A 3D Biomimetic Artificial Mouth: Enabling the Predictive Design of Safer Foods

From ingestion to bolus formation and safe swallowing.

Pour le Prix Marcel LONCIN 2025

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Why?

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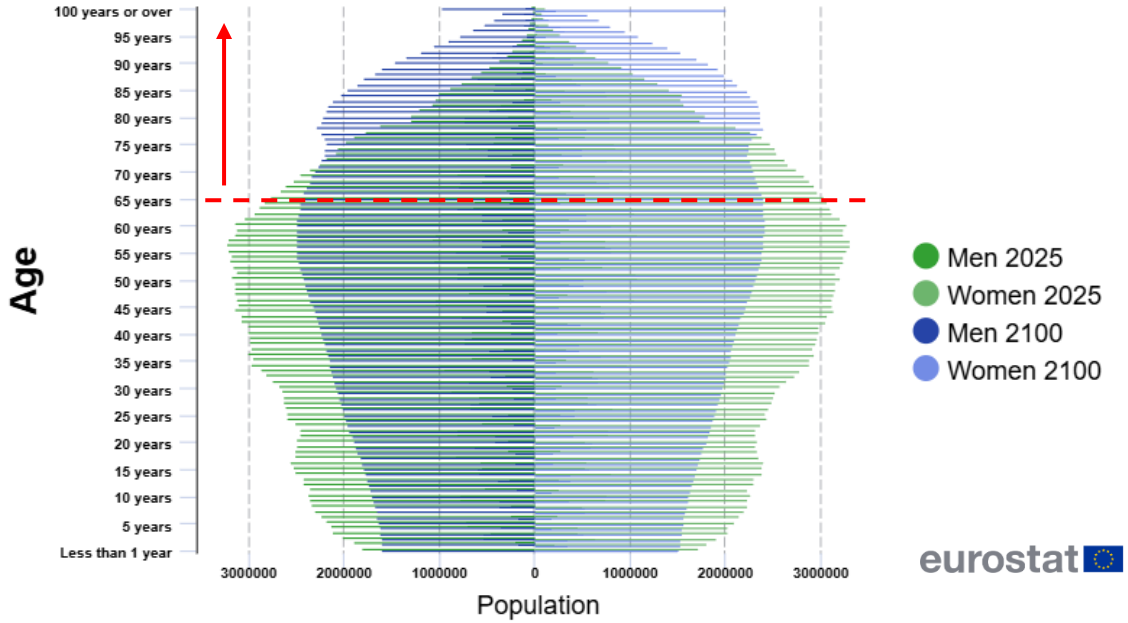
Food texture is not only preference – It is safety

9.7 billion people [1]

1 in 6 over 65 y.o. [2]

[1] United Nations, 2019. World Population Prospects 2019
[2] United Nations, 2019. World Population Ageing 2019

A major demographic transition



This is a food engineering challenge because ageing affects oral functionality.

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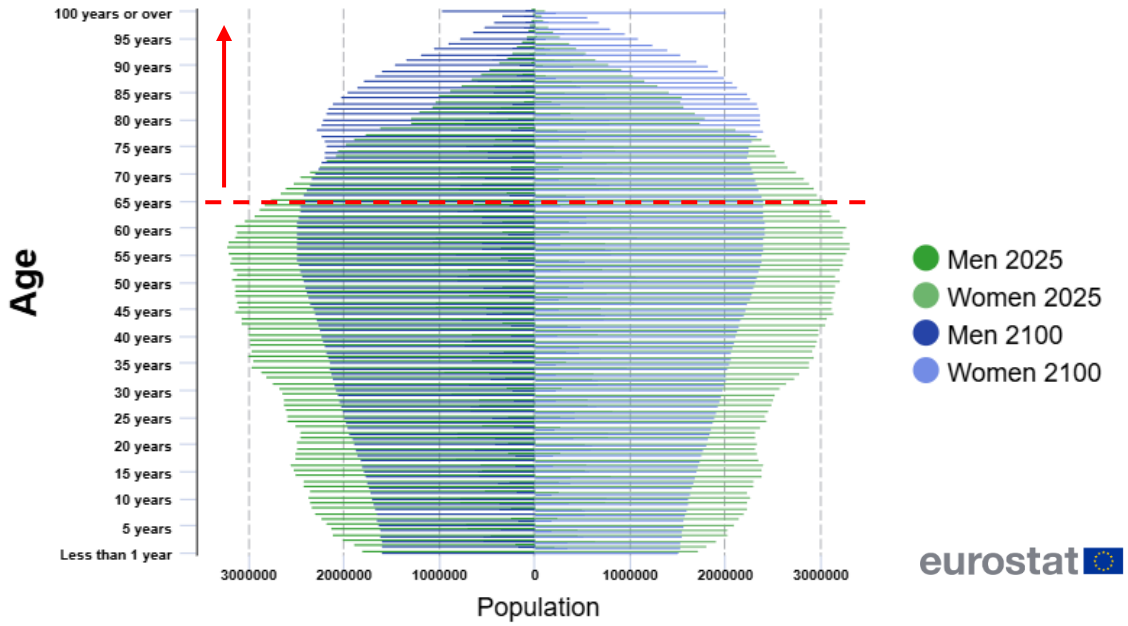
Food texture is not only preference – It is safety

- Reduced Saliva Production
- Progressive Loss of Muscle Mass
- Tooth Loss
- Swallowing Difficulties

For millions of older adults, eating presents acute risks of choking, aspiration, and malnutrition if food texture is misaligned with oral capabilities.

A major demographic transition



Designing safer foods requires understanding how humans physically transform food inside the mouth.

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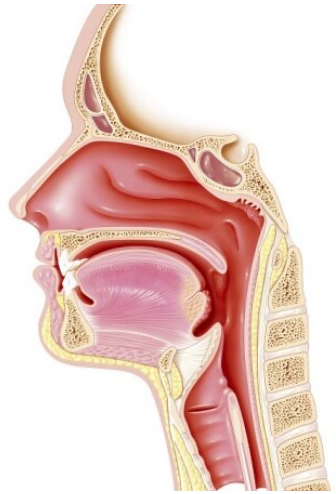
The blind spot

