



Department of Mechanical Engineering – University of Málaga
School of Industrial Engineering, Málaga (SPAIN)

Speakers:

Juan A. Cabrera - jcabrera@uma.es

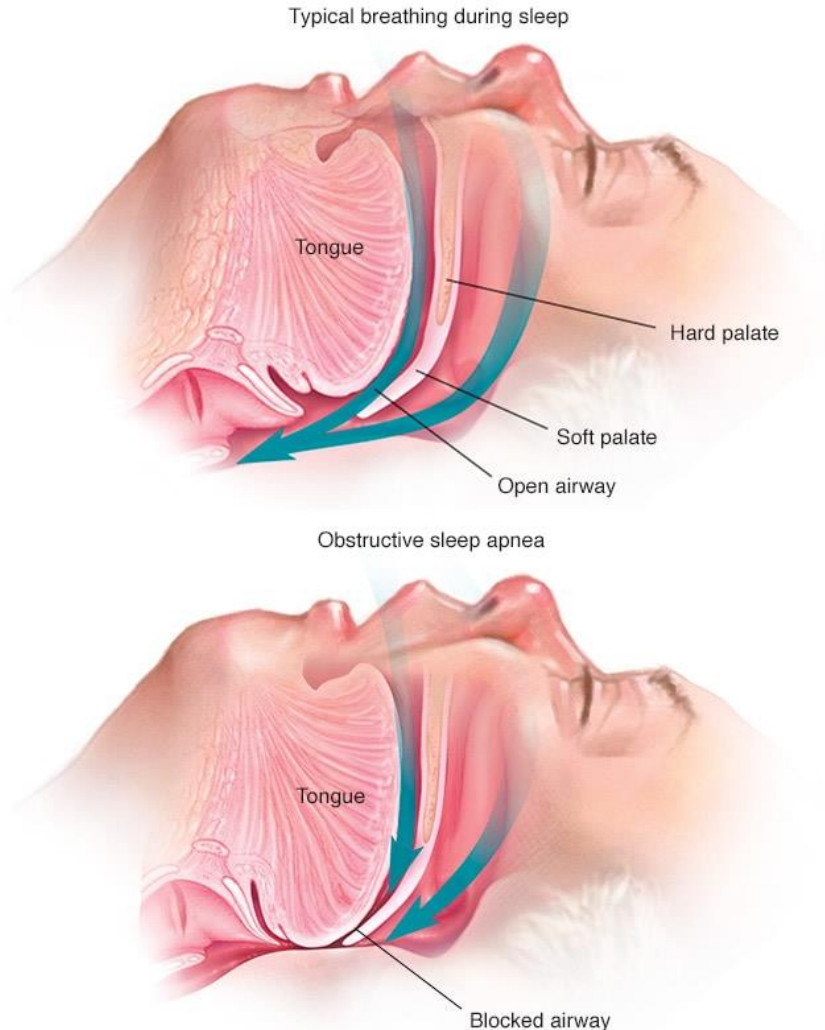
Javier Pérez – javierperez@uma.es

Outline:

- 1. Introduction**
2. Types of Mandibular Advancement Devices (MADs)
3. Mandible kinematics
4. Kinematic model: MAD + Mandible
5. Problems in the use of MADs
6. Optimal MAD design with bars
7. Optimal MAD design with cams
8. Conclusions

Introduction

- What is sleep apnoea?



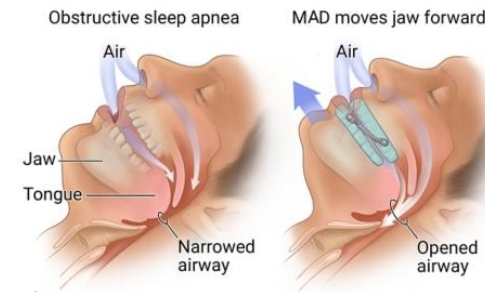
* Source Mayo Foundation

- Ways to solve apnoea nowadays

1. CPAD (Continuous Positive Airway Pressure)



2. MAD (Mandibular Advancement Device)

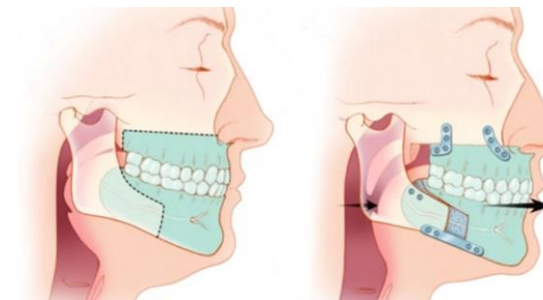


* Source Helthwise



* Source Narval

3. Surgery

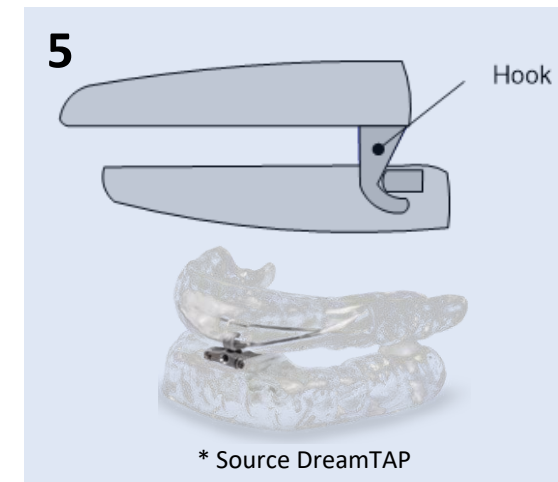
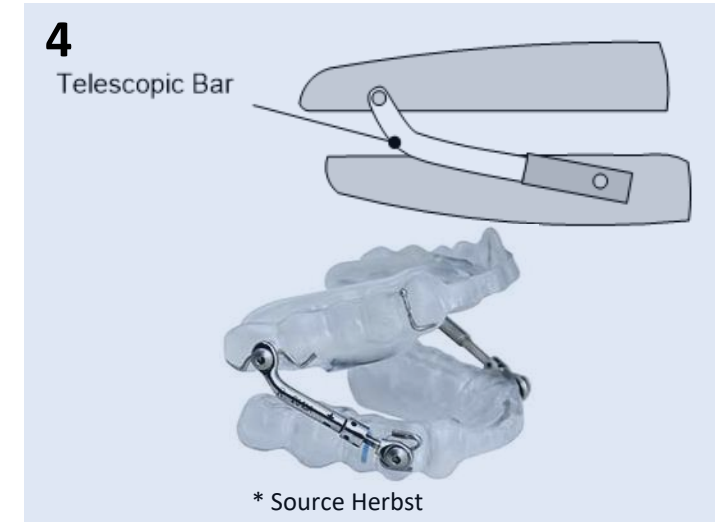
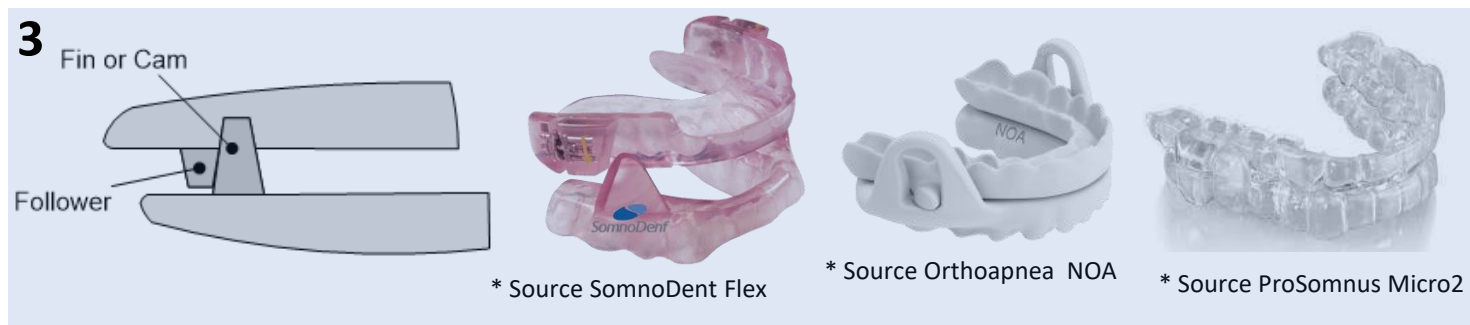
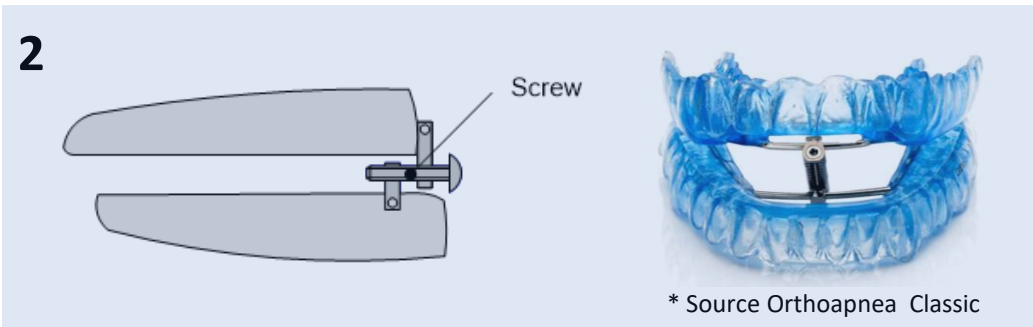


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Types of Mandibular Advancement Devices (MADs)

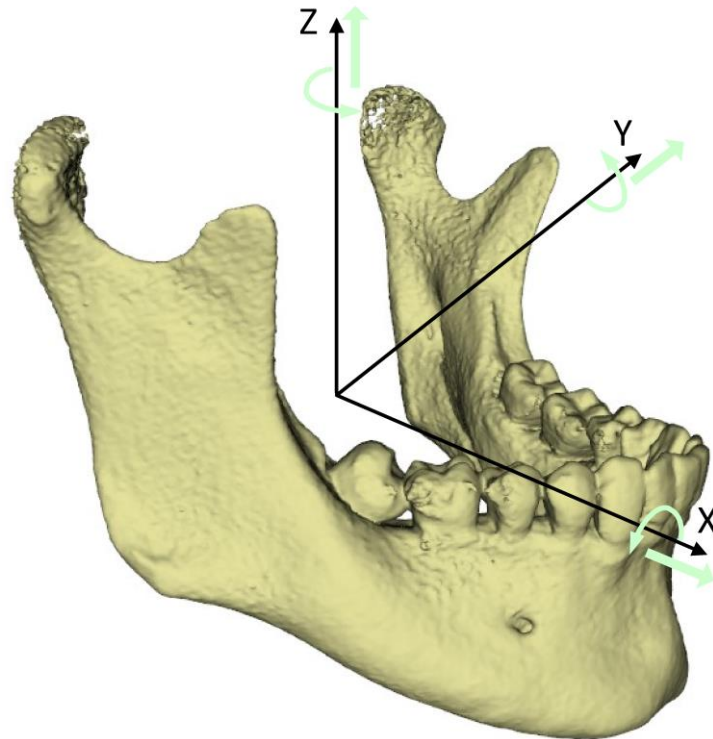
- Two dental splint with different coupling mechanism



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Mandible kinematics

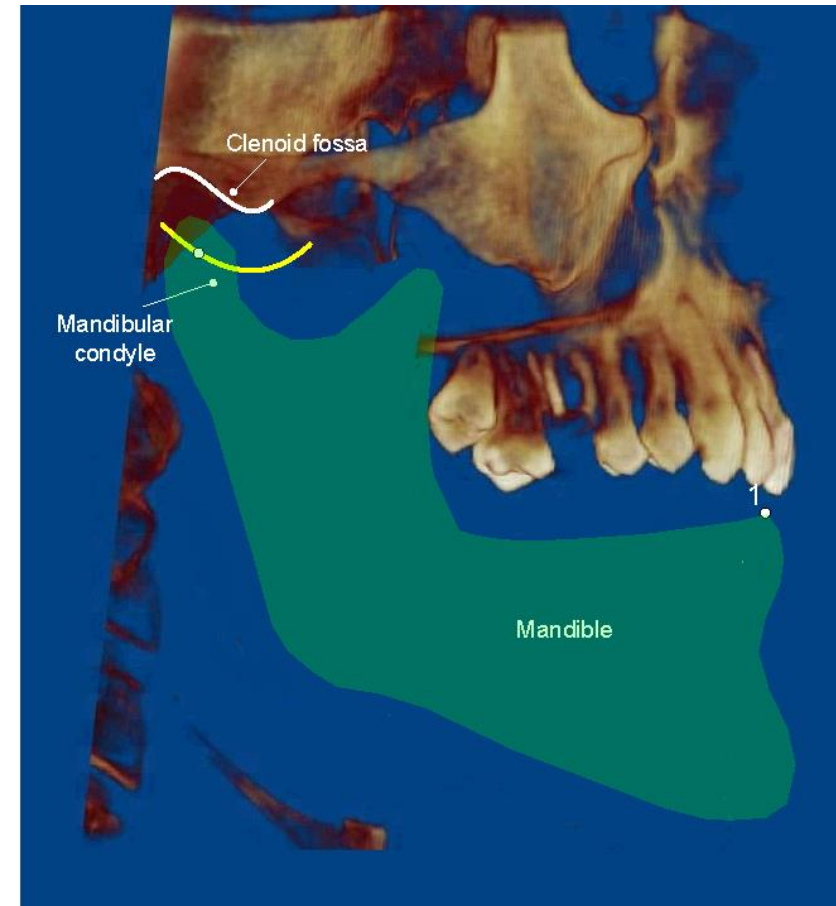


- The jaw movement has 6 DOF
- With certain simplifications 4 DOF

[1] J.H. Koolstra. Dynamics of the Human Masticatory System. Critical Reviews in Oral Biology & Medicine. Vol.13, 2002.

