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In-Ear Energy Harvesting: Source Characterization and Mechanical Simulator (Part I)

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CRITIAS NSERC-EERS INDUSTRIAL RESEARCH CHAIR IN IN-EAR TECHNOLOGY
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SYMME
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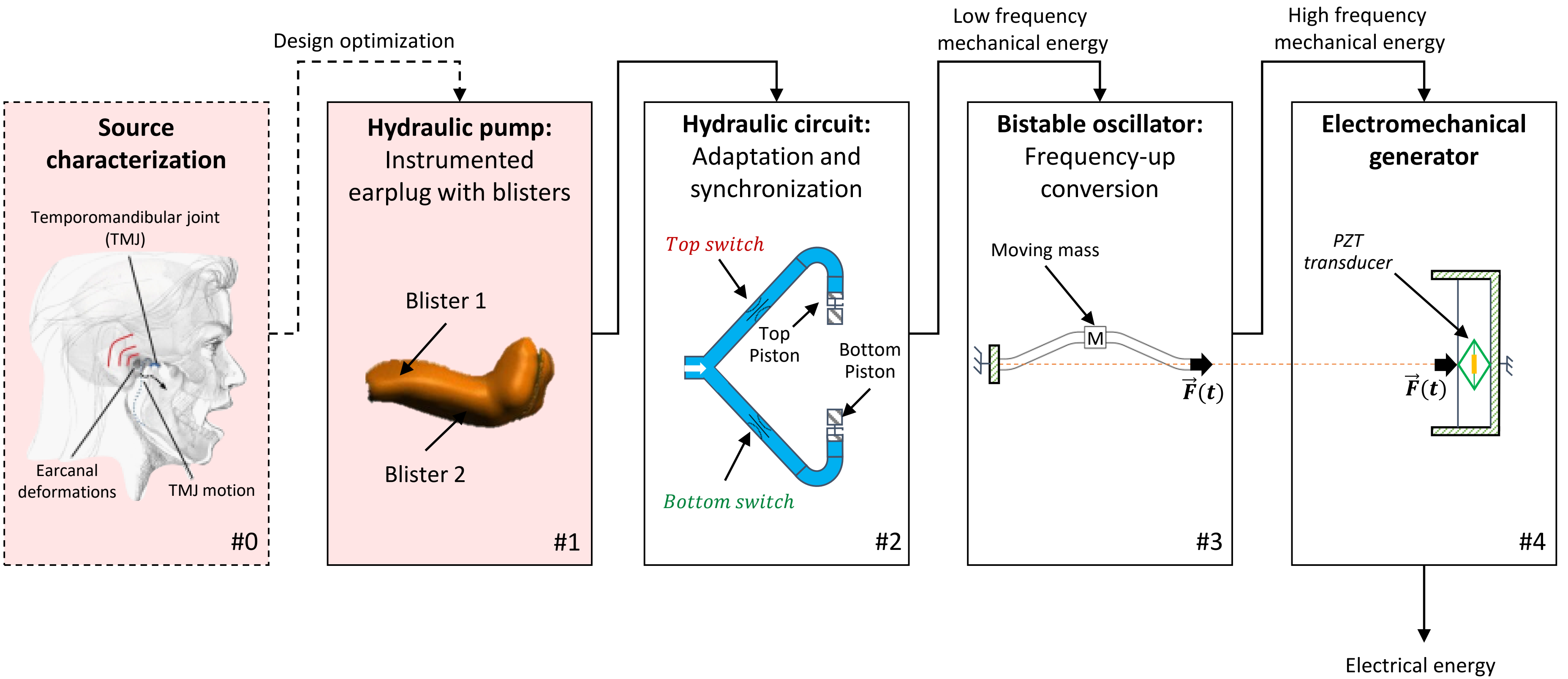
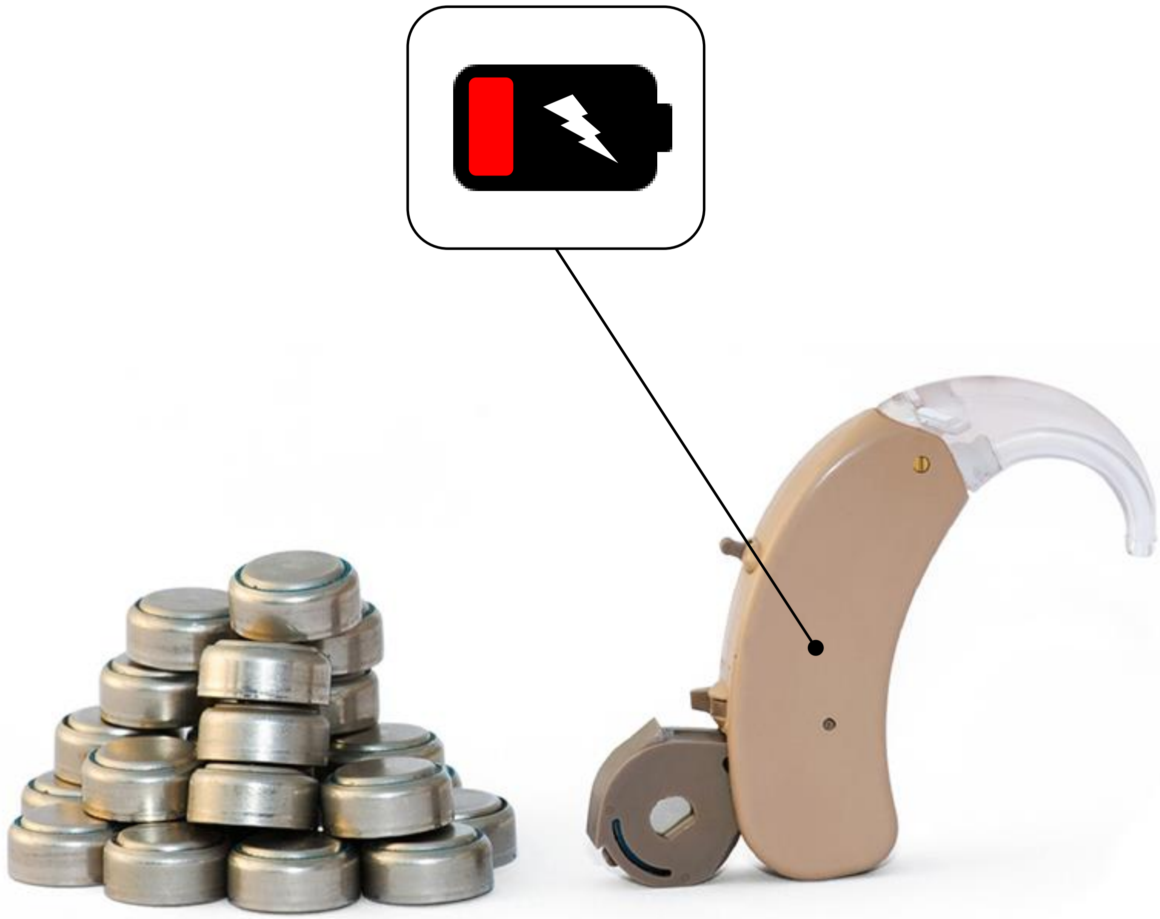
Graphical abstract