Standard test cannot replicate human oral biomechanics

Food formulation & processing

Rheology &
Texture testing



Human clinical trials:
Sensory / Acceptance / Swallowing

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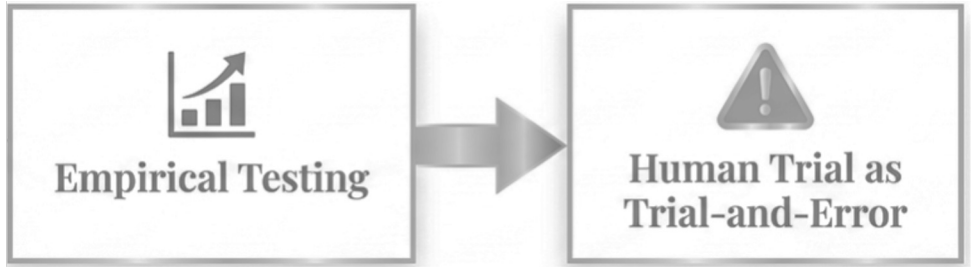
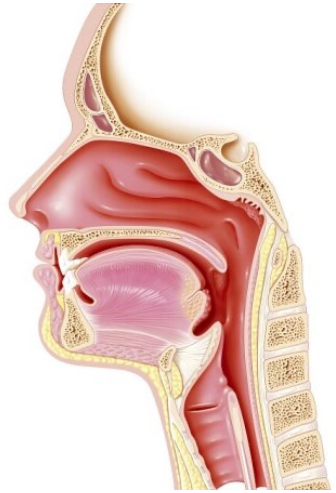
The blind spot

Standard test cannot replicate human oral biomechanics



Human testing is used to discover what we cannot predict, exposing vulnerable populations to unsuitable food prototypes



Human clinical trials:

Sensory / Acceptance / Swallowing

Can we move from empirical testing toward predictive food engineering?

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The blind spot

Standard test cannot replicate human oral biomechanics

Two first-of-their-kind 3D biomimetic in vitro systems.

The complete transformation of food from ingestion to swallowing.

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The biomechanics of food recognition

Hard foods

Soft/viscous foods

Teeth driven

Tongue driven

MSCA

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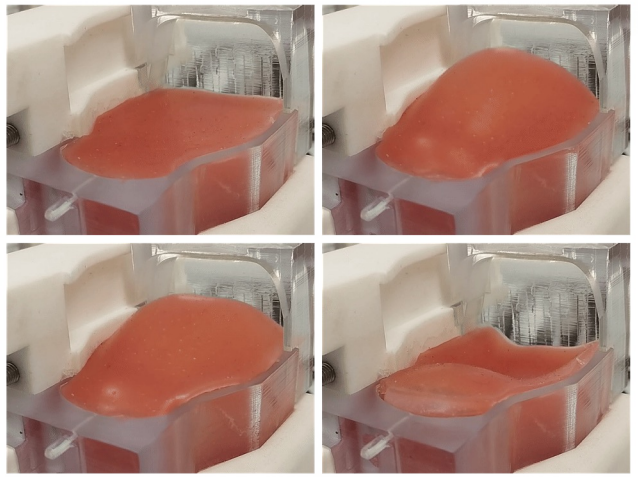
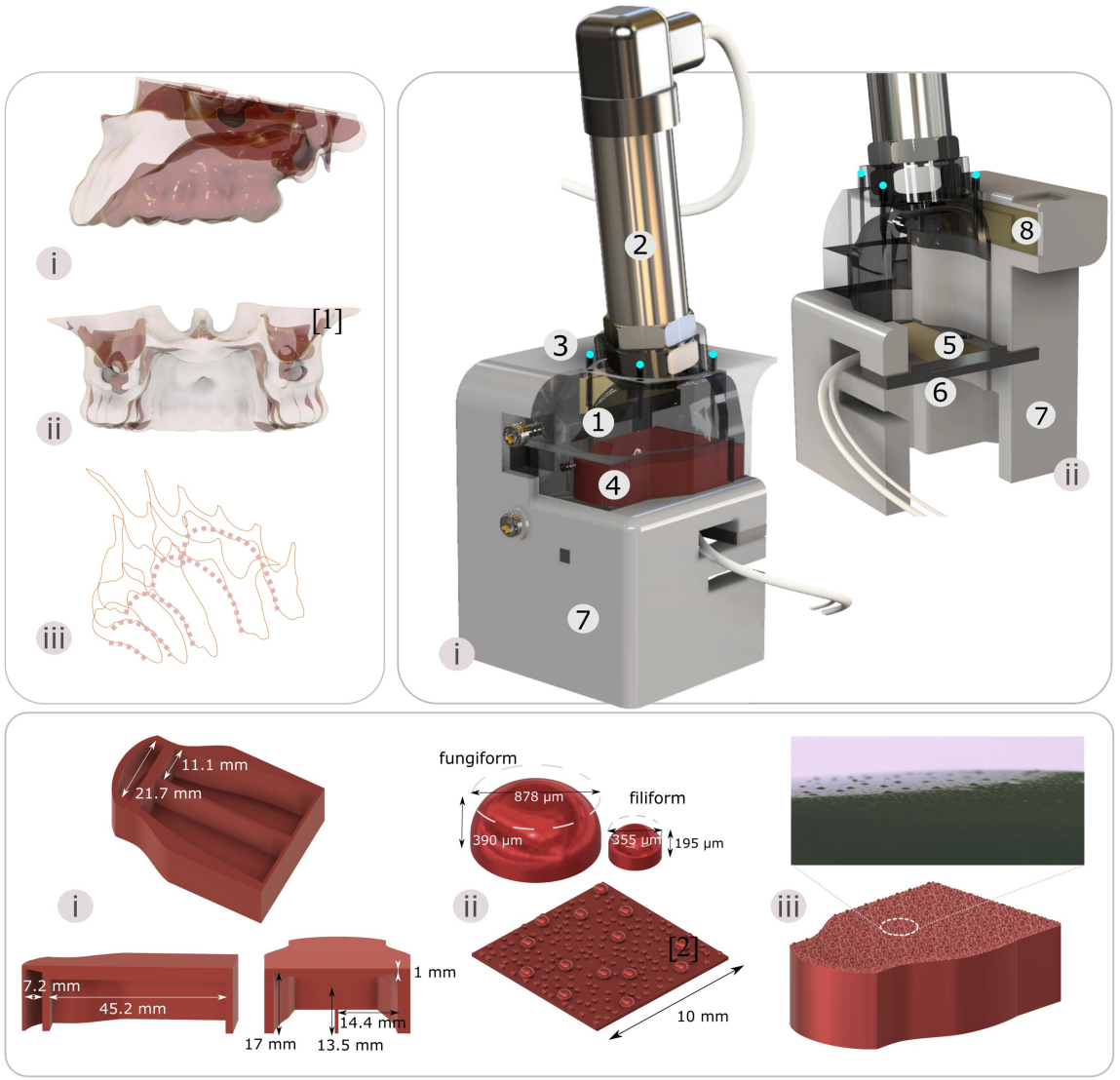
A 3D Biomimetic Artificial Mouth



Marie Skłodowska-Curie Actions Research Fellowship Programme

SENSINGTech ID 101066647

The in vitro system



Avila-Sierra et al., 2024. *Scientific Reports*

[1] Kobayashi et al., (2019).
[2] Andablo-Reyes, (2020).