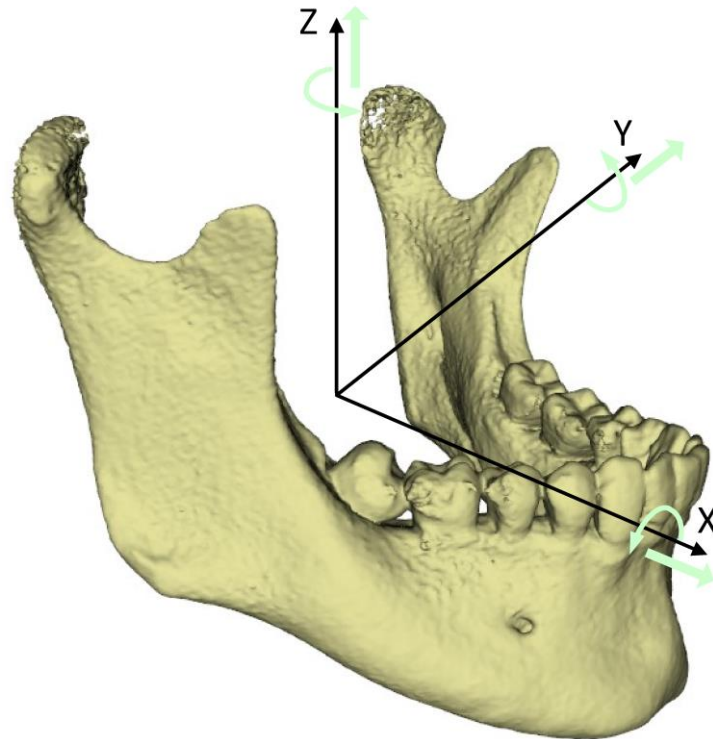
- Movement in the sagittal plane (ZX) 2 DOF → Posselt's Diagram [2]

- Initial position of maximum retrusion



[2] Posselt U (1952) Studies in the mobility of the human mandible. Acta Scand 10:1-60

Mandible kinematics

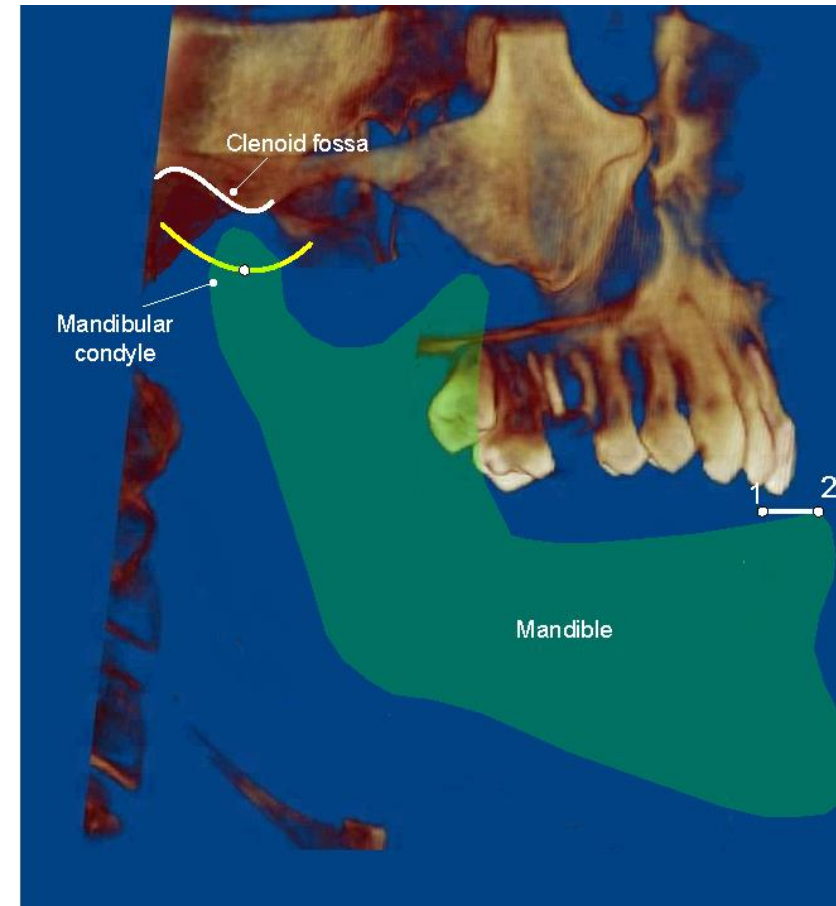


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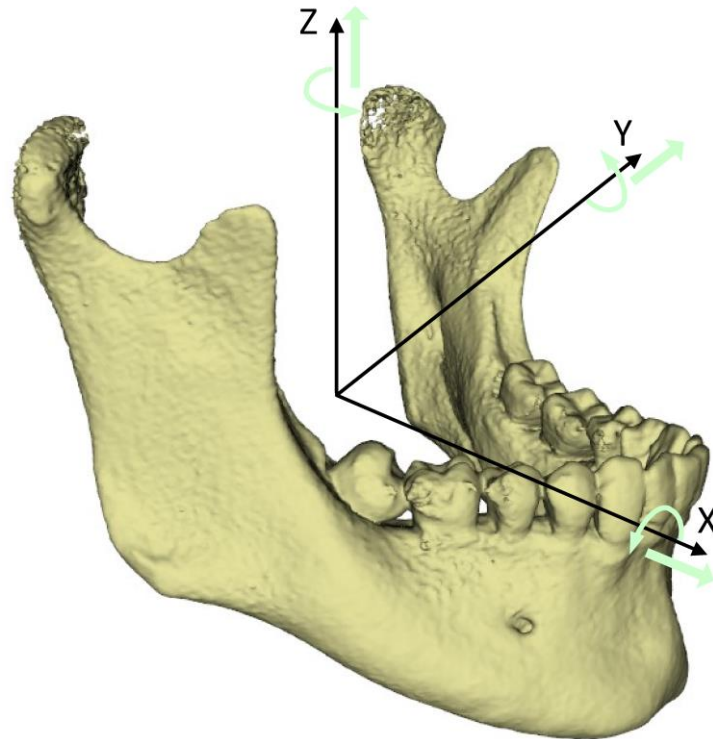
- Movement in the sagittal plane (ZX) 2 DOF → Posselt's Diagram [2]

- 1-2: Translation to maximum protrusion



[2] Posselt U (1952) Studies in the mobility of the human mandible. Acta Scand 10:1-60

Mandible kinematics

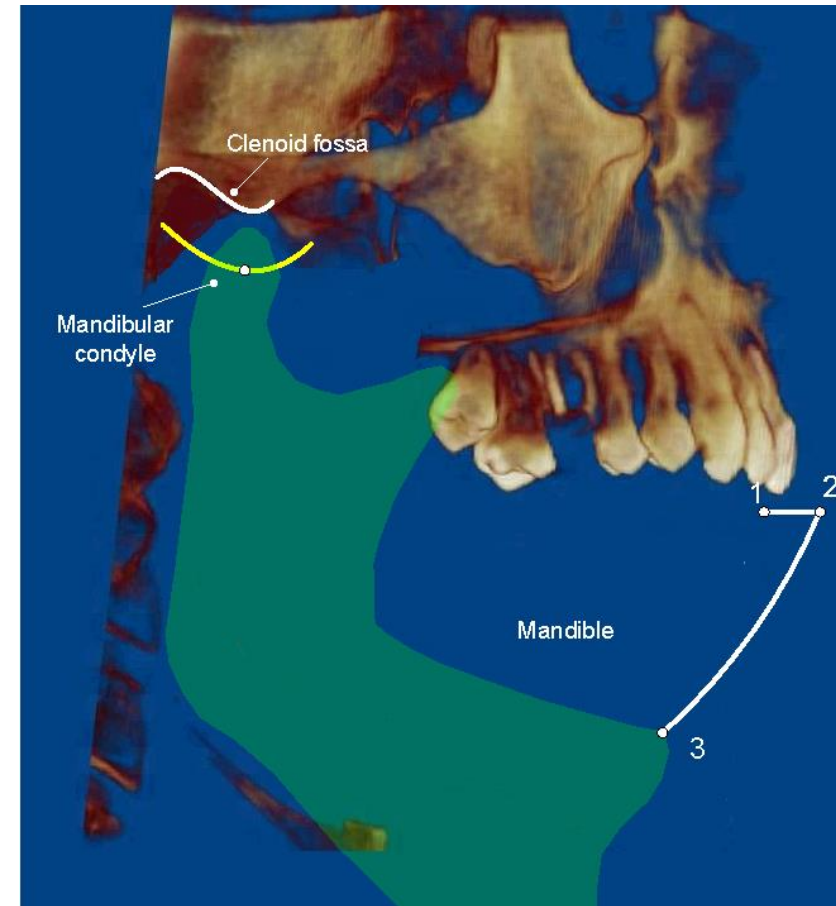


- The jaw movement has 6 DOF
- With certain simplifications 4 DOF

- 2-3: Rotation to maximum mouth opening

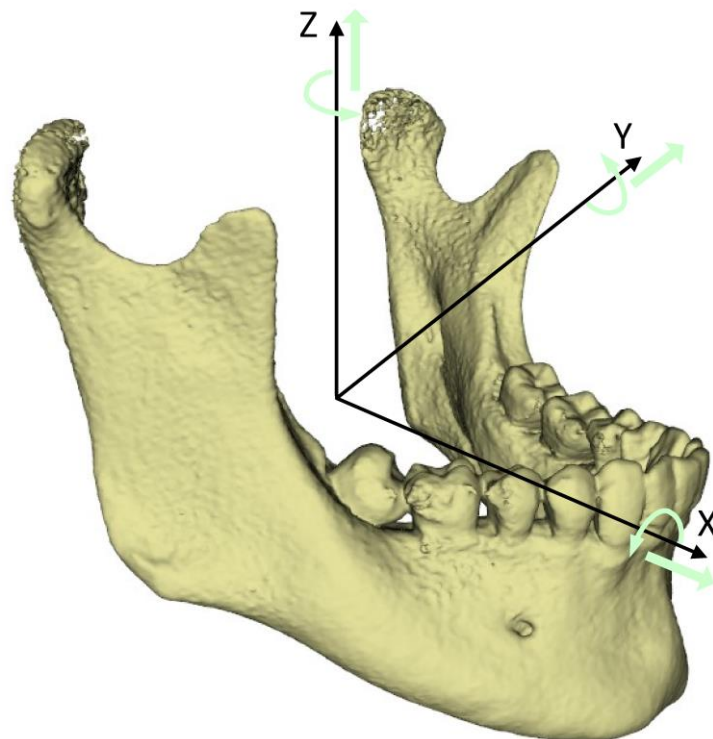
[1] J.H. Koolstra. Dynamics of the Human Masticatory System. Critical Reviews in Oral Biology & Medicine. Vol.13, 2002.