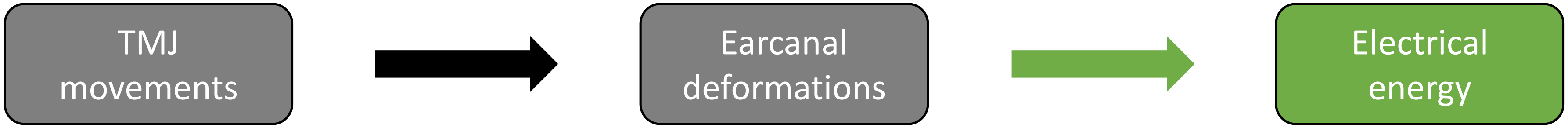
Abstract

During the jaw's daily activities, the human earcanal is deformed by its anatomic neighbor called the Temporomandibular Joint (TMJ). Given the frequency of those activities, the earcanal dynamic movement is a promising source of energy within the ear, which can be harvest by using a mechanical-electrical transducer. Yet, the optimal design of such micromachine requires to characterize the TMJ's range of motion, its mechanical action on the earcanal and its capability. For that purpose, this research presents two methods to analyse the earcanal dynamic movements: 1) an in-situ approach based on measuring the pressure variation in a water-filled earplug fitted inside the earcanal; and 2) an anatomic-driven mechanism as a chewing test fixture with micrometric precision in reproducing the TMJ kinematics. The pressure earplug system provides the earcanal global dynamics which can be derived as an equivalent displaced volume; while the chewing test fixture gives the discrete displacement along the earcanal wall.Both approaches contribute to a better analysis of the interaction between TMJ and earcanal. Ultimately, the knowledge of the maximum displacement area and the derived generated power within the earcanal will lead to the design of a micromachine allowing to further investigate in-ear energy harvesting.

Keywords: Energy harvesting; earcanal dynamic motion; TMJ



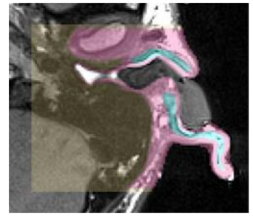
Introduction



Introduction

In situ
(Willigen, 1976, Carioli et al., 2018)

MR imaging
(Oliveira et al., 1992)



Earmolds
(Willigen, 1976; Oliveira et al., 1992; Pirzanski, 1996; Grenness et al., 2002; Delnavaz et Voix, 2013)

TMJ movements → Earcanal deformations → Electrical energy

Introduction

In situ

(Willigen, 1976, Carioli et al., 2018)

MR imaging

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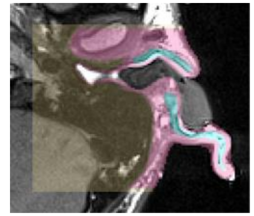


Earmolds

(Willigen, 1976; Oliveira et al., 1992; Pirzanski, 1996; Grenness et al., 2002; Delnavaz et Voix, 2013)

TMJ movements → Earcanal deformations → Electrical energy

Mechanical energy capability

Earmolds	5.0 mW	Delnavaz et Voix (2014)
Bending modeling	15.0 mW	Carioli et al. (2016)
Radial compression modeling	3.9 mW	

Hydro-electromagnetic	0.3 μW	Delnavaz et Voix (2014)
Piezo-Ring	0.2 μW	
Piezo-earpiece	70.0 μW	Delnavaz et Voix (2013)
Earcanal bending sensor	0.5 pW	Carioli et al. (2018)