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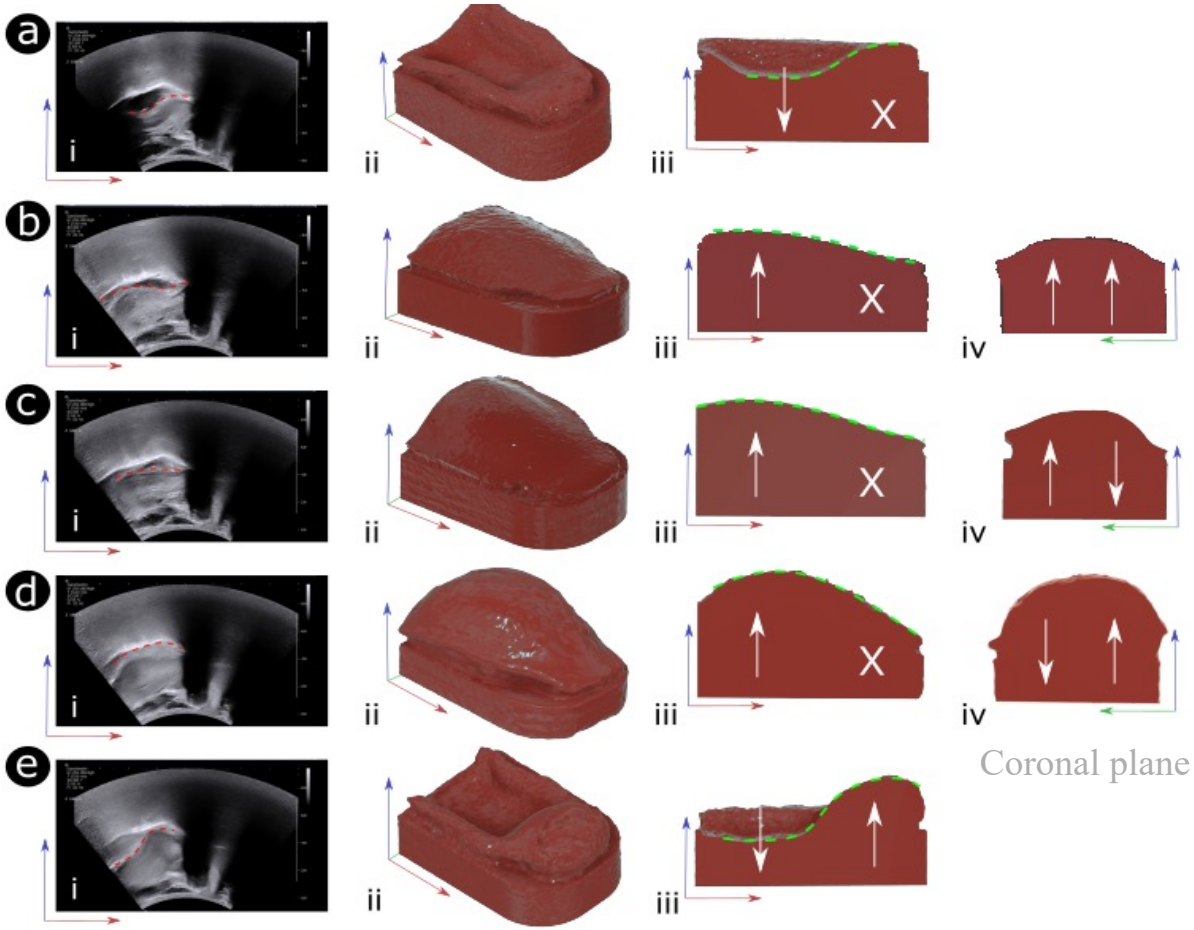
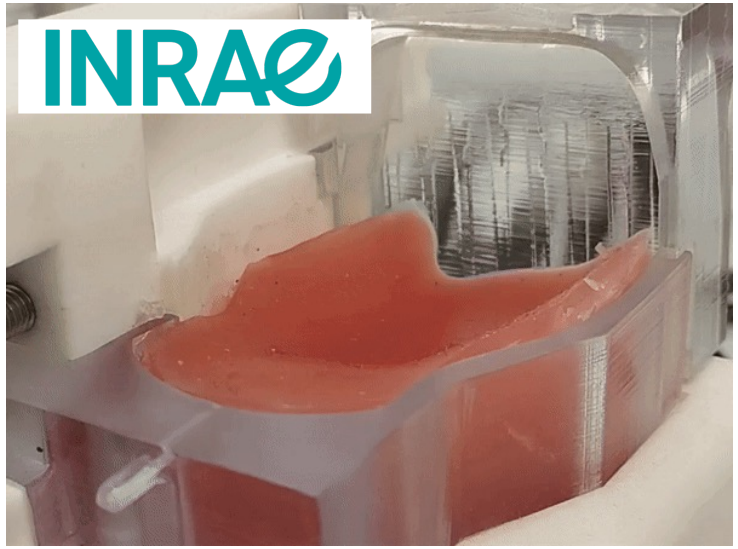
Representative tongue motions





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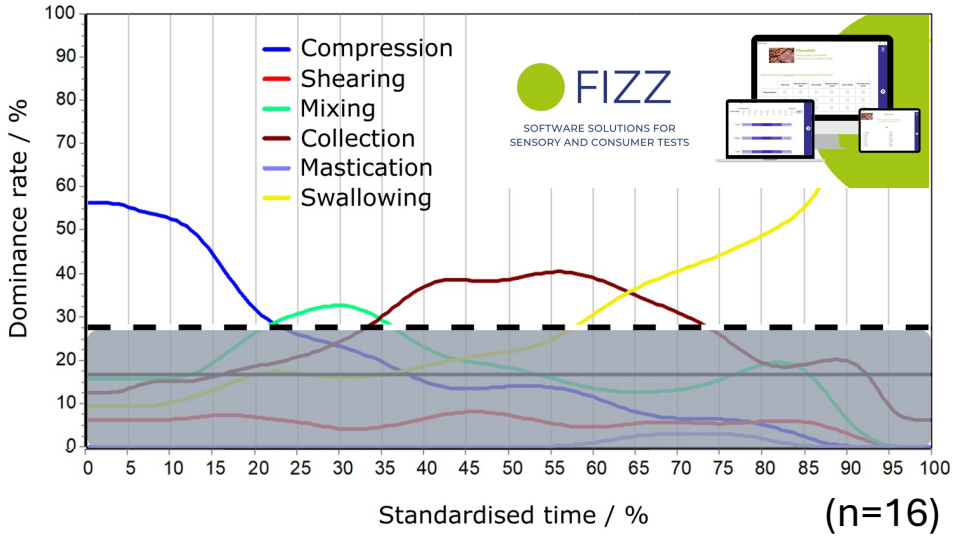
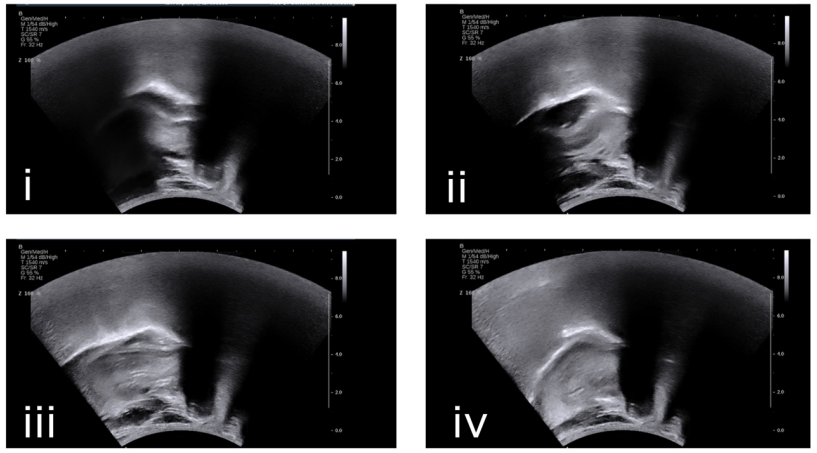
In vivo study: healthy panellists