- Movement in the sagittal plane (ZX) 2 DOF → Posselt's Diagram [2]



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Mandible kinematics

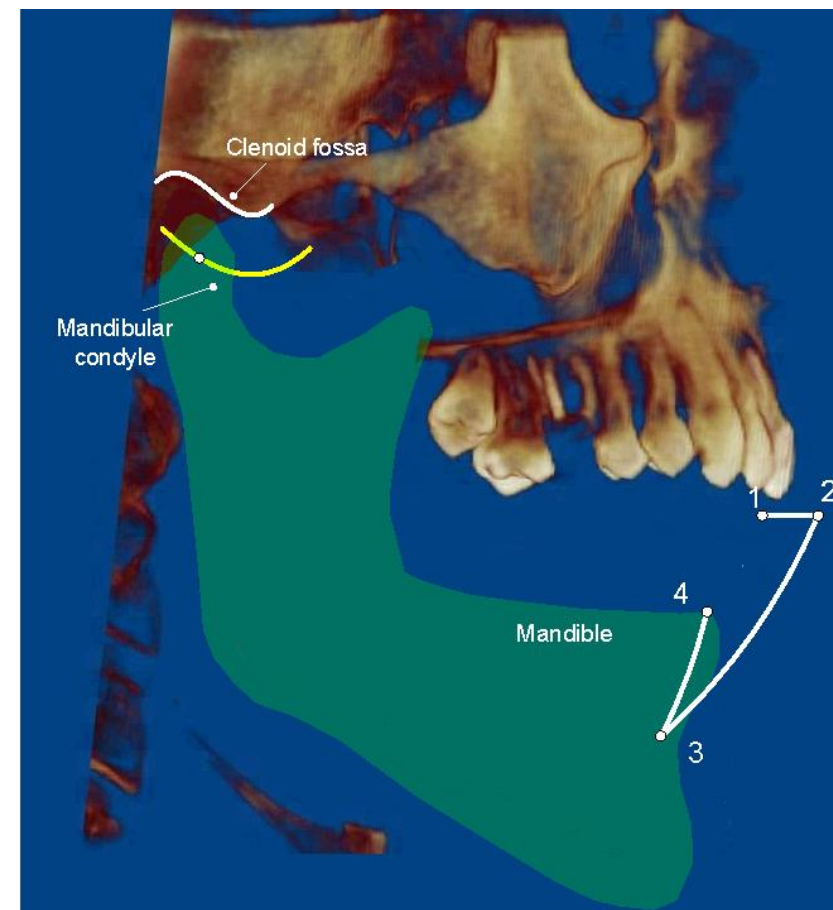


- The jaw movement has 6 DOF
- With certain simplifications 4 DOF

- 3-4: Rotation + Translation

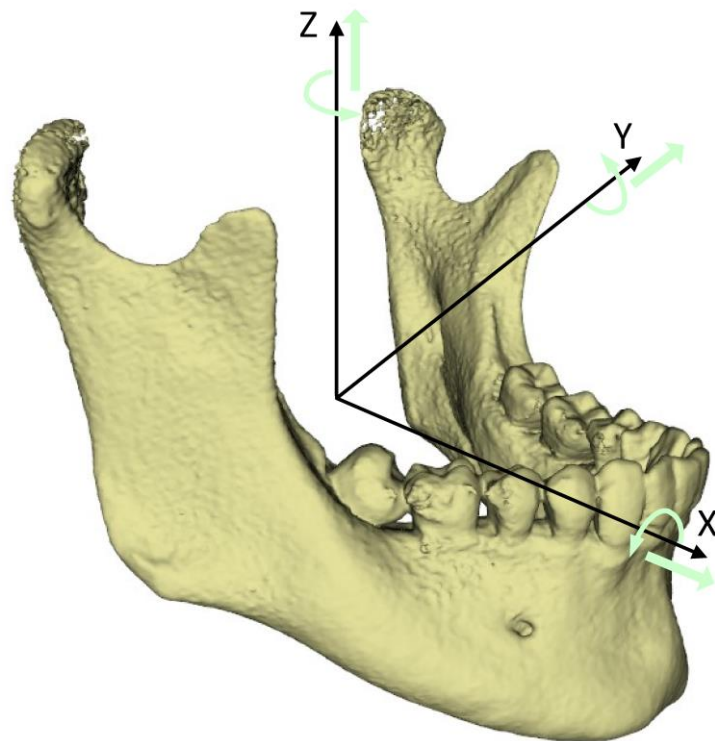
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- Movement in the sagittal plane (ZX) 2 DOF → Posselt's Diagram [2]



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Mandible kinematics

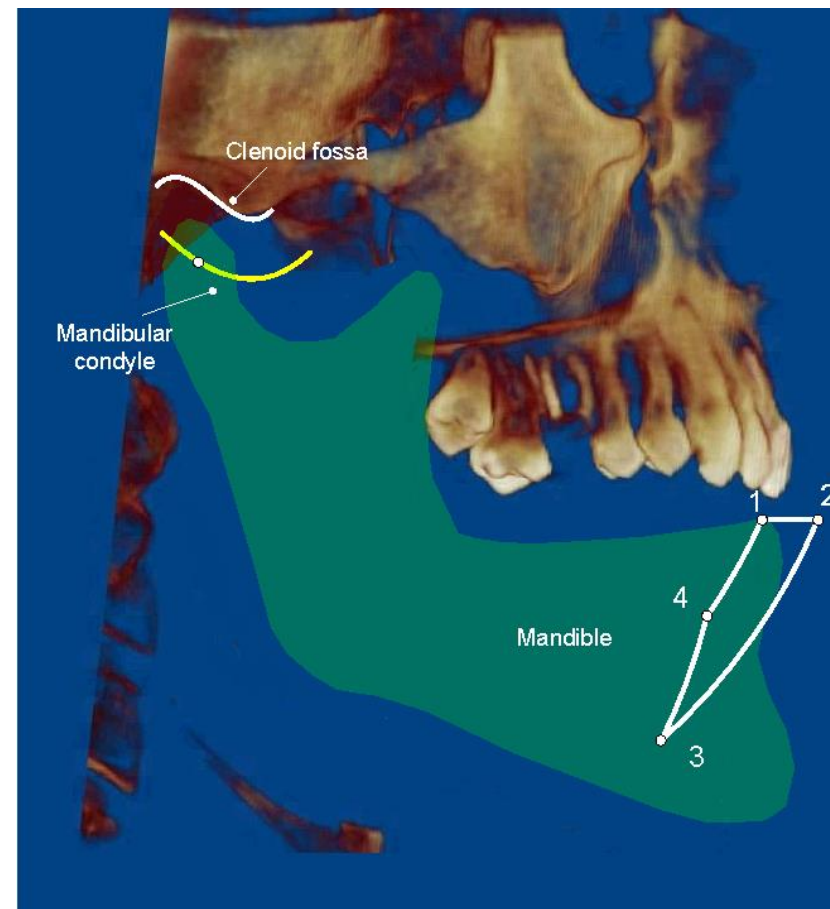


- The jaw movement has 6 DOF
- With certain simplifications 4 DOF

[1] J.H. Koolstra. Dynamics of the Human Masticatory System. Critical Reviews in Oral Biology & Medicine. Vol.13, 2002.

- Movement in the sagittal plane (ZX) 2 DOF → Posselt's Diagram [2]

- 4-1: Rotation to initial position



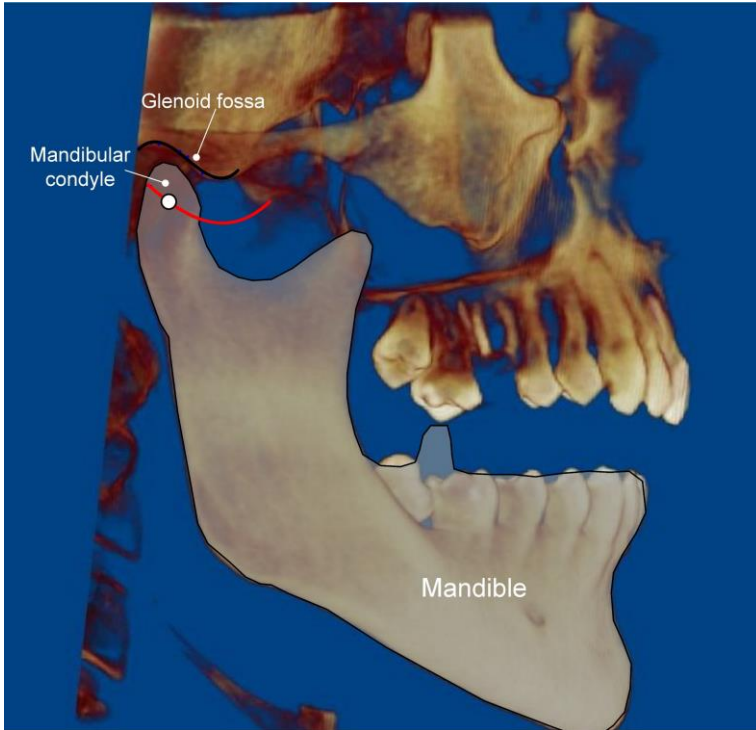
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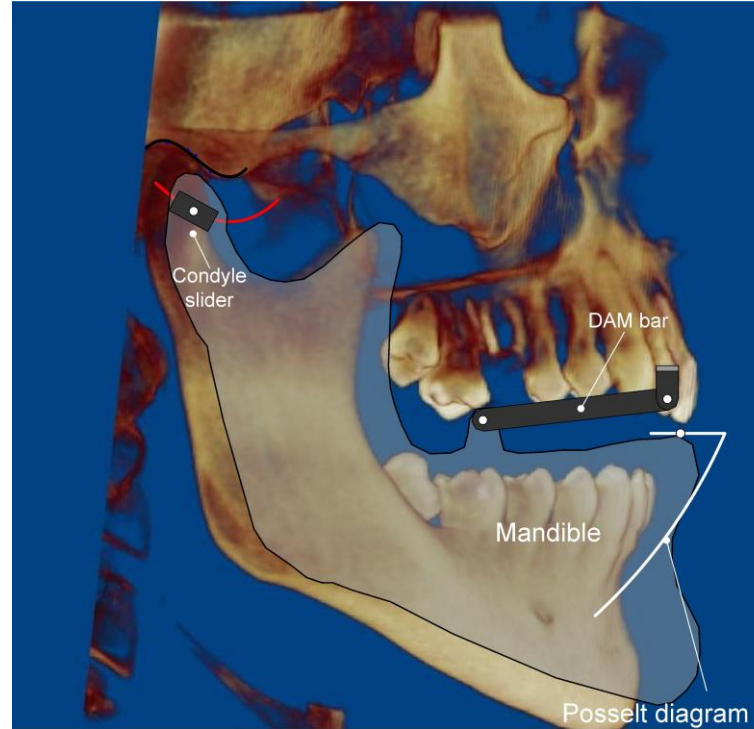
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Kinematic model: MAD + Mandible