Introduction

Mechanical energy capability

Study #1: Global approach

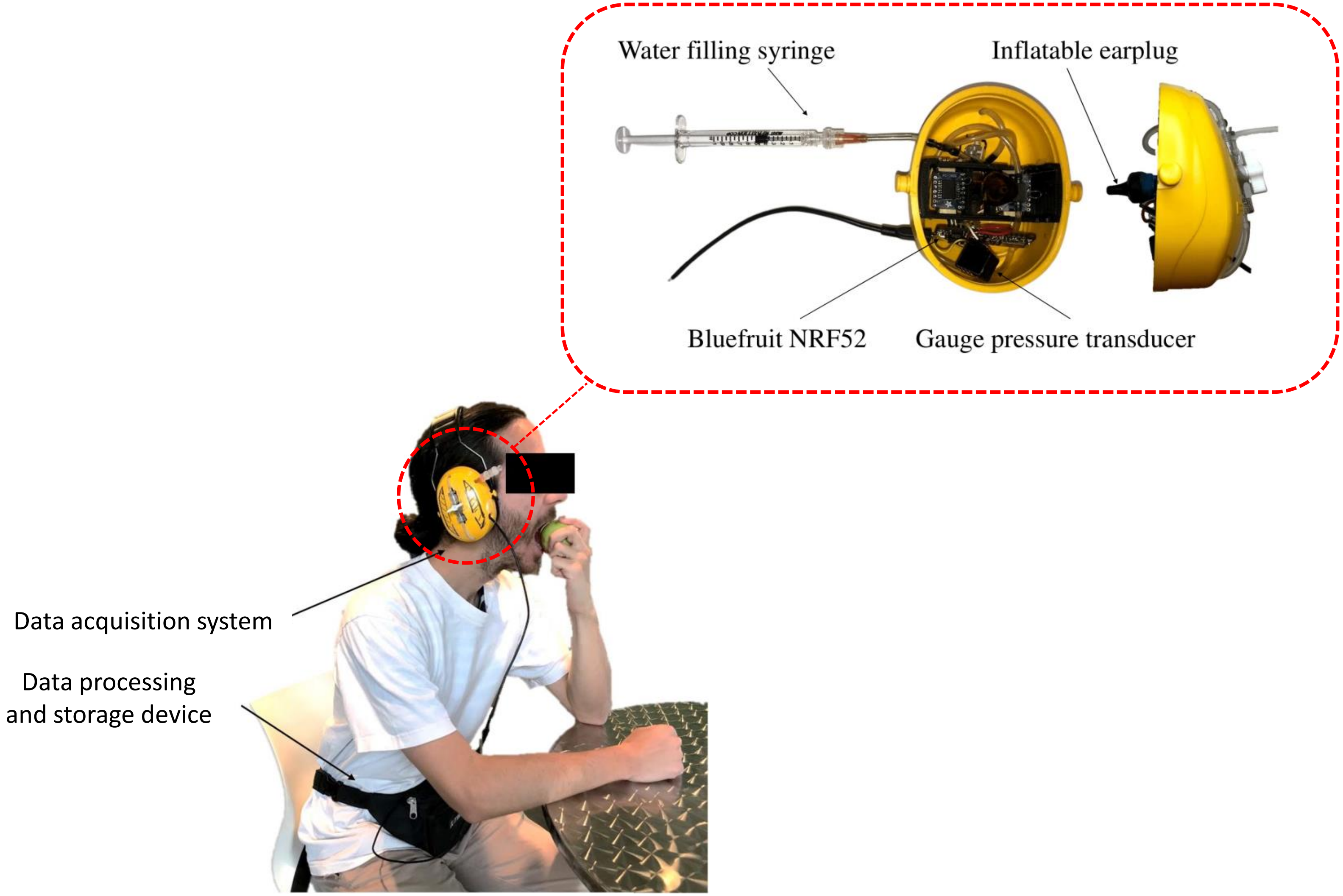
1. To improve previous results
2. To evaluate inter-subject variability
3. To test the feasibility of an all-in-one portable sensor

Earcanal deformations

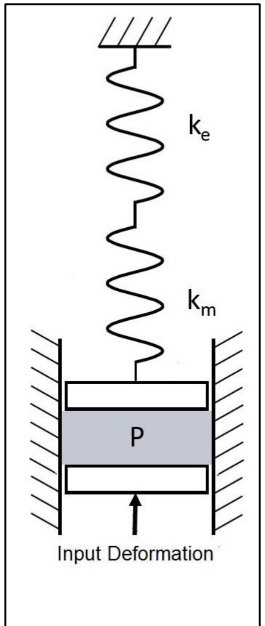
Study #2: Local approach

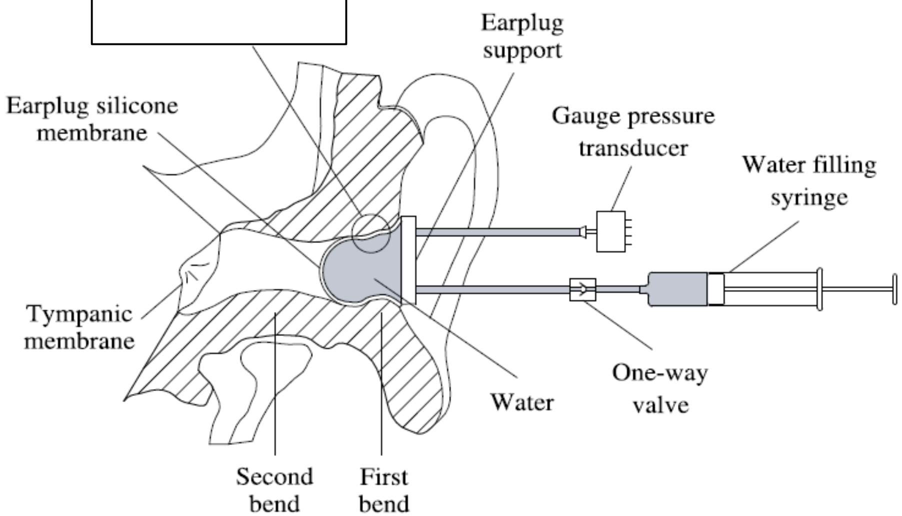
1. To locate the maximal deformation areas
2. To characterize the deformation mode involved
3. To determine if they are antagonist displacements