Temporal Dominance of Motions (TDM) [3]



(n=16)

US imaging technique



Sagittal plane

(n=10)

[3] Saint-Eve et al., 2018. 5th international conference on Food Oral Processing, Nottingham, UK.

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Representative in vitro sequence

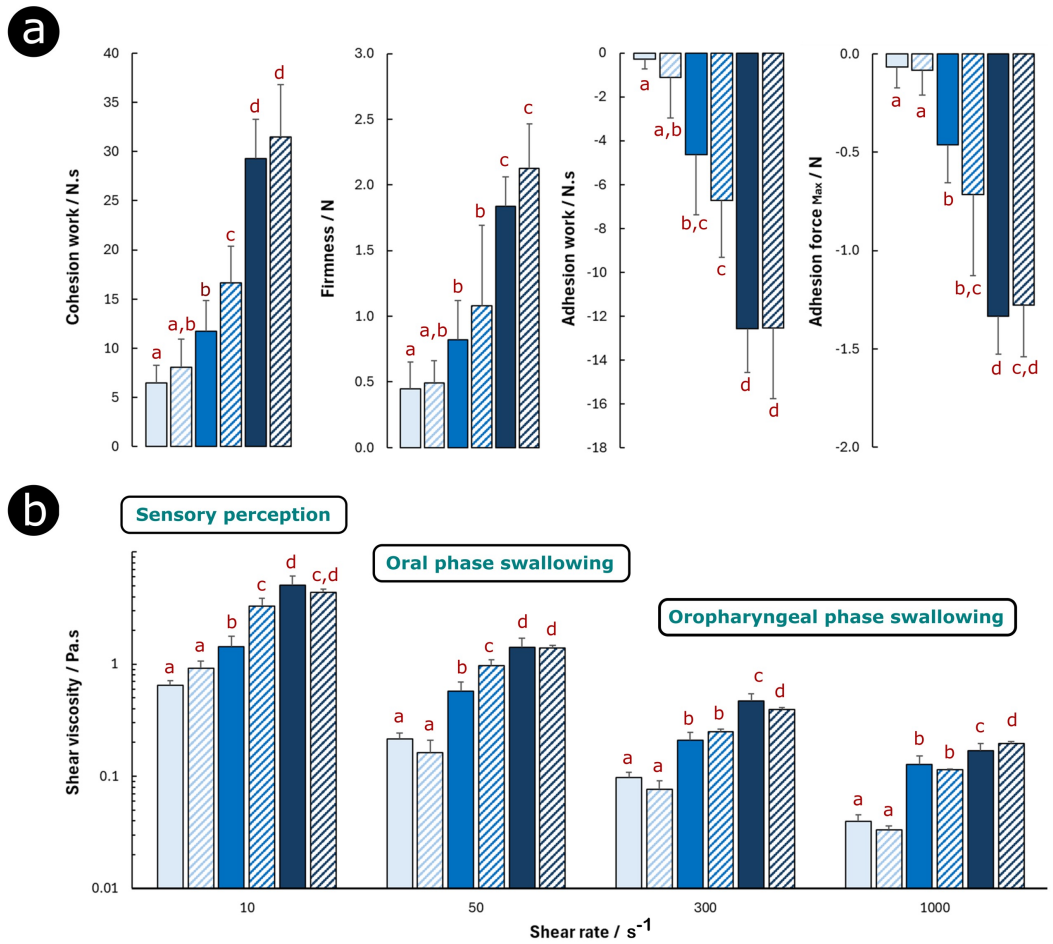
Sagittal plane

Assessment of in vitro food oral procesing

Viscous Liquid (VL)

Aerated Soft Solid (ASS)

Soft Solid (SS)



The system is not only mechanically realistic, it also is physiologically relevant.

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The biomechanics of food recognition

Hard foods

Soft/viscous foods

Teeth driven

Tongue driven

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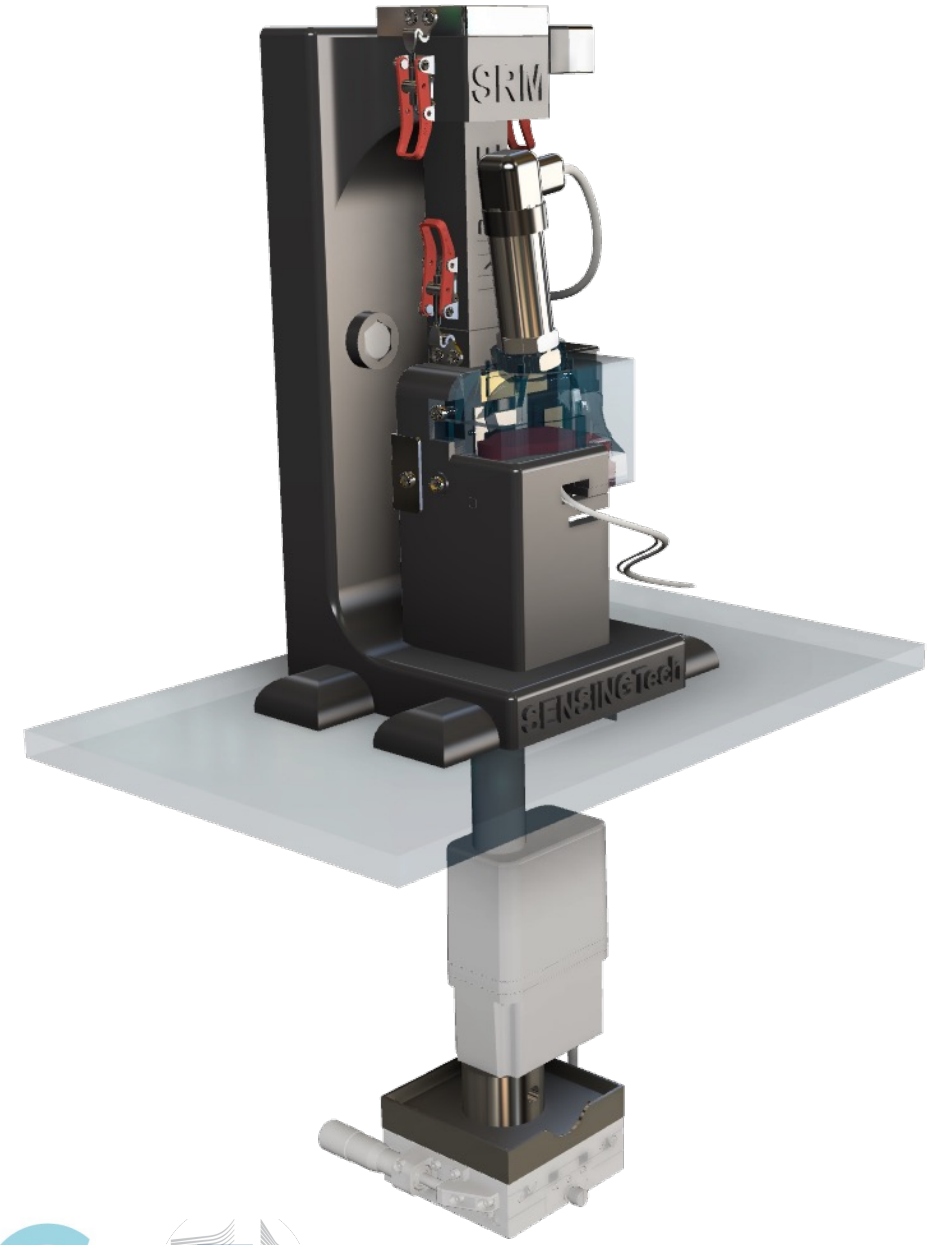