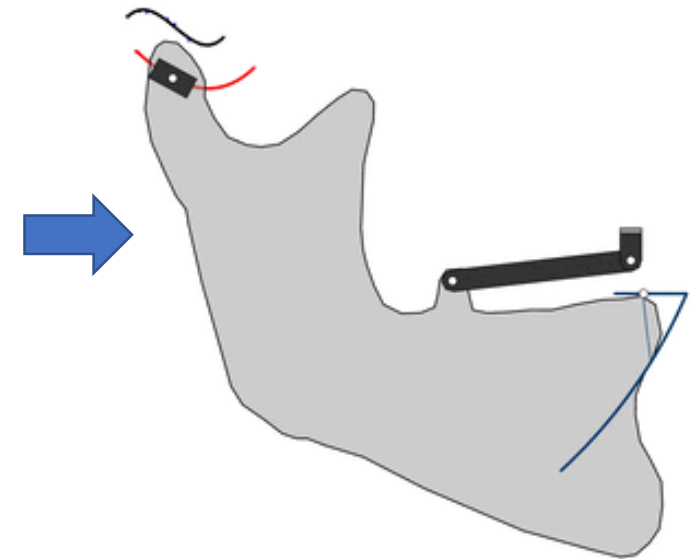
Mandible



Mandible + MAD



Mechanism 1 DOF



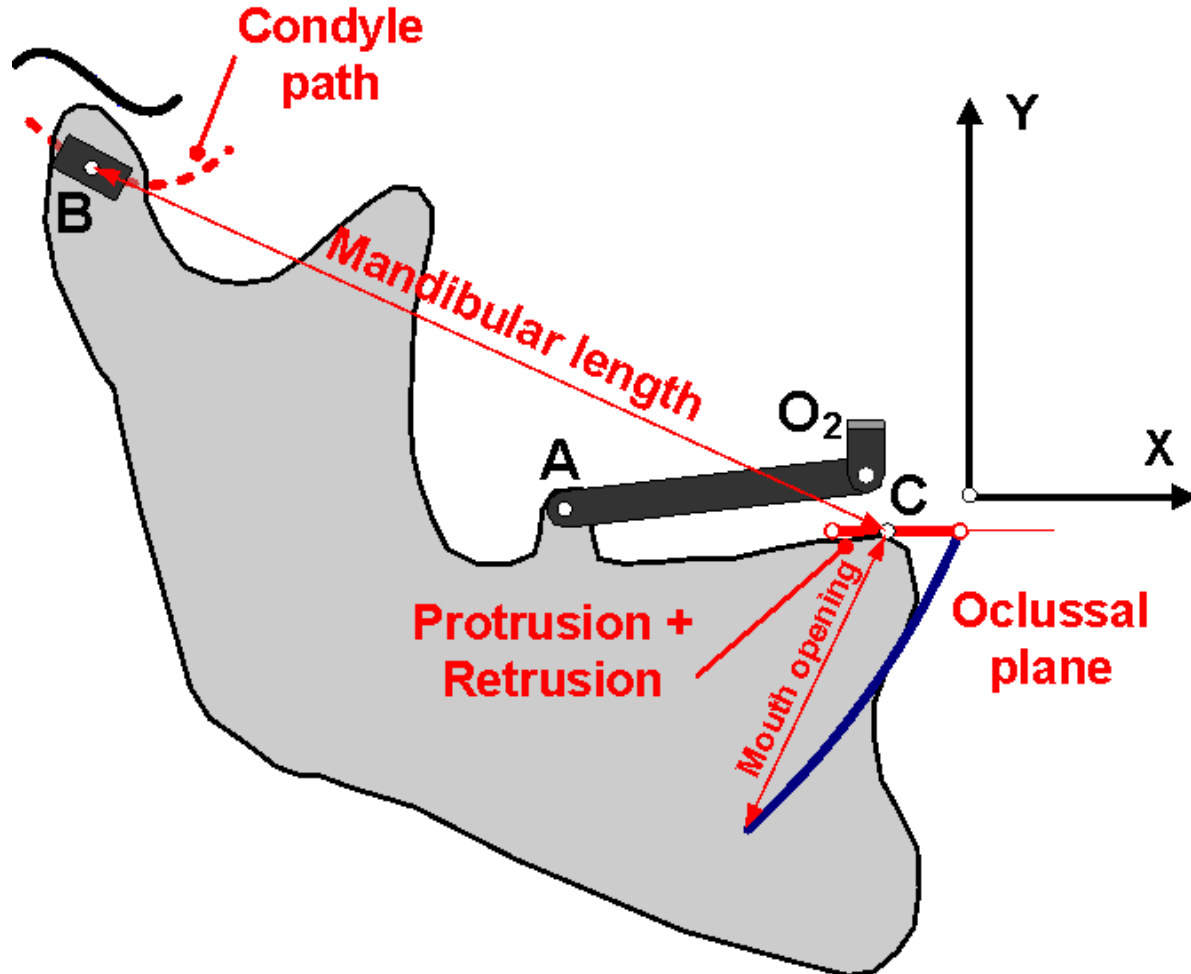
+



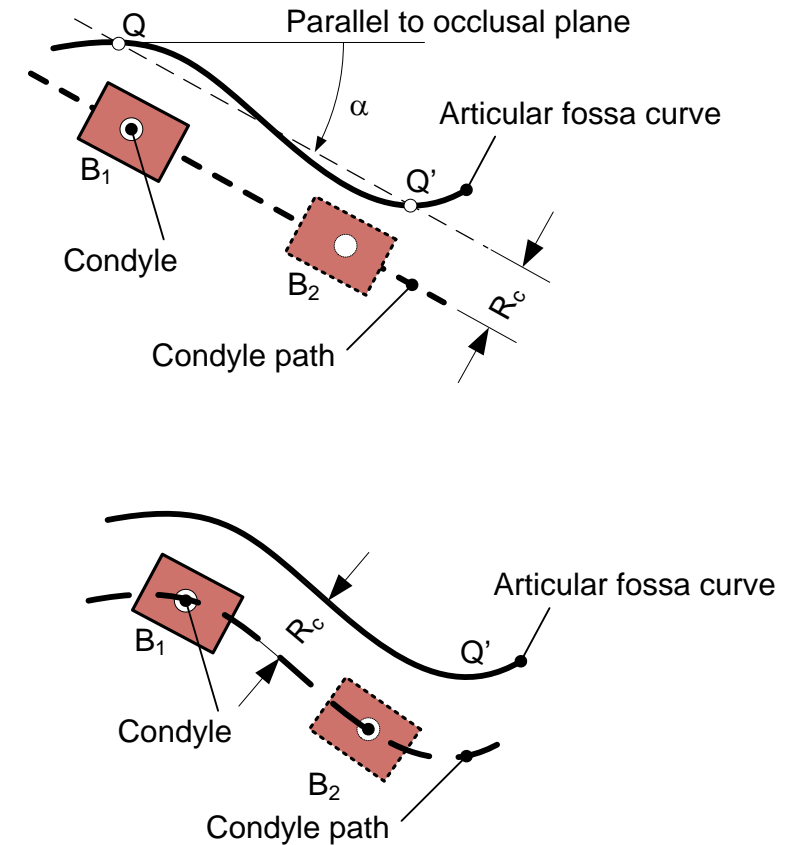
* Source Panthera

Kinematic model: MAD + Mandible

Data required for the mathematical model:



Temporomandibular joint (TMJ):



Kinematic model: MAD + Mandible

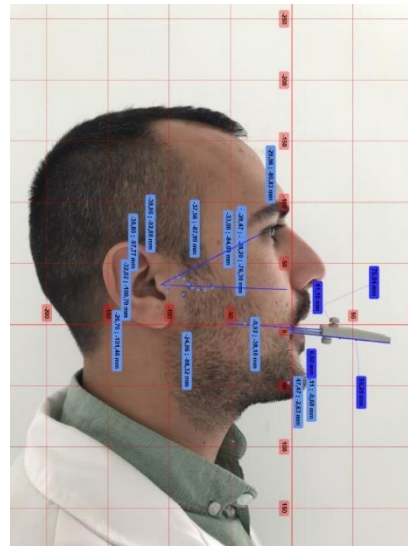
Traditional data

- Retrusion
- Protrusion
- Mouth opening

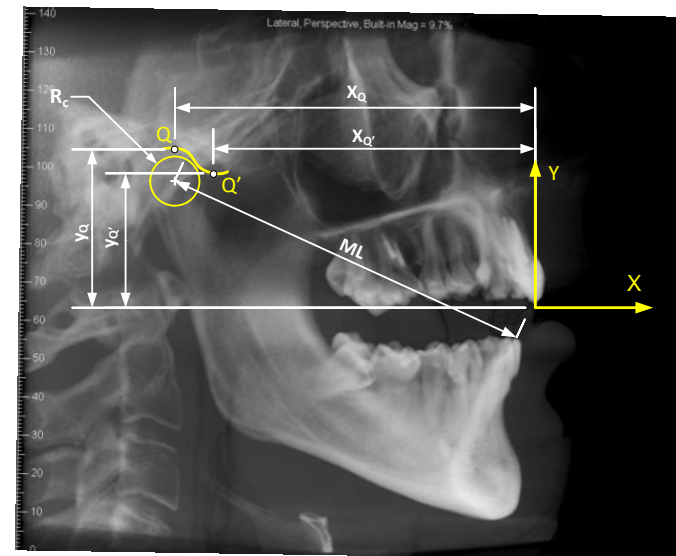


Options for the rest of data

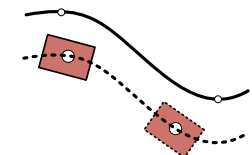
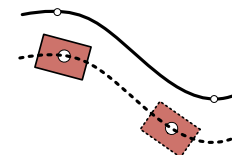
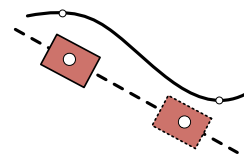
- Mandibular length
- Condyle path
- Occlusal plane



Photograph

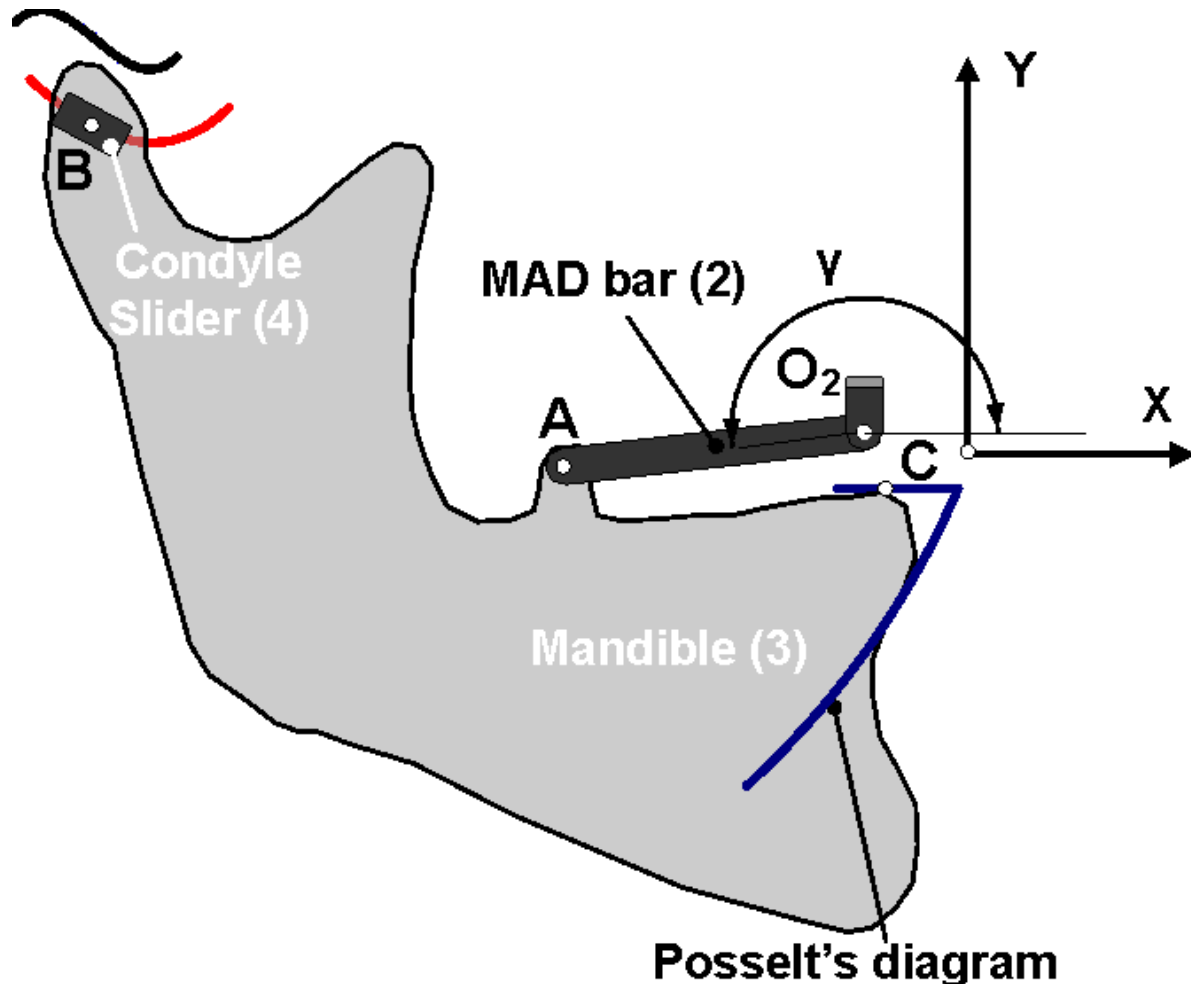


Lateral Cephalogram



Kinematic model: MAD + Mandible

Mechanism 1 DOF:



Coordinates:

$$\mathbf{q} = \{x_A, y_A, x_B, y_B, x_C, y_C, \gamma\}$$

Constraints $\Phi(\mathbf{q})$:

$$(x_{O2} - x_A)^2 + (y_{O2} - y_A)^2 - L_{O2A}^2 = 0$$

$$(x_A - x_B)^2 + (y_A - y_B)^2 - L_{AB}^2 = 0$$

$$(x_B - x_C)^2 + (y_B - y_C)^2 - L_{BC}^2 = 0$$

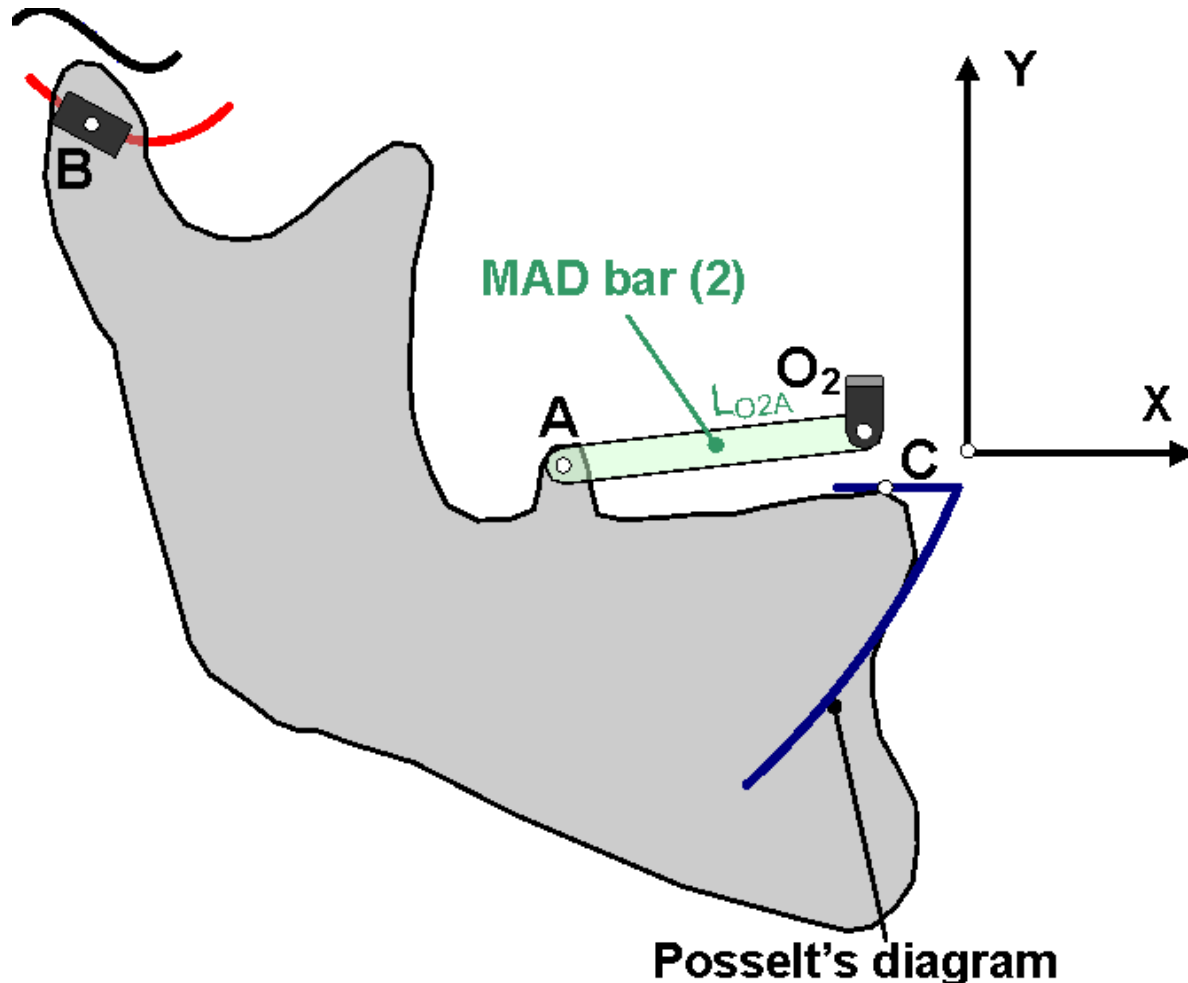
$$(x_C - x_A)^2 + (y_C - y_A)^2 - L_{CA}^2 = 0$$

$$y_B - (ax_B^3 + bx_B^2 + cx_B + d) = 0$$

$$(x_A - x_{O2}) - L_{O2} \cos \gamma = 0$$

Kinematic model: MAD + Mandible

Mechanism 1 DOF:



Coordinates:

$$\mathbf{q} = \{x_A, y_A, x_B, y_B, x_C, y_C, \gamma\}$$

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$$(x_B - x_C)^2 + (y_B - y_C)^2 - L_{BC}^2 = 0$$

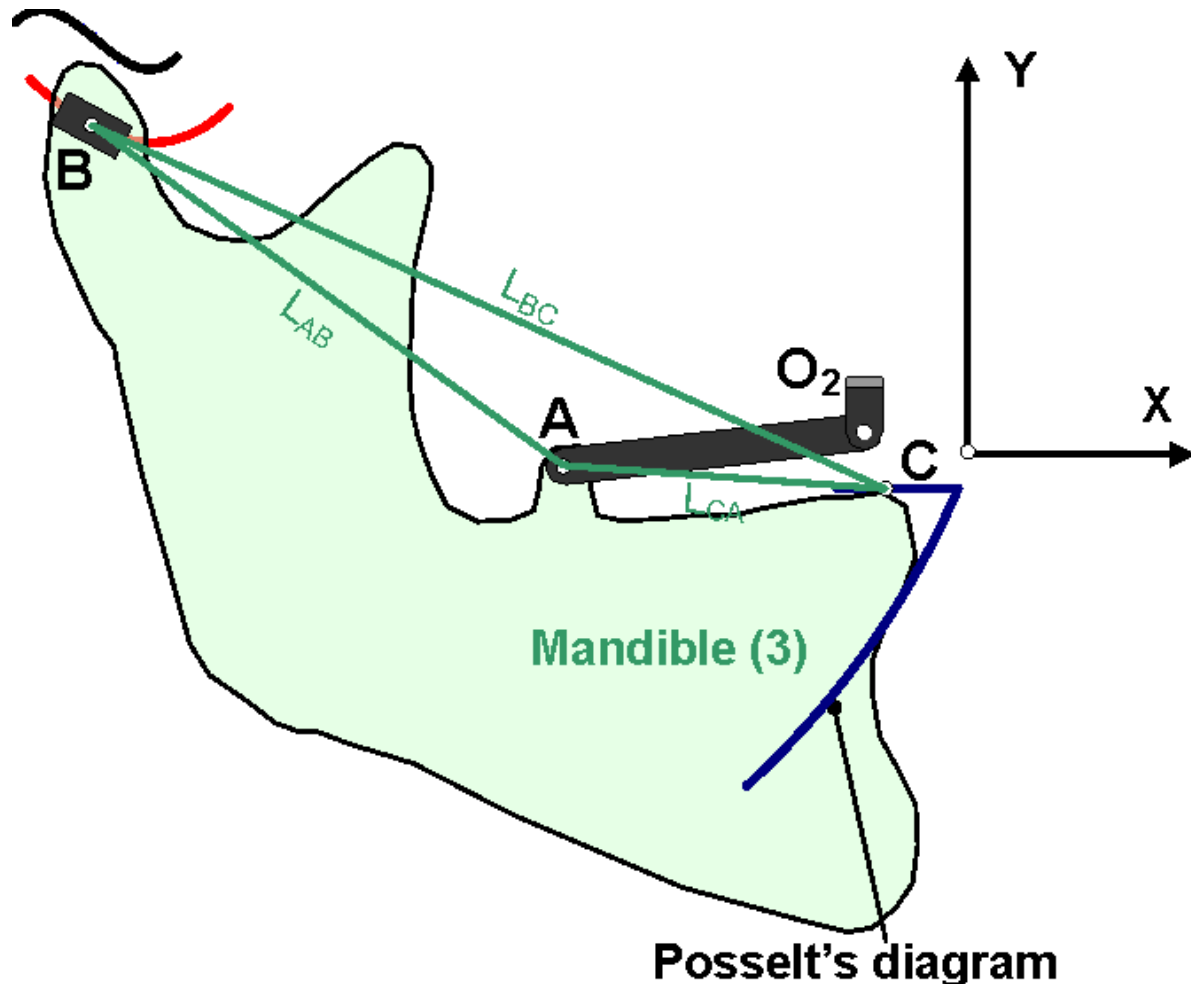
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Kinematic model: MAD + Mandible

Mechanism 1 DOF:



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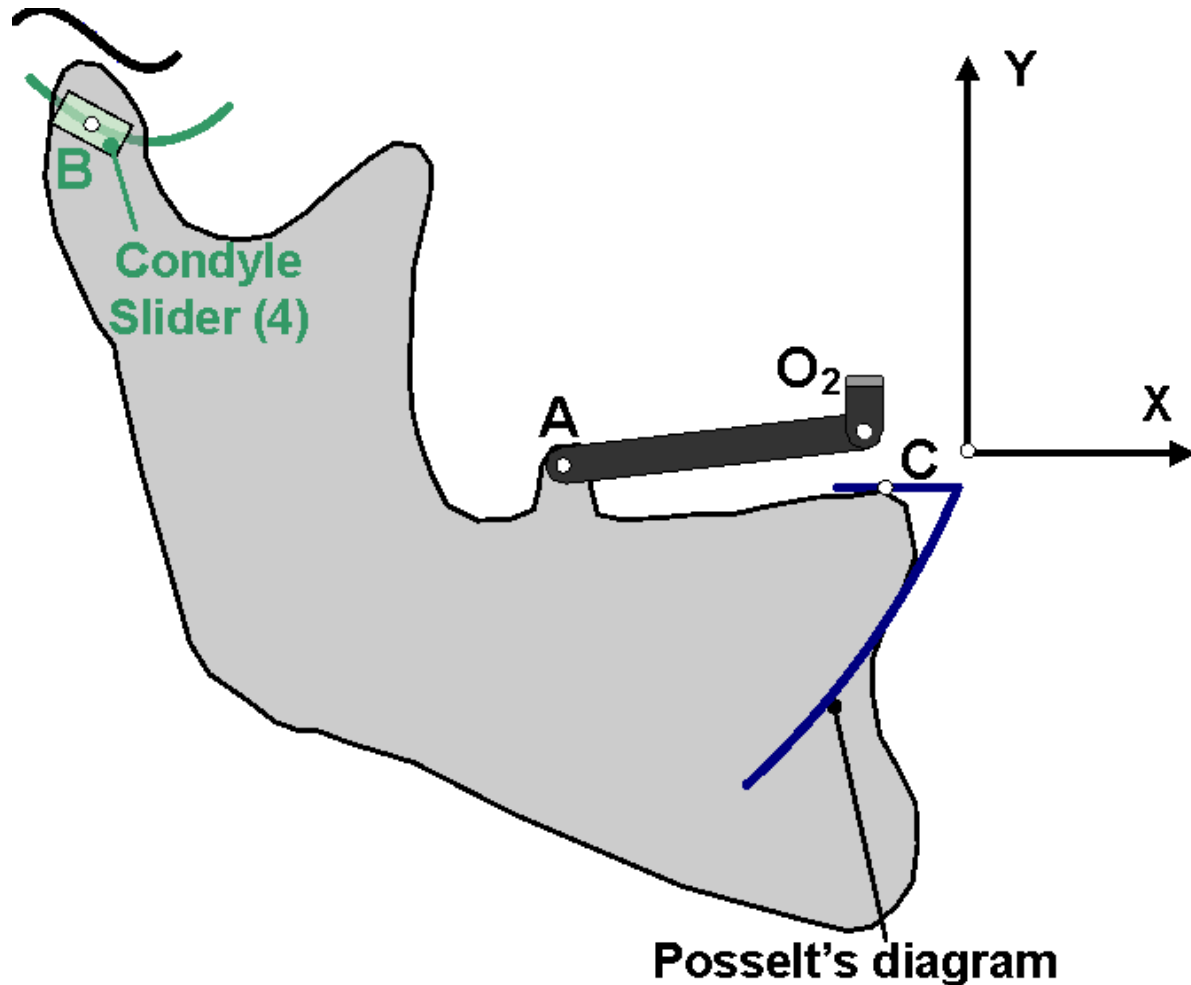
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$$y_B - (ax_B^3 + bx_B^2 + cx_B + d) = 0$$

$$(x_A - x_{O2}) - L_{O2} \cos \gamma = 0$$

Kinematic model: MAD + Mandible

Mechanism 1 DOF:



Coordinates:

$$\mathbf{q} = \{x_A, y_A, x_B, y_B, x_C, y_C, \gamma\}$$

Constraints $\Phi(\mathbf{q})$:

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$$(x_B - x_C)^2 + (y_B - y_C)^2 - L_{BC}^2 = 0$$

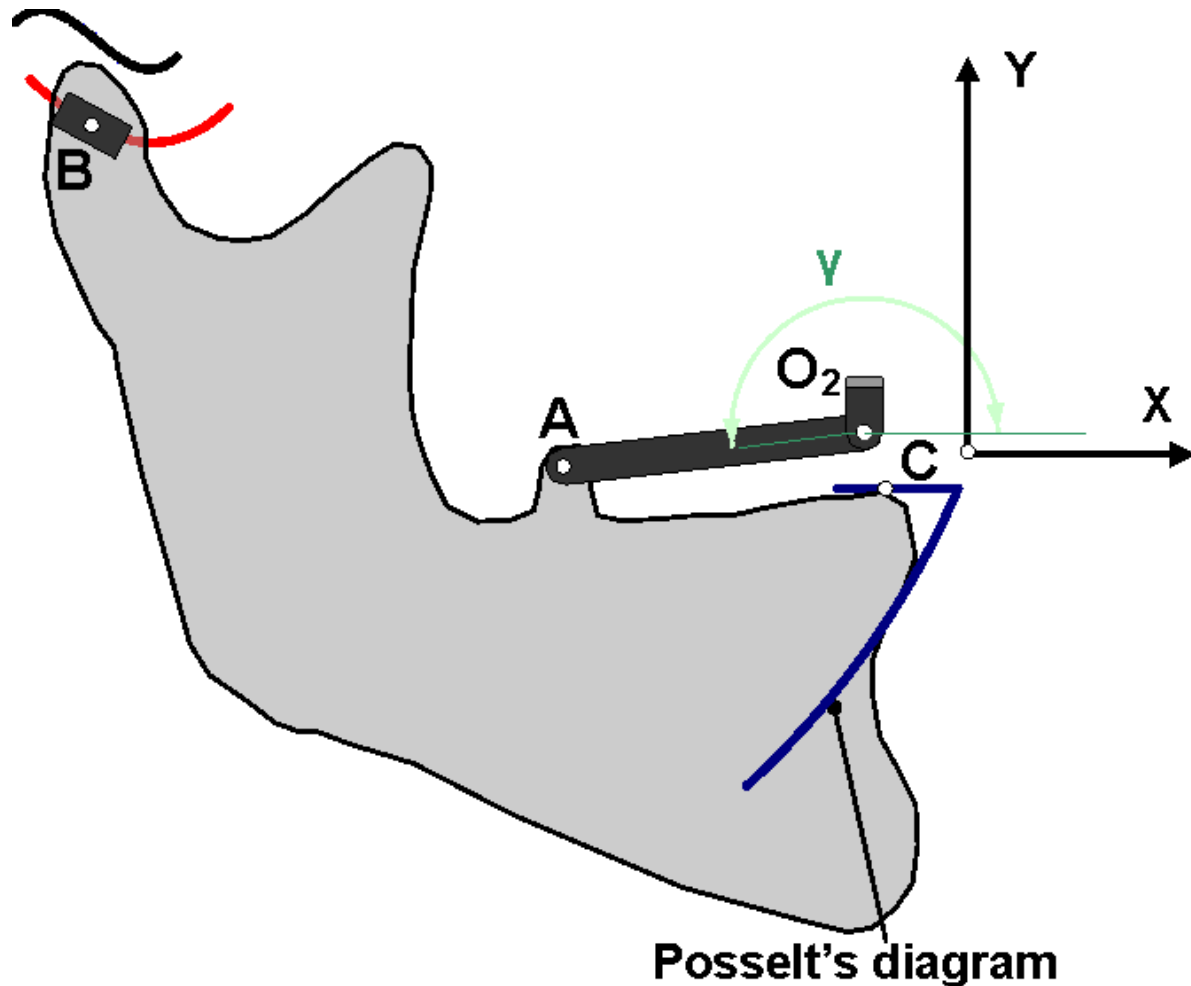
$$(x_C - x_A)^2 + (y_C - y_A)^2 - L_{CA}^2 = 0$$

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$$(x_A - x_{O2}) - L_{O2} \cos \gamma = 0$$

Kinematic model: MAD + Mandible

Mechanism 1 DOF:



Coordinates:

$$\mathbf{q} = \{x_A, y_A, x_B, y_B, x_C, y_C, \gamma\}$$

Constraints $\Phi(\mathbf{q})$:

$$(x_{O2} - x_A)^2 + (y_{O2} - y_A)^2 - L_{O2A}^2 = 0$$

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$$(x_C - x_A)^2 + (y_C - y_A)^2 - L_{CA}^2 = 0$$

$$y_B - (ax_B^3 + bx_B^2 + cx_B + d) = 0$$

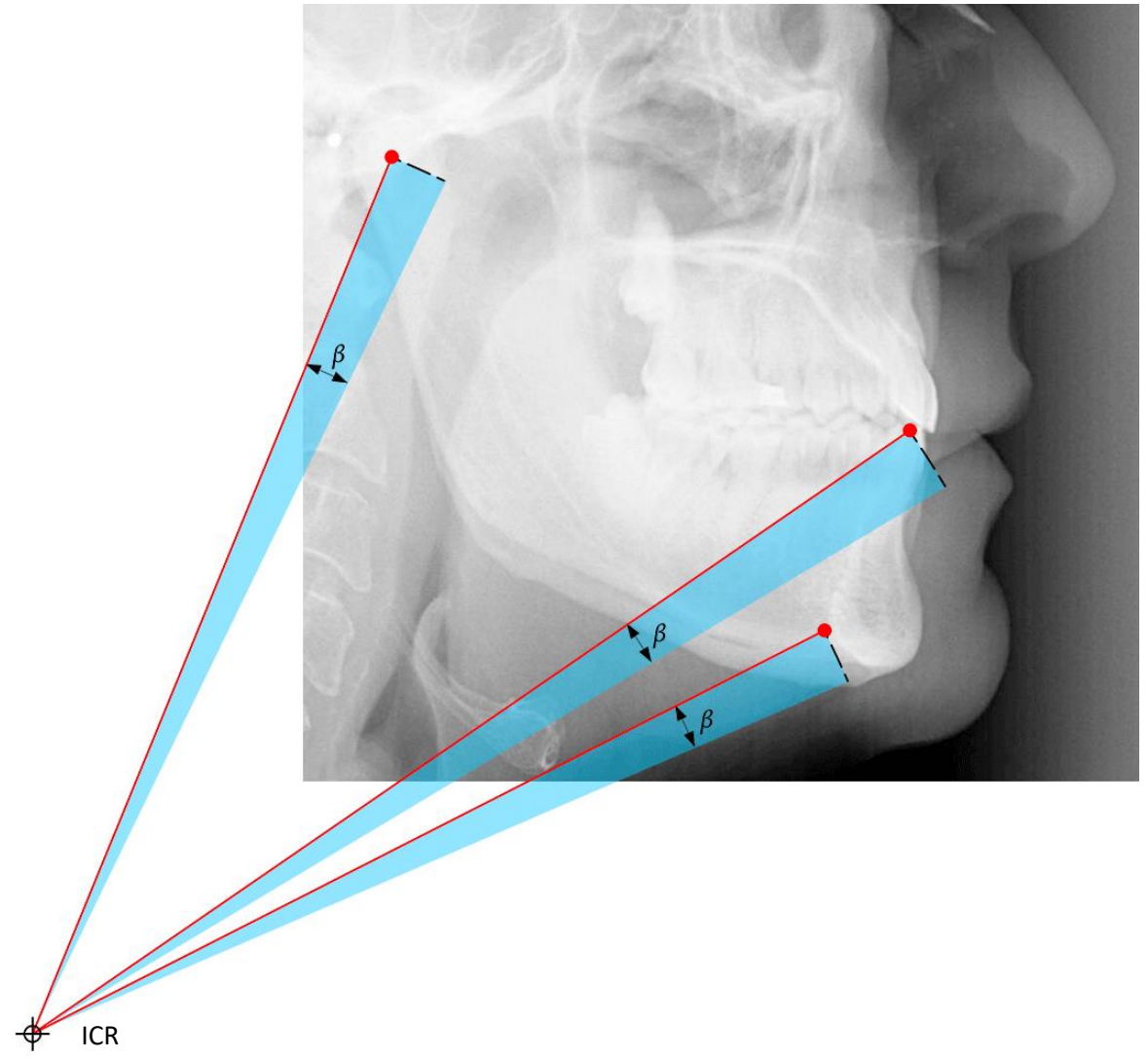
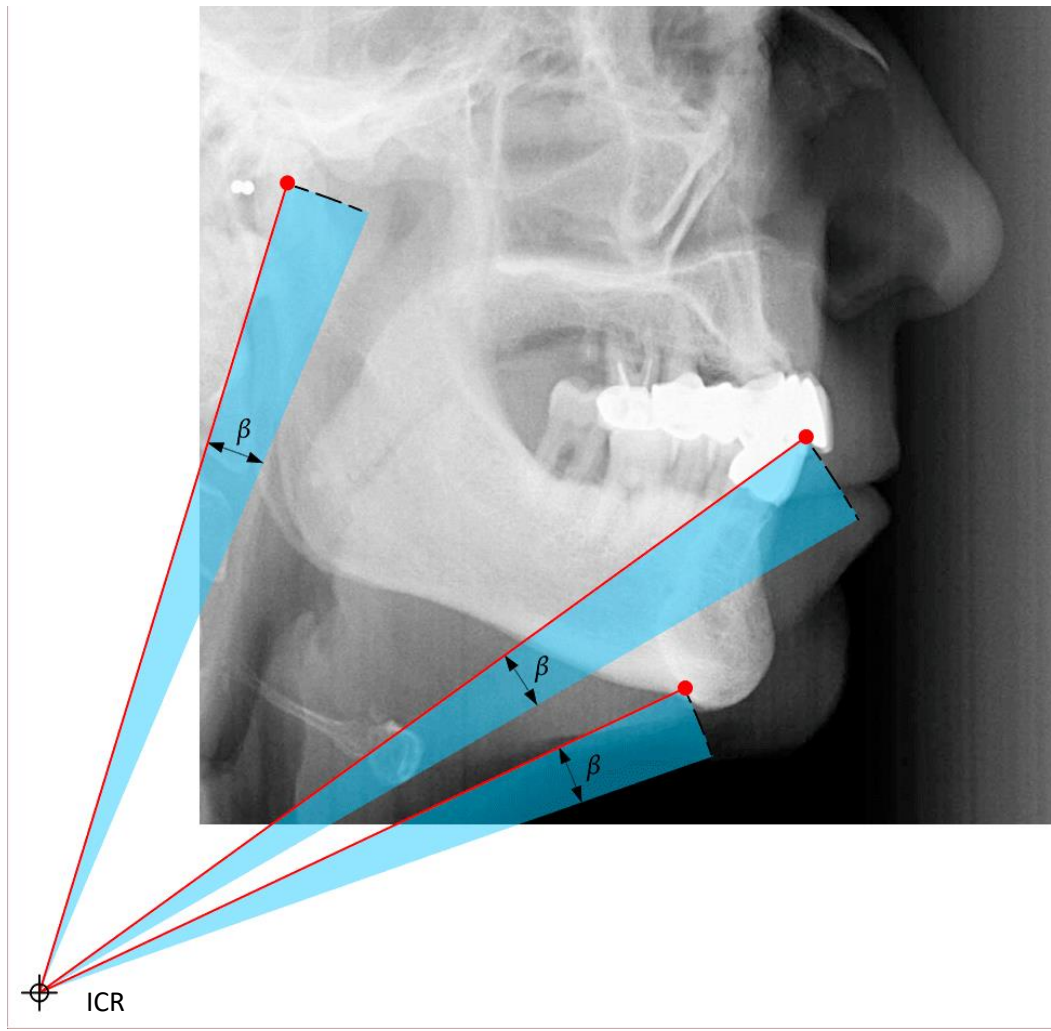
$$(x_A - x_{O2}) - L_{O2} \cos \gamma = 0$$