Global approach: Portable water-filled earplug
Experimental set up



Global approach: Portable water-filled earplug
Energy modeling





fluid　　membrane

$$E_T = E_{int} + E_{ext}$$

=PV　　=½kΔU²

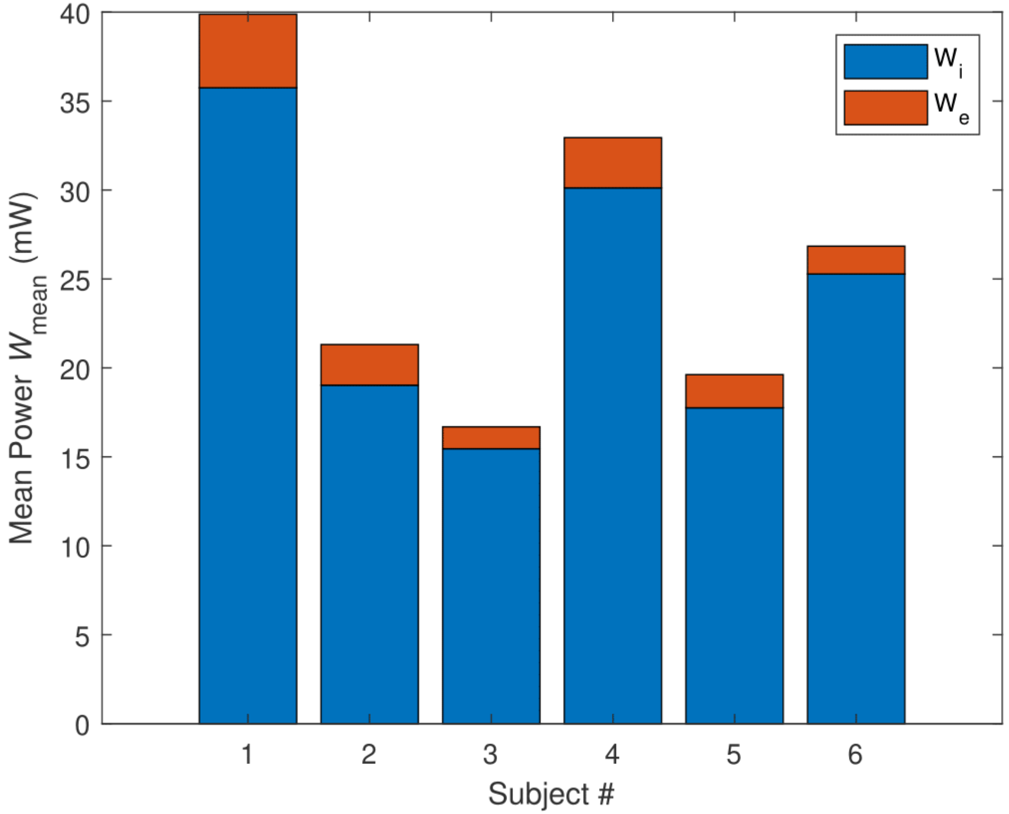
$$dE = VdP + kUdU$$

Determined experimentaly

$$W = \frac{dE}{dt}$$

Global approach: Portable water-filled earplug
Experiment & Results

- **Participants:** 6
- **Process:**
  1. Earplug filled until P=14 kPa
  2. Closing the one-way valve
  3. Recording during lunch time
- **Results:**
  - $W_{\text{average}} = 26.2\ \text{mW} \pm 1.9$
  - $r = \frac{E_{\text{int}}}{E_{\text{T}}} = 91\% \pm 1.7$