A 3D Biomimetic Hybrid Soft/Rigid Robotic Masticator

MSCA

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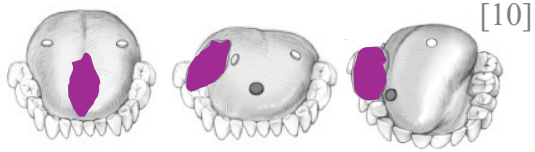
Food Intra-Oral Transformation (FIOT)

St1Tr

The ingested food is placed on the occlusal plane of the post-canine area using pushing, tilting, and twisting moves [7,8].



[10]

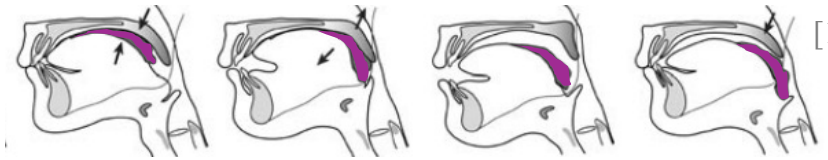
Oral processing

OP begins as the teeth close. Each power stroke fragments the food, whilst subsequent reposition cycles of rhythmic tongue and cheek-pushing ensure the food remains on the occlusal surface [8].

[11]

St2Tr

The tongue aggregates ready-to-swallow food and squeezes it back into the oropharynx, repeating this process multiple times until all the ingested food is ready for swallowing [9].



[11]

The complete oral transformation sequence

[7] Mikushi et al., 2014.
[8] Mioche et al., 2002.
[9] Okada et al., 2007.
[10] Iida et al., 2023.
[11] Matsuo et al., 2005.

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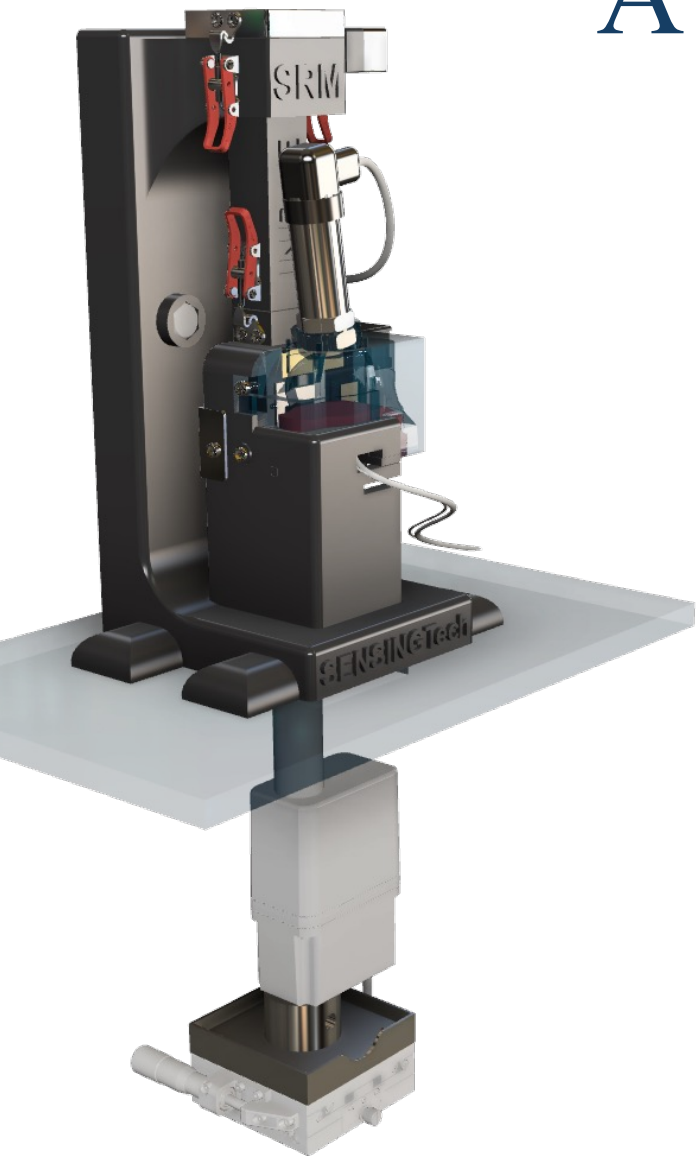
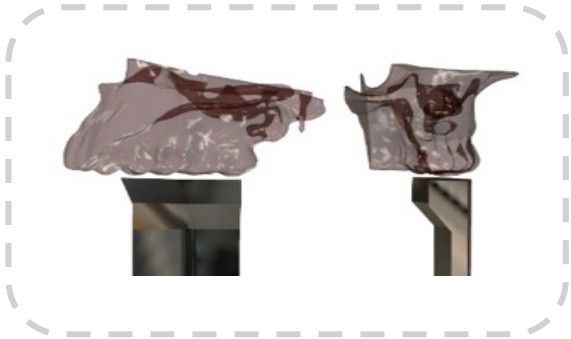
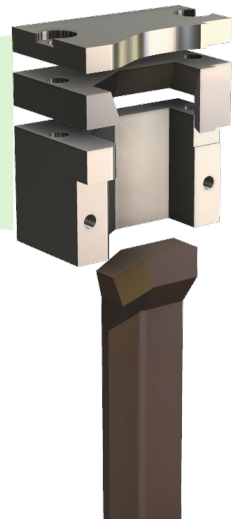
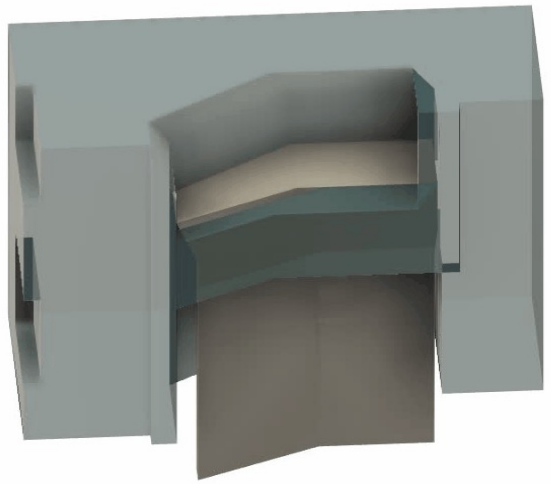
A Unique Robotic Masticator

