping movement. That cumbersome movement was replaced by the couple in brackets, by EH Angle (1927)

This nuanced understanding of a tooth's C_{Res} challenges a clinician's concept of traditional physics applied to orthodontics. However, Case's "Root Movement Machine" underscores the critical role of precise biomechanics in achieving optimal treatment outcomes.[14] This level of precision is not possible with a flexible plastic CA designed to create root torque by engaging ridges on bonded attachments with the aligner material.[15]

An alternative fixed appliance (FA) method for root movement is an archwire-mounted torque spring, which generates a tipping vector that relies on an axis of rotation determined by the archwire.[16] The latter is retained by fixed appliances bonded to the teeth. However, the torque spring load is typically lower than rectangular archwire torsion because of the torque spring lever arm. Torque springs are usually applied to a single tooth that requires root movement (Fig. 3).

The third FA option is to apply a couple directly in the rectangular slot of the bracket (Fig. 1). This form of root torque depends on torsion in a rectangular

Fig. 3: *Torquing spring*

archwire when it is inserted into a rectangular bracket attached to the tooth. With these mechanics, the center of rotation (C_{Rot}) is identical to the C_{Res} location. Both correspond to the point of action of the couple.[4]

Orthodontic couples precisely applied are complex and demanding mechanics governed by four strict rules outlined below.[11-13] The center of rotation, due to the mechanical restraint of the tooth, resides at the center of the bracket bonded to the tooth crown:

1. **Equal magnitude of opposite forces** (vectors) generating the couple.
2. **Exact opposition in the direction** of the vectors.
3. **Action in separate planes**, ensuring the vectors do not intersect.
4. **Essential integration** demands that the components generating the couple on a tooth (or teeth) remain securely connected throughout the entire period of movement. For example, a stable bond is required between the wire (e.g., a rectangular metallic archwire) and the tooth via a bracket affixed to its surface. The same principle applies to groups of teeth.[15]

The developed and/or frictional forces between the appliance components add to the natural restraint of the tooth. Collectively these physical factors are deemed artificial restraint. Due to its relatively high magnitude, this artificial restraint shifts the C_{Res} from the root to the bracket. While the artificial restraint is active and maintains its magnitude, the C_{Res} remains at the bracket level. However, when the bond between the bracket and the wire weakens due to less activation the artificial restraint diminishes or disappears. Then the C_{Res} reverts to its natural location, influenced by the natural restraining structures such as alveolar bone and periodontal ligament (PDL). This is the restrained body concept in orthodontic biomechanics that is critical for understanding orthodontic tooth movement.

Any couple or force applied to the bracket that results in activation exceeding the natural restraint will relocate the C_{Res} to the bracket corresponding to the C_{Rot}.[5] Even slight deviations from the specified conditions will nullify couple mechanics resulting in rotation of the tooth at the bracket level.

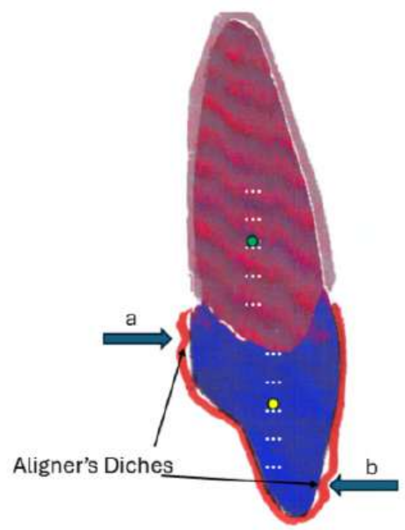

Fig. 4:
The center of resistance is the green point with the root and the center of rotation is the yellow point midway between the lines of the opposite force supposedly generated by the couple. This 2D concept is invalid for clinical use of aligners. Aligners always apply forces in 3D despite the position of ridges and attachments. The 3D force system when an aligner is seated completelynegates simplified 2D concepts.