Global approach: Portable water-filled earplug
Limitations

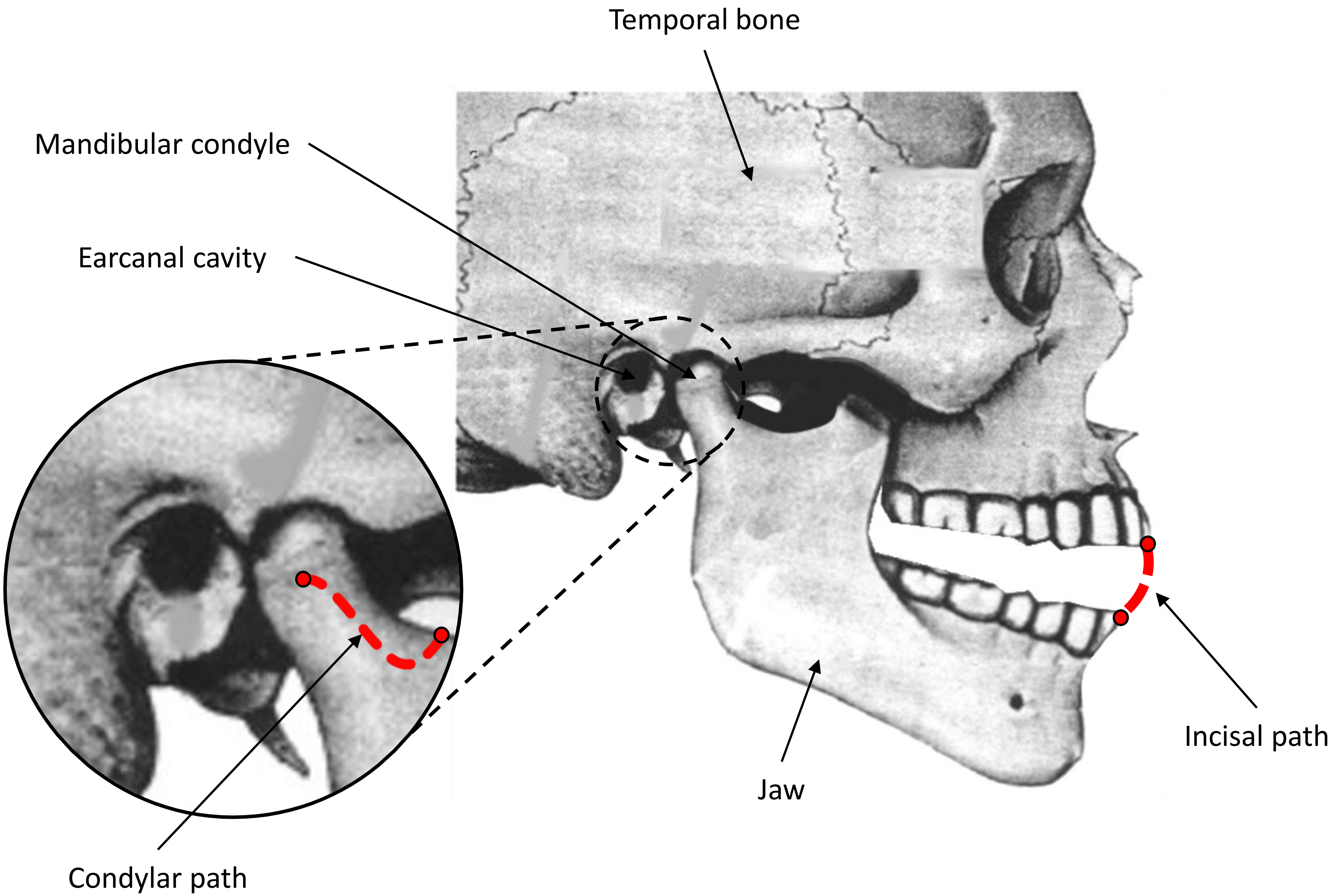
- Portable design AND adapted to every human ear anatomy

→ BUT can be **uncomfortable** due to occlusion effect

- Measure performed where maximal of the earcanal deformations occur (between 1st and 2^{nd} bend)

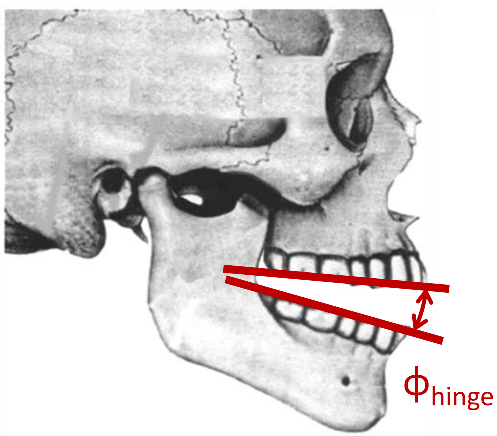
→ BUT only the **resulting dynamic motion** between open- and closed-mouth position is available

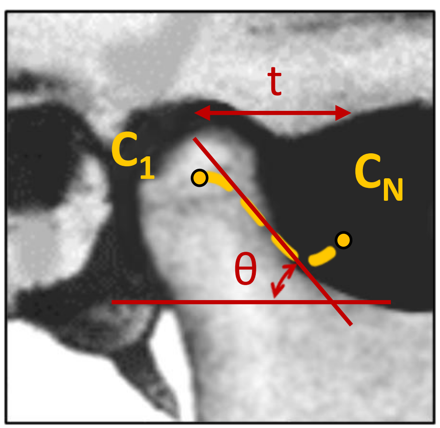
Local approach: Chewing test fixture
TMJ kinematics



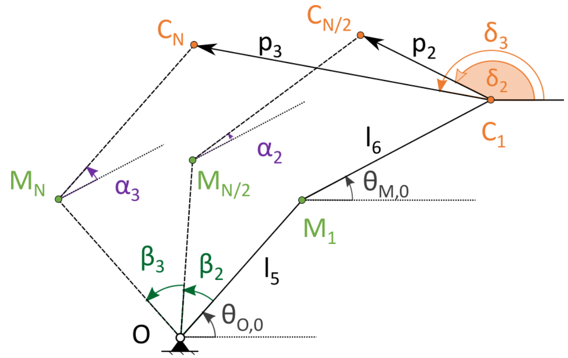
Local approach: Chewing test fixture
TMJ kinematics modeling