Masticatory Side (Unilateral)









Avila-Sierra et al., 2025. *Food Research International*

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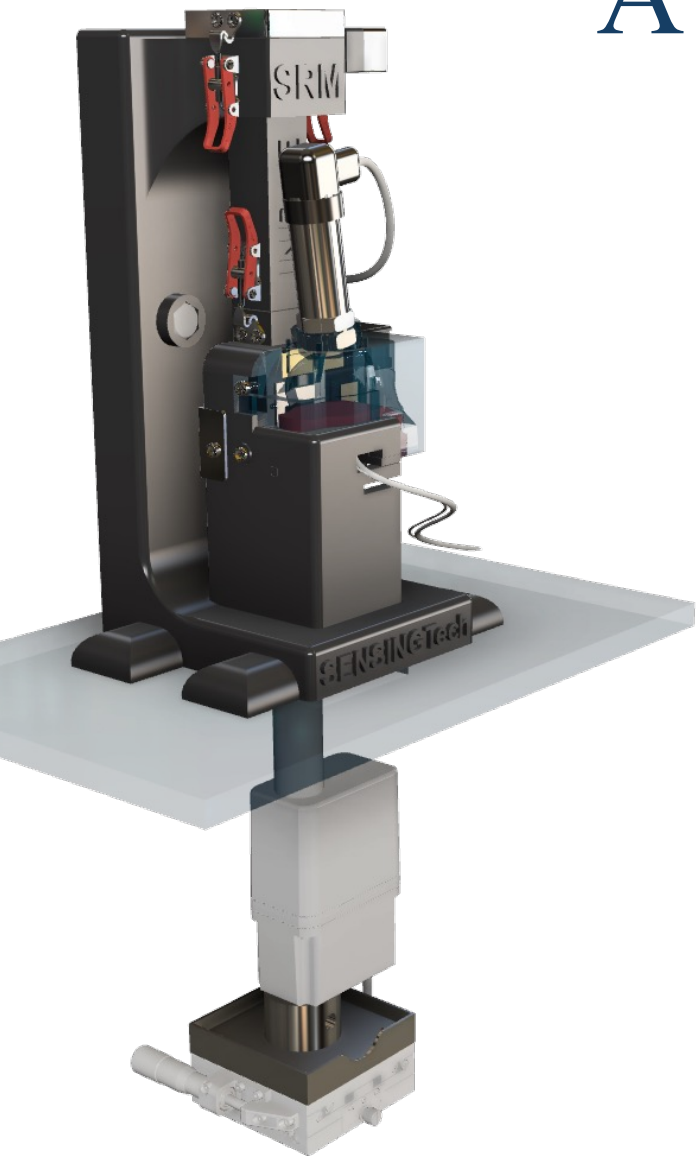