Generating Couples with CAs

J.J. Sheridan[17] and R. Nanda[18] report a couple is generated by a CA on the tooth crown via opposite vectors applied via ridges in aligners or bonded attachments. It is presently argued that their concept is more aspiration than science.[15] It is not possible to routinely produce a couple on the surface of a tooth in the desired plane of tooth movement using a removable appliance like CAs.[19]

Fig. 4 illustrates the claimed generation of a "couple" using internal protrusions (prominent bands) in aligners. Such a system fails to meet the stringent criteria for a couple. It lacks a continuous integral connection to the tooth throughout the path of tooth movement.

Aligners are removable devices that cannot produce a couple typical of fixed appliances (Fig. 1), so their scope of action is limited to a single type of movement: tipping. This type of movement is achieved via a single force vector (or the resultant of forces in different directions resolved with a parallelogram).

Applying a single vector to a naturally restrained tooth crown causes tipping, meaning the tooth rotates near its natural C_{Res} located in the root, according to the vector's direction. To maintain the desired tipping direction over time, the vector must be applied consistently to maintain the rotation axis relative to the estimated C_{Res}. The variables are the magnitude and direction of the vector relative to the exposed portion of a tooth which is usually the crown. Deviations from this axis, particularly during relatively long-term movements, may cause undesirable tooth rotation requiring corrective adjustments that extend treatment time (new set of aligners). However, aligners only achieve about 50% of programmed tooth movement.[6,9] An acceptable finished result is only achieved by overcorrection with a new set of finishing aligners to deliver what turns out to be an array of tipping forces.[20]

The challenge of maintaining precise tipping over time contributes to the inefficiency of aligners. Complex treatment typically requires many reboots with new sets of aligners. This limitation stems from the inability to generate couples typical of fixed appliances. Simulations of bodily translations with overtreatment by multiple sets of aligners may be deemed "walking" teeth to the desired position. This is a limitation for all removable devices compared to the precise mechanics of fixed orthodontic appliances.

Compensating for Aligner Limitations

In recent years, numerous studies have proposed methods to improve treatment outcomes with aligners, primarily through finite element analysis (FEA).[21-25] These studies suggest enhancements to improve efficiency such as attachment placement, ridges in aligners or composite bumps on teeth to secure seating. Treatment planning involves overcorrection, over-treatment strategies, and other compensating techniques. These recommendations assume that such preemptive adjustments will finally achieve the desired tooth positions. Compensations can improve outcomes with CAs, but there is no improvement in biomechanics efficiency. Aligners deliver indeterminate mechanics.

So it requires multiple sets of records and new aligners along the way.[19]

Shifts in C_{Res} During Fixed Appliance Treatment

C_{Res} shifts occur naturally due to natural and artificial restraints during fixed appliance treatment. For example, consider the distal movement of a canine to close a first premolar extraction space. Using a power chain or closed spring applied at bracket height, the canine initially rotates around its natural C_{Res} in the root. As deformation and friction in the slot-wire junction increases, the movement transitions to a couple, shifting the C_{Res} to the slot. This autogenous interplay continues cyclically until the space is closed. This example demonstrates the dynamic C_{Res} relocation required for translational movement with fixed appliances.

Fundamental Differences in Biomechanics

Orthodontic biomechanics must distinguish between the capabilities of fixed versus removable appliances. Fixed appliances, with interaction between natural and artificial restraints, enable all types of orthodontic movements (e.g., tipping, torque, as defined above, via couples, and translation). In contrast, removable appliances like CAs can only perform complex patterns of tipping movements. With programmed overcorrection and multiple sets of aligners, a reasonable outcome is possible. However, precise finishing in 3D requires fixed appliances.

The most definitive advantage of fixed appliances over CAs lies in their ability to dynamically control the C_{Res} position. Precise shifting of the C_{Res} between the root and crown enables ideal orthodontic outcomes. This precision is absent in aligners. Achieving optimal outcomes with respect to translation requires overcorrection with multiple sets of aligners. Rebooting with new 3D records at whatever position the teeth achieve with a particular set of aligners is essential. The entire aligner alignment process is "walking" the teeth to an optimal outcome with a complex array of tipping movements.