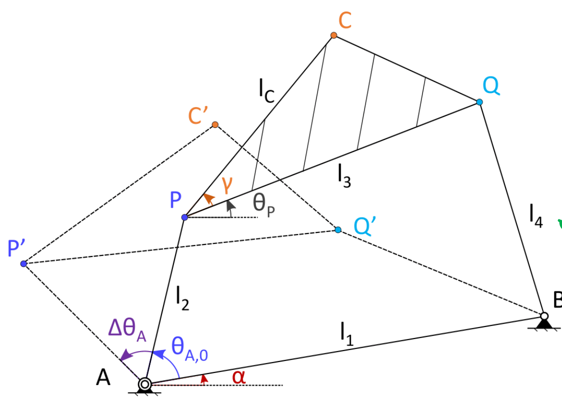
Biomechanical parameter identification



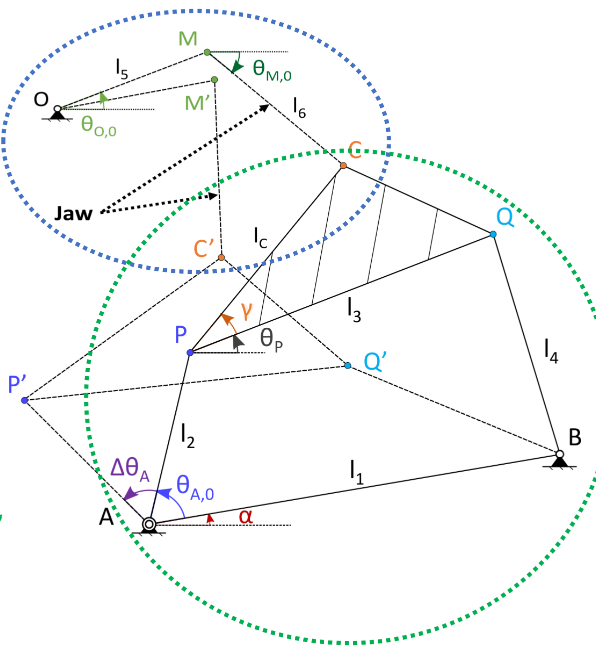


Bar-linkage sub-mechanism modeling



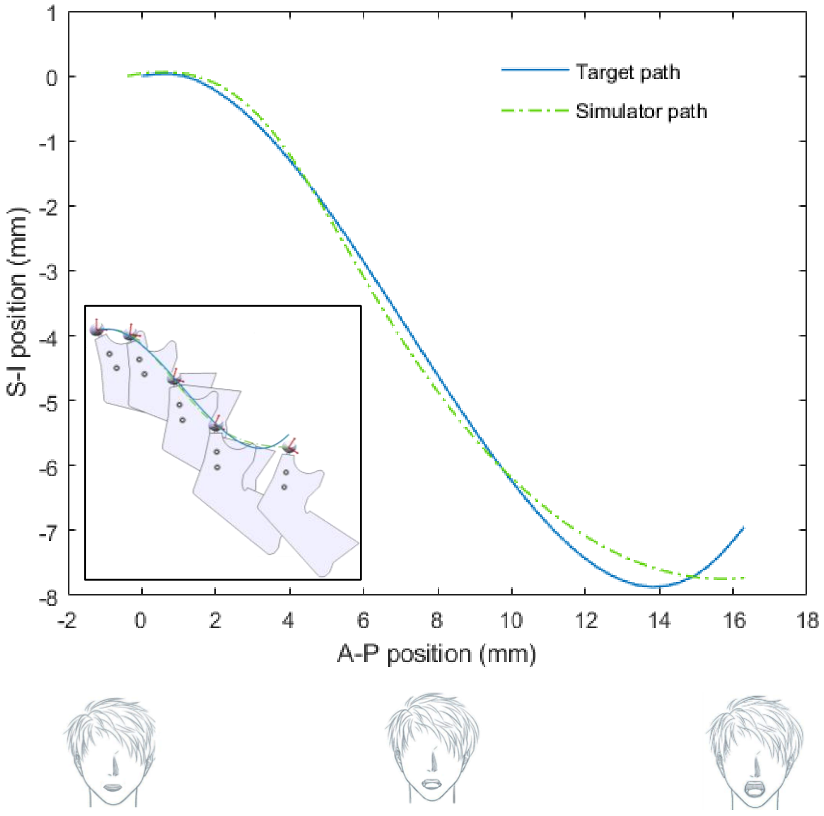


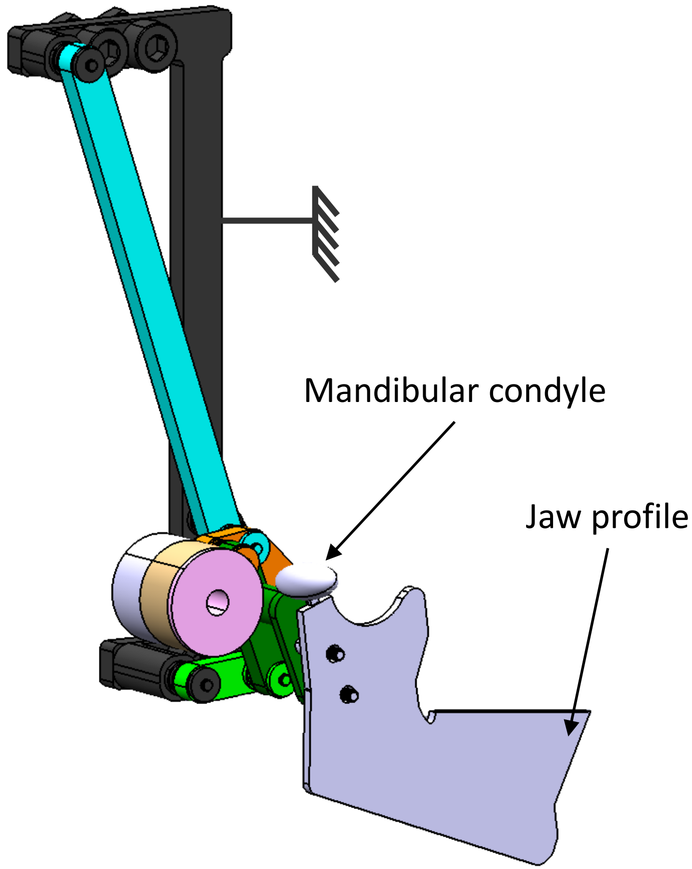
TMJ simulator modeling



Local approach: Chewing test fixture