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Problems in the use of MADs

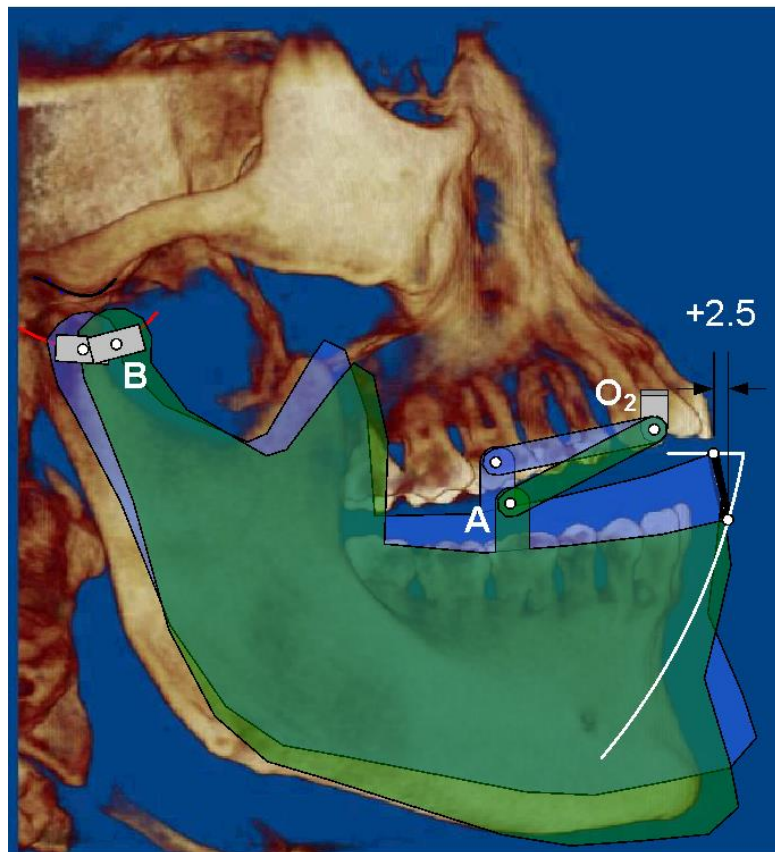
The same MAD in different patients:



Problems in the use of MADs

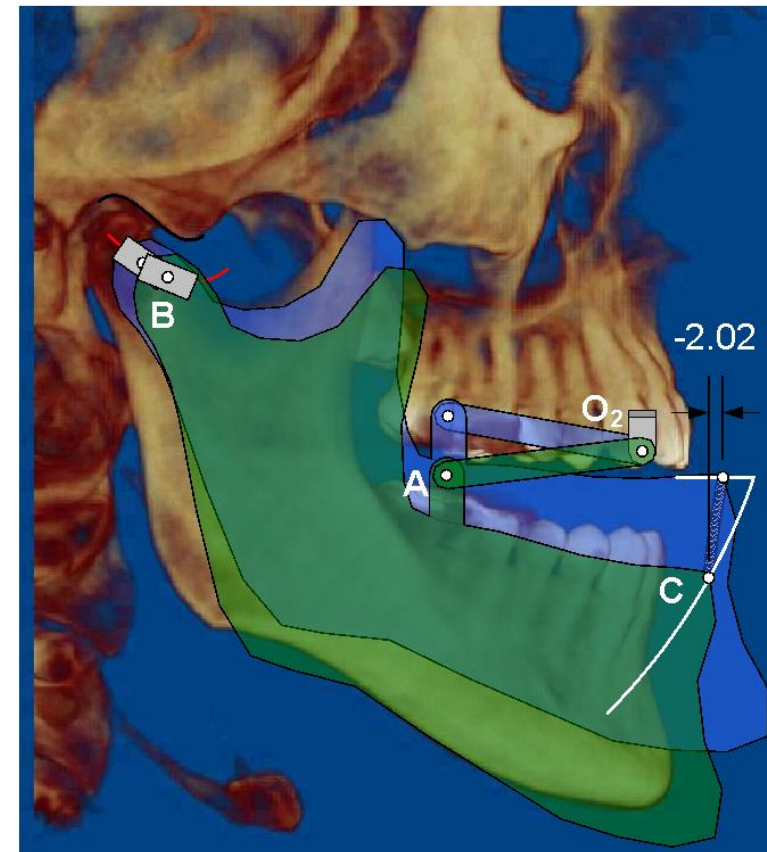
Kinematic behavior of MADs depending on the patient's morphology:

Patient 1



The MAD works properly and moves the incisor forward

Patient 2



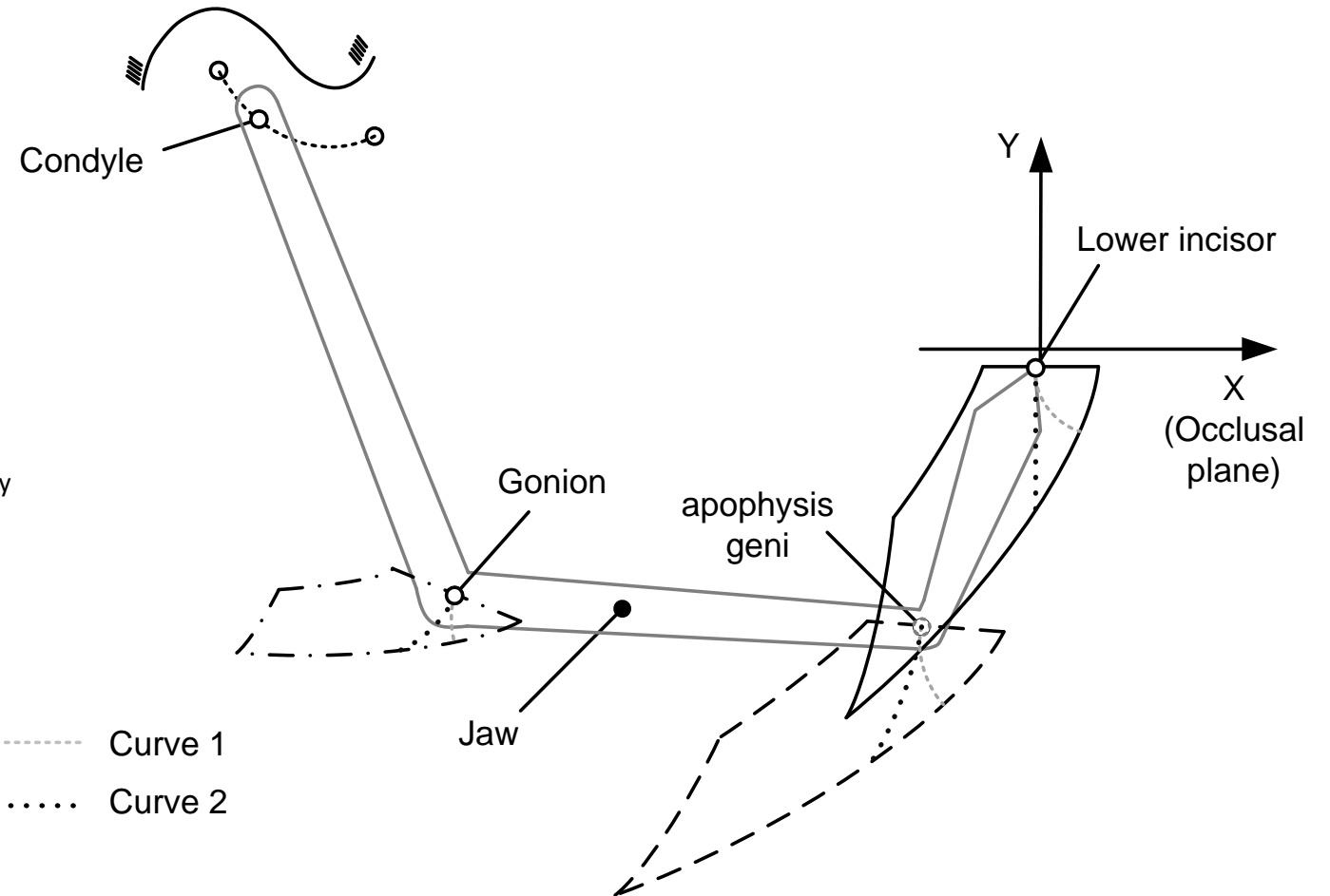
The MAD does not work properly and moves the incisor backwards

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Optimal MAD design with bars

- Trajectory of different points on the mandible that should be considered when designing a MAD.

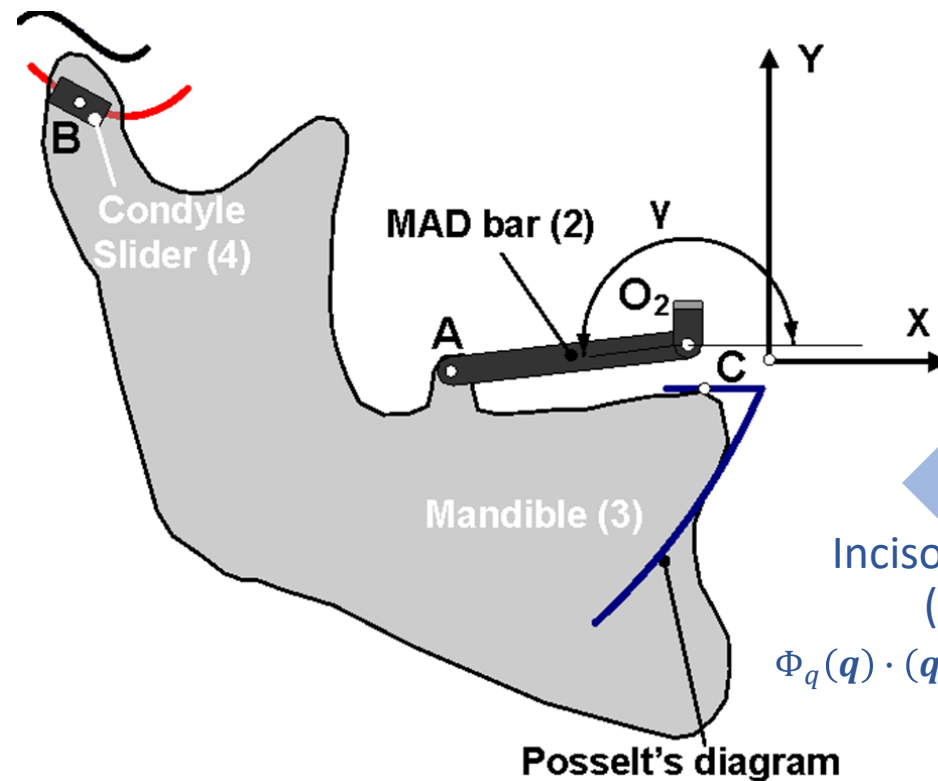
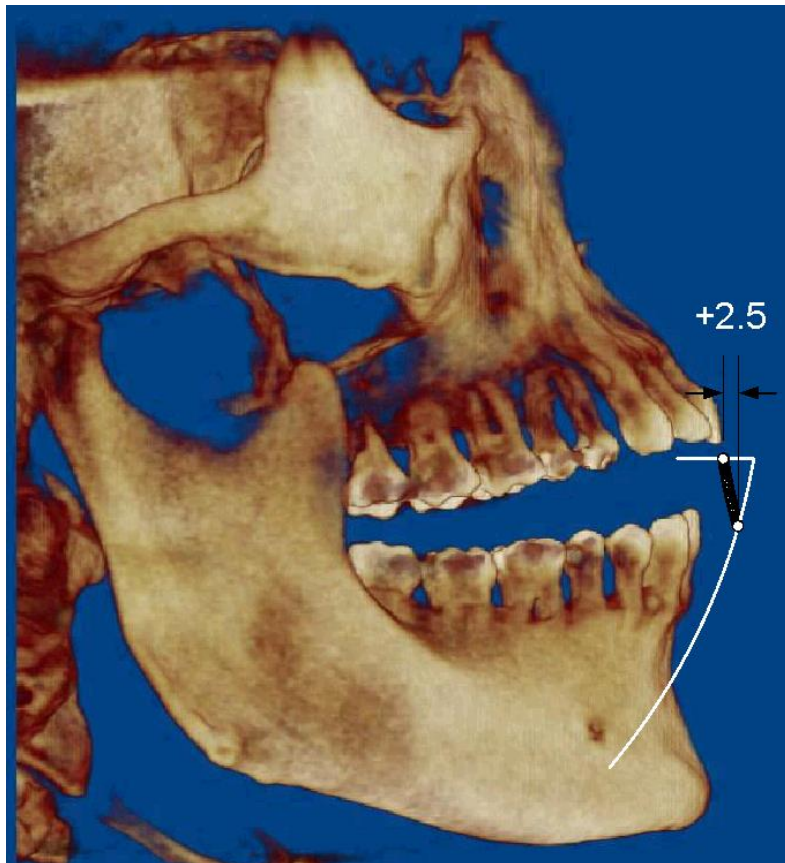


[3] M. Garcia, J.A. Cabrera, A. Bataller et al. Mandibular movement analysis by means of a kinematic model applied to the design of oral appliances for the treatment of obstructive sleep apnea. *Sleep Medicine*, 2020.