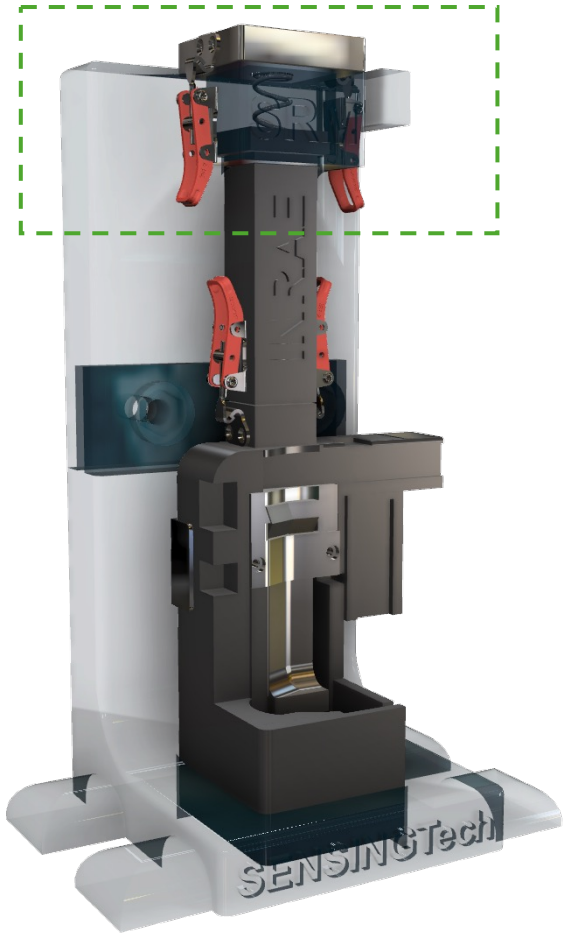

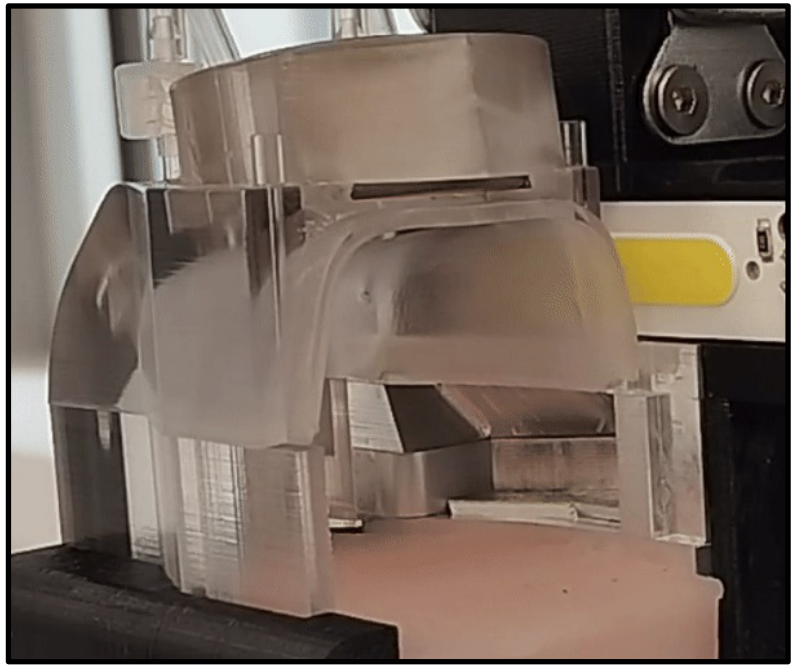

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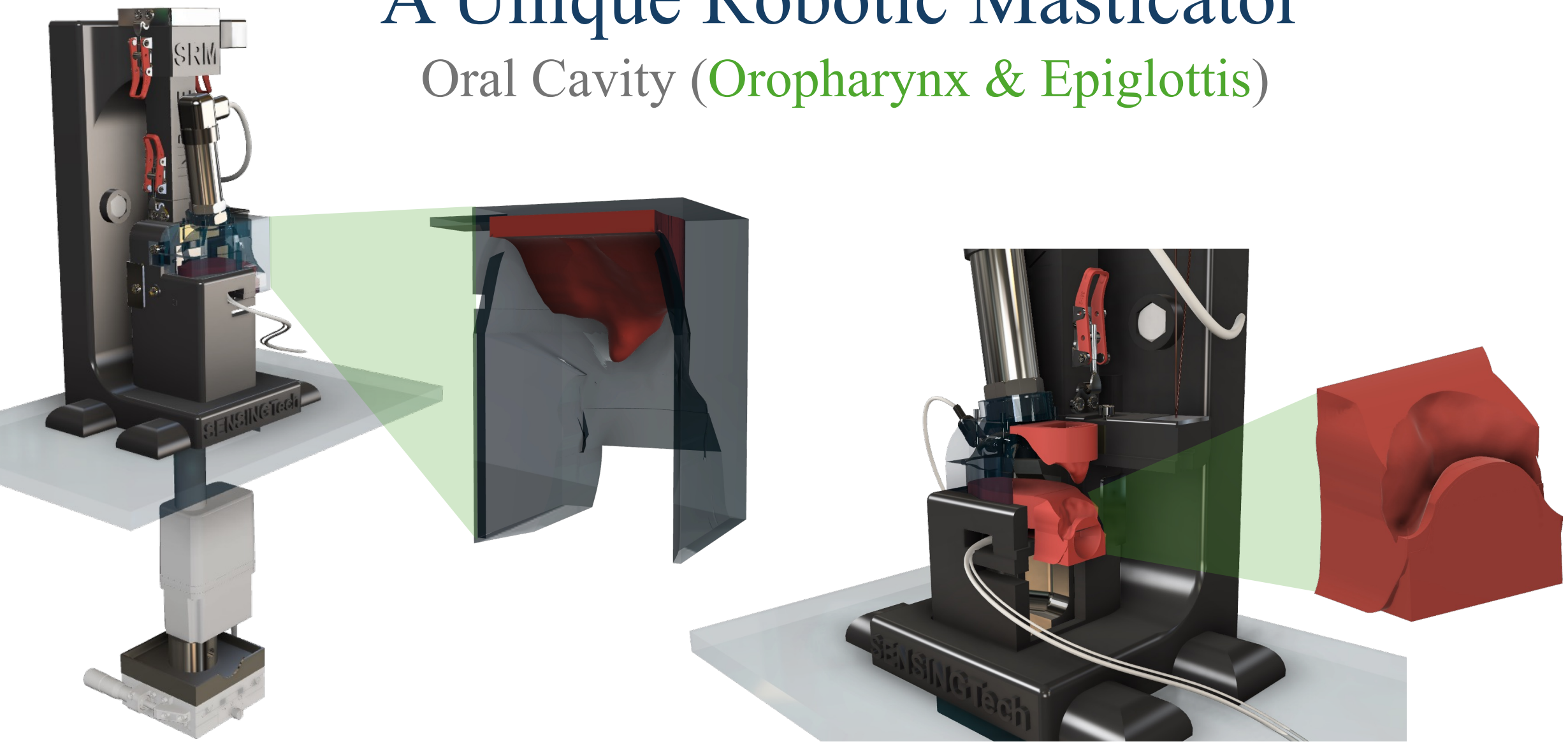
A Unique Robotic Masticator

Oral Cavity (Oropharynx & Epiglottis)



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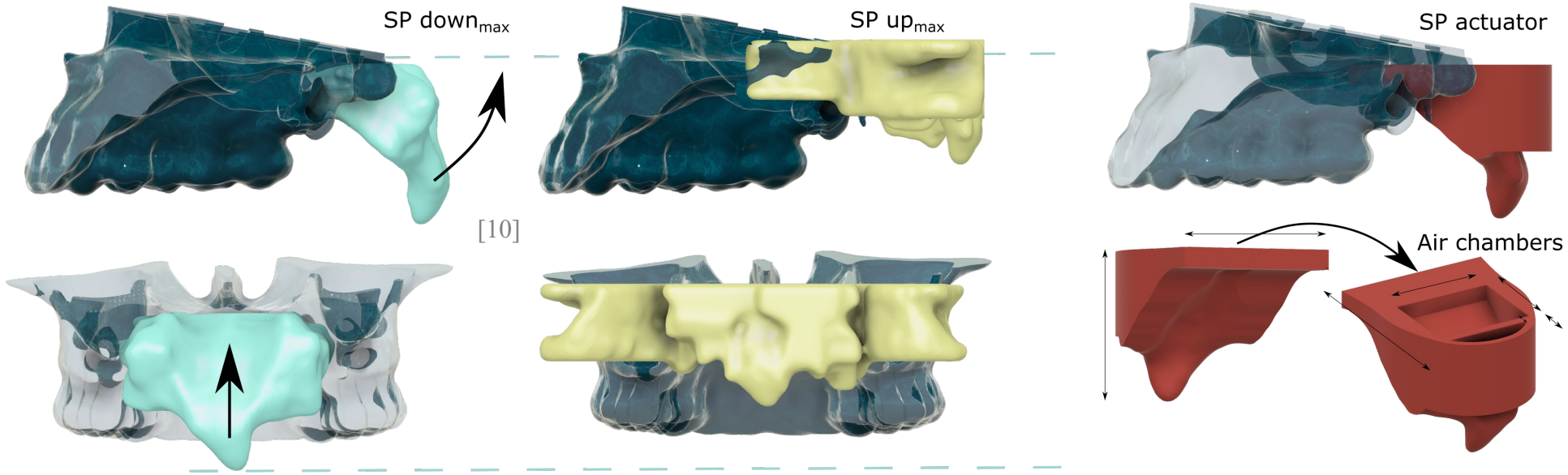
A Unique Robotic Masticator

Oral Cavity (Soft Palate)



[10]

[10] Kobayashi et al., (2019).

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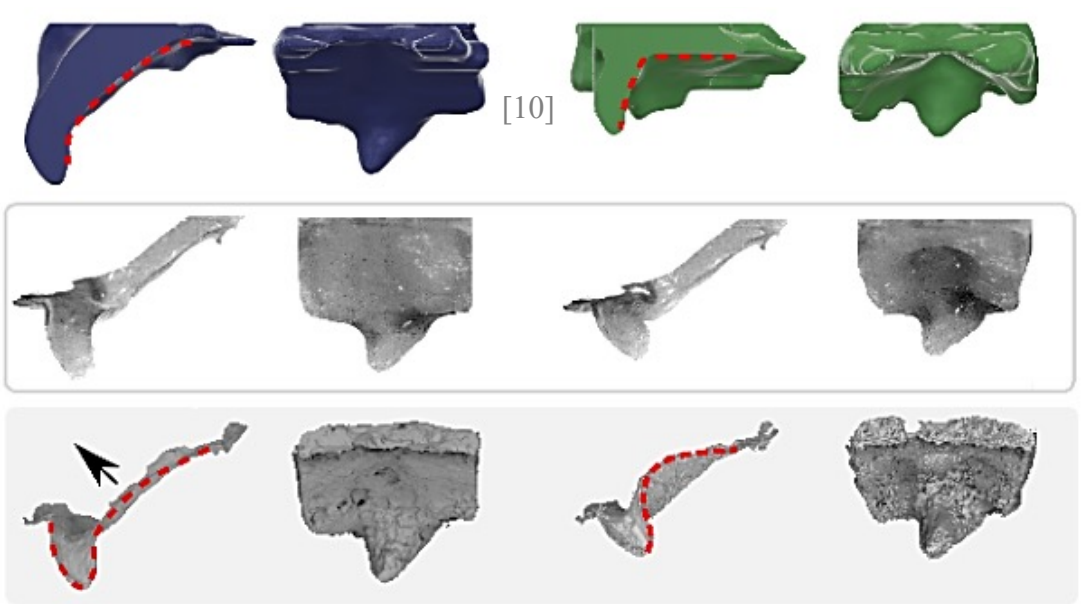
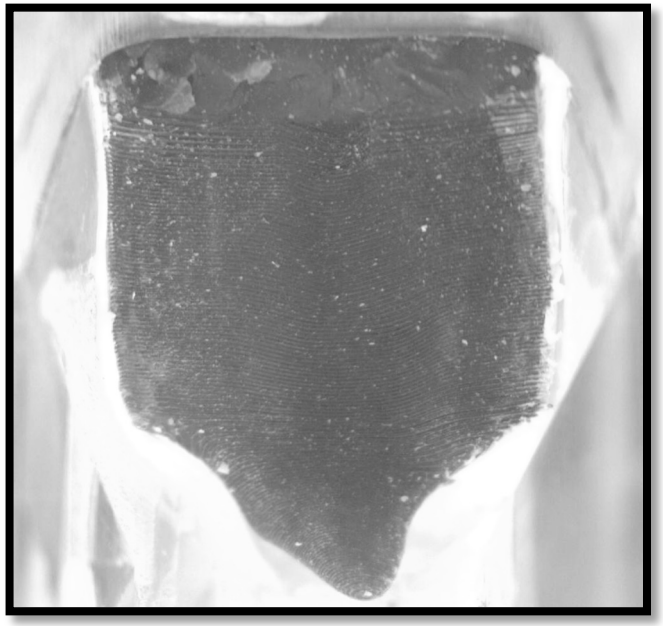
A Unique Robotic Masticator

Oral Cavity (Soft Palate)

Soft Palate Elevation





Slow down 10x

[10] Kobayashi et al., (2019).

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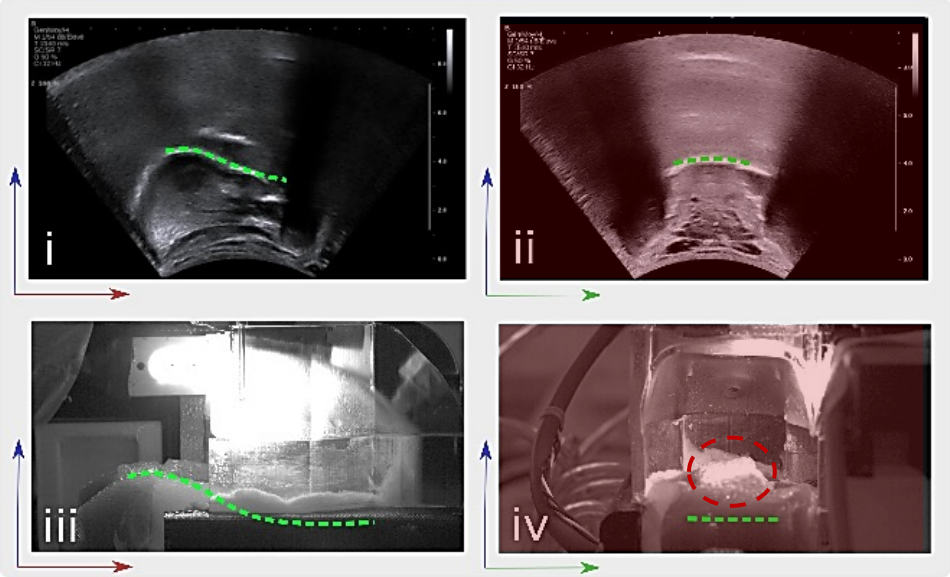
Stage I of Transport (St1Tr)

Food intra-oral transformation (FIOT)

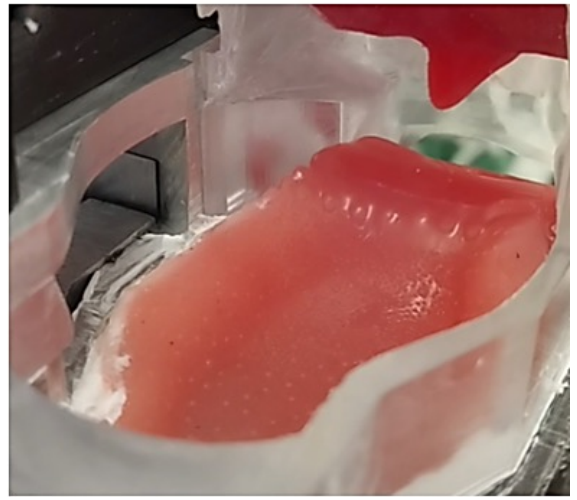
Stage I Transport (St1Tr)

Tongue Pull-back (TPB)



Sagittal plane

Coronal plane



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