TMJ simulator design

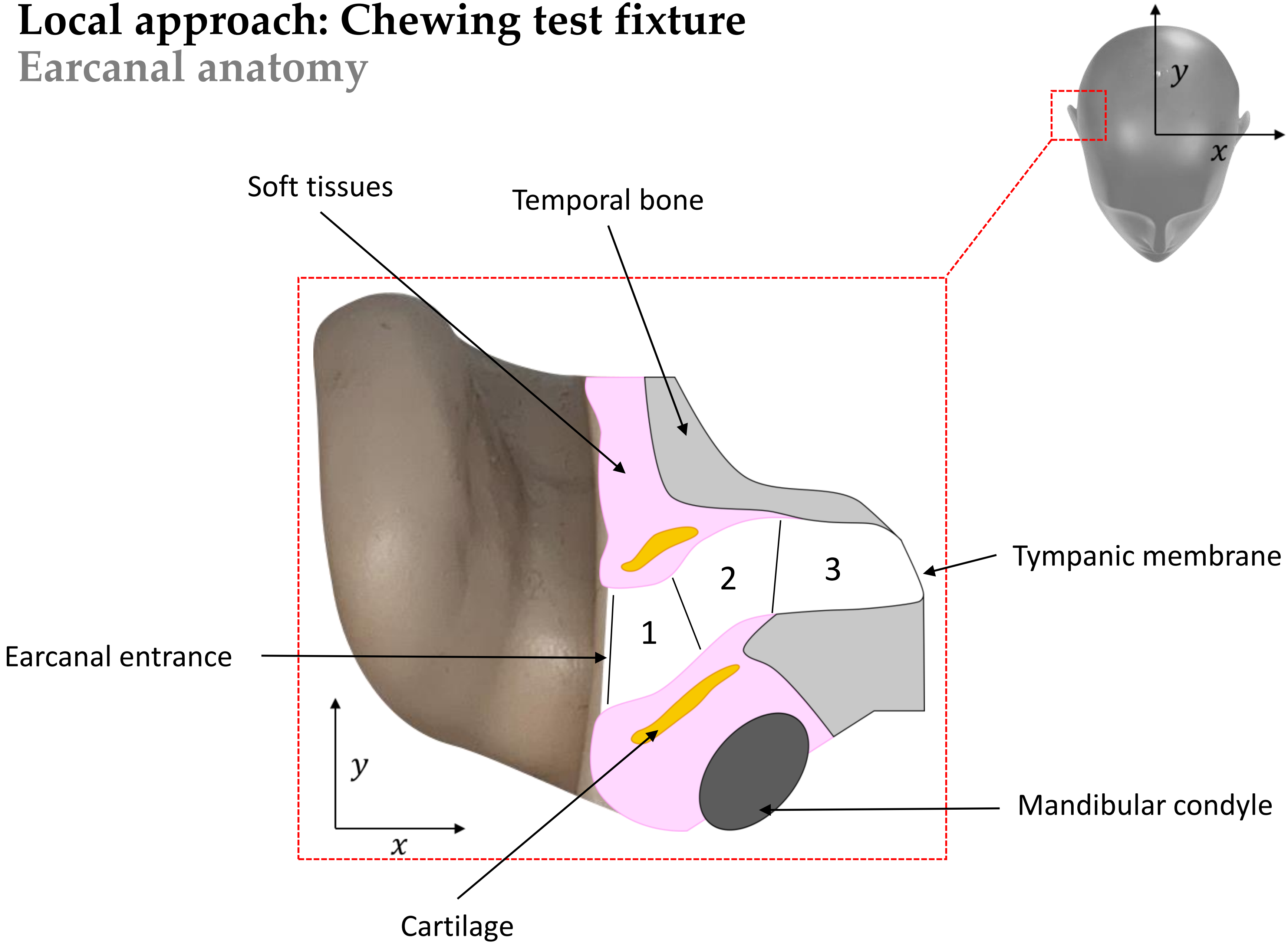




Target VS optimal generated path

Root mean square error	Horizontal translation	Slope	Opening angle	Roto-translation correlation
1.65%	1.9%	3.2%	0%	2.5%

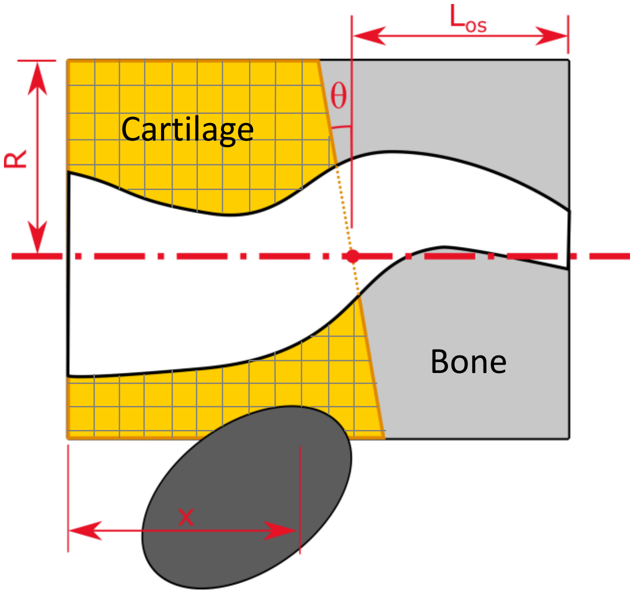
Local approach: Chewing test fixture
Earcanal anatomy

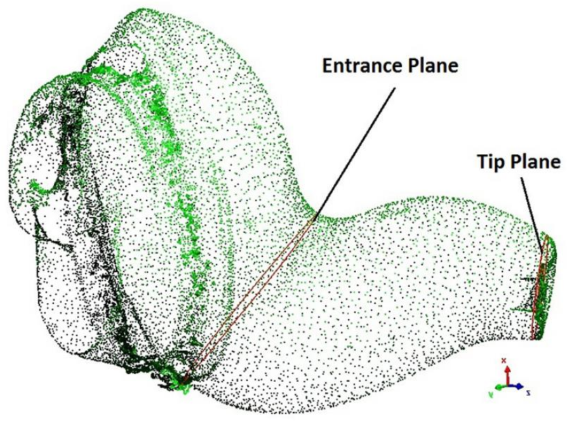


Local approach: Chewing test fixture
Earcanal modeling & anatomical coupling

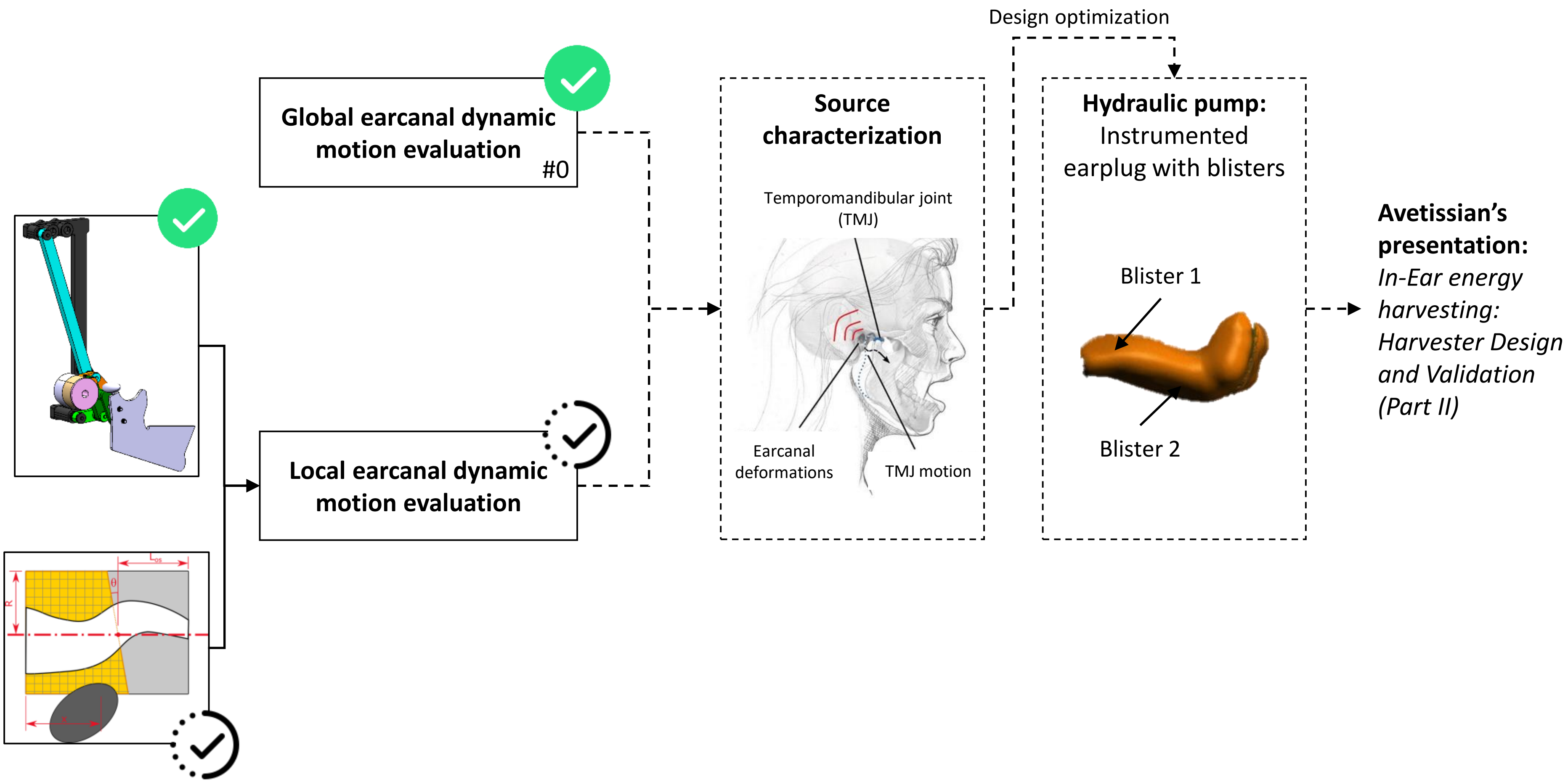
- **3D finite element (FE) analysis** to find the optimal biomechanic setting:
    1. The surrounding tissues geometry reproducing the mechanical behavior of the earcanal cavity
    2. The anatomical coupling between earcanal and TMJ

- **Trial-and-error method** to compare FE earcanal cavity with earmold scatter plots in both open- and closed-mouth positions





Conclusion & Expected outcomes



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