Conclusions

1. Artificial restraint imposed by fixed appliances plays a pivotal role in shift of the C_{Res}.

2. Optimizing fixed appliance capabilities to dictate the position of the C_{Res} is essential for advancing excellence in treatment outcomes.

3. Achieving precise tooth movement with fixed appliances requires control of the interface between the archwire and bracket slot, i.e it must be a 'strong' or 'unequivocal' connection.

4. Movement boundaries are significantly greater with fixed appliances than with removable ones.

5. Lack of precision in controlling boundary conditions decreases the clinical efficiency of clear aligners.

6. Consequently, aligner-based treatment is unlikely to match the clinical excellence of fixed appliances particularly with respect to finishing details.

7. Fixed appliances exceed all removable appliances including clear aligners in achieving precise tooth movement in 3D.

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2025 一年一度 Damon Master Program

+

全新改版的 2025 年貝多芬高效 Damon 矯正大師系列課程，是由**國際知名講師張慧男醫師親自規劃及授課**，課程特色強調由臨床病例帶動診斷、分析、治療計畫擬定與執行技巧，本年度亦特別加入最新的**數位矯正與隱形牙套**的內容，並邀請了貝多芬牙科集團各院院長演講**特別矯正專題**。

此外，透過數位影片反覆觀看，結合矯正與電腦教學，課堂助教協助操作，讓學員在短時間能快速上手，感染「熱愛矯正學，熱愛學矯正」的熱情。

名額有限，一年僅有一次機會在台完整體驗 Damon 矯正大師課程，錯過只能等明年囉！

Module 1 - 3/13

1. Selecting your ideal first case
2. Bonding position
3. Bonding + BT + ceph tracing
4. TADs + space closing + hook + spring
5. Finishing bending & fixed retainer

Practice: Clinical photography（黃亭雅, 陳韻如醫師）

Module 2 - 4/17

1. Four stages of efficient orthodontic treatment
2. Simple and effective anchorage system
3. Extraction vs. non-extraction analysis

Practice: Patient photo management（金牛頓工程師）

Module 3 - 5/1

1. Soft & hard tissue diagnostic analysis
2. Big overjet correction
3. Damon diagnosis & fine-tuning

Practice: Ceph tracing（金牛頓工程師）

Module 4 - 5/15

1. Excellent finishing
2. Retention & relapse

Practice: Ceph superimposition & measurement（金牛頓工程師）

Module 5 - 5/22

1. Simplify your system
2. Extraction vs. non-extraction

Practice: Case report demo（陳俊宏醫師）

▲ Computer training (Mac): 1:30-3:00 pm

Module 6 - 6/5

1. Class III correction
2. Class II correction

Topic: Early orthodontic treatment（曾淑萍醫師）

Module 7 - 6/19

1. Upper impaction
2. Lower impaction
3. Gummy smile correction

Topic: Modified VISTA（蘇筌瑋醫師）

Module 8 - 7/3

1. ABO DI, CRE workshop (林彥君醫師)
2. Open bite

Topic: Ortho-viewed interdisciplinary treatment（徐重興醫師）

Module 9 - 7/17

1. Implant-ortho combined treatment
2. Asymmetry

Topic: Impacted cuspid treatment（張譯文, 張瑜珍, 黃亭雅, 陳韻如醫師）

Module 10 - 7/31

1. Minor surgeries in orthodontics
2. Digital orthodontics

Topic: Modified 2X4 appliance in ortho treatment（李亮賢醫師）

Module 11 - 8/14

1. Aligner design
2. Comprehensive aligner treatment
3. Aligner & its challenges

Topic: Pre-aligner treatment（林詩詠醫師）

▲ Special lecture: 1:30-3:00 pm

時間：週四全天（9:20 am - 5:00 pm）
地點：金牛頓藝術科技（新竹市建中一路 25 號 2 樓）
費用含課程視訊*、iPad、課程電子書與材料。

*贈送之課程視訊提供兩年時間串流觀看。

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