Optimal MAD design with bars

- We start with the desired path or advance for the lower incisor .

- We define the design variables for optimal design by means of an evolutionary algorithm [4].



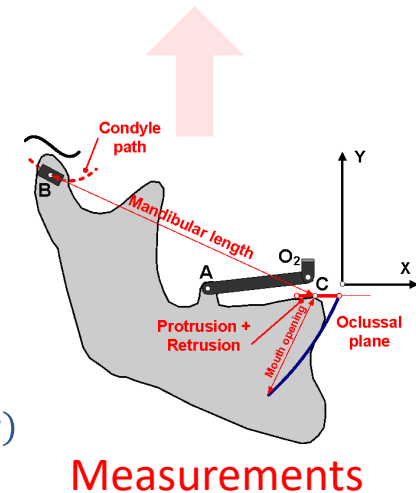
Design variables

$$\chi = \{x_{O_2}, y_{O_2}, L_{O_2A}, \gamma\}$$

$$q = \{x_A, y_A, x_B, y_B, x_C, y_C, \gamma\}$$

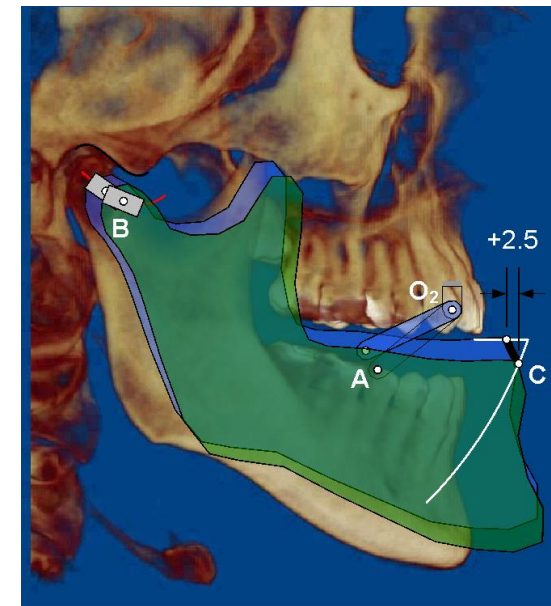
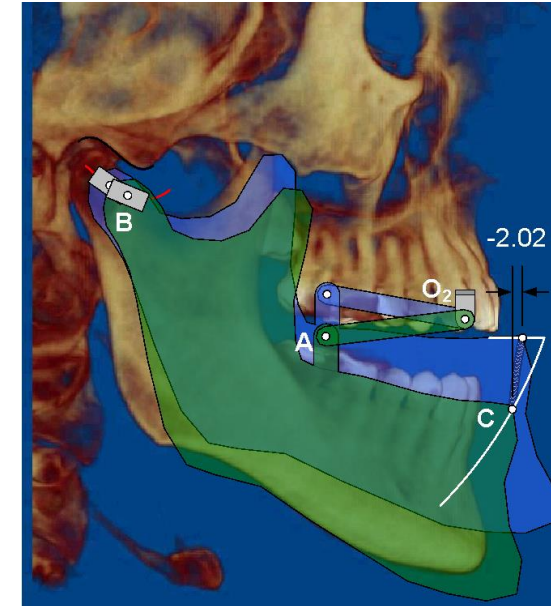
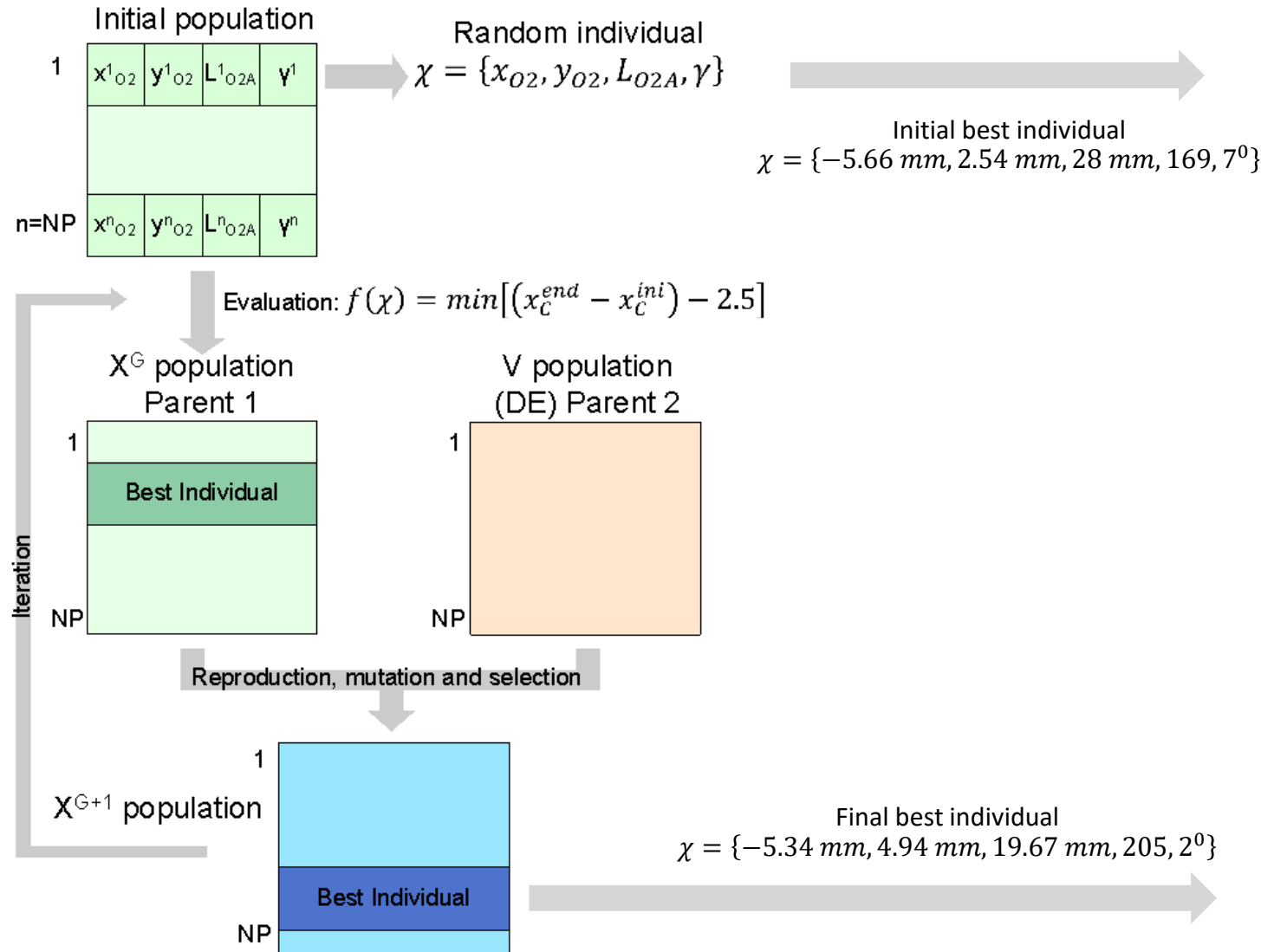
Incisor movement (point C)

$$\Phi_q(q) \cdot (q_{i+1} - q_i) = -\Phi(q)$$



[4] J.A. Cabrera, A. Ortiz, F. Nadal et al. An evolutionary algorithm for path synthesis of mechanism. Mechanism and Machine Theory, 2011.

Optimal MAD design with bars



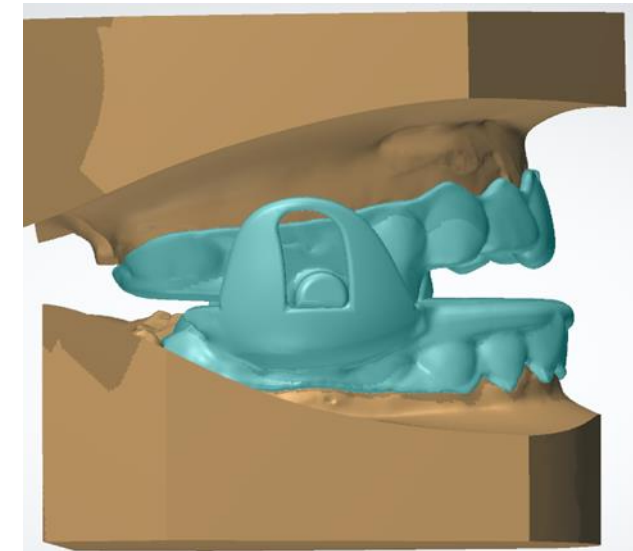
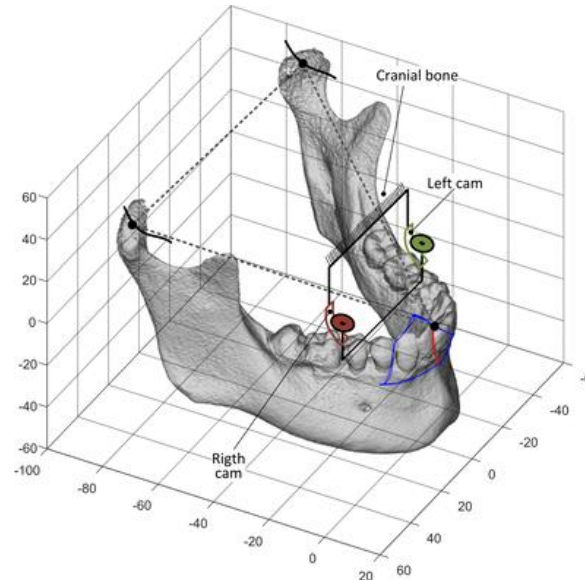
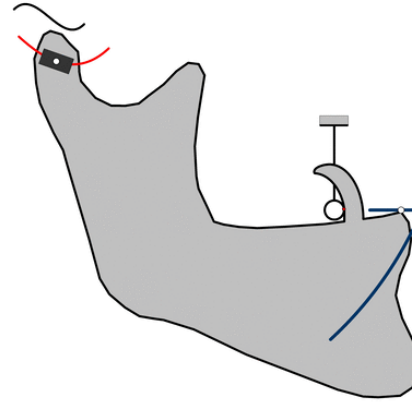
* Source MUMSA algorithm [4]

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Optimal MAD design with cams

[5] M. García, J.A. Cabrera, A. Bataller et al. Intra-oral device for mandibular adjustment. WO2017149523A1 patent, 2017



[6] A. Bataller, J.A. Cabrera, M. García et al. Cam synthesis applied to the design of a customized mandibular advancement device for the treatment of obstructive sleep apnea. *Mechanism and Machine Theory*, 2018.

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Conclusions

- All MADs keep the mandible in a protruded position with mouth closed.
- Patient's mandible retrusion or protrusion when opening the mouth depends on the MAD coupling system and patient's morphology.
- The analyzed MADs have the same design for all patients.
- Mechanism synthesis techniques can help optimize MAD kinematic behavior for each patient.



Thank you for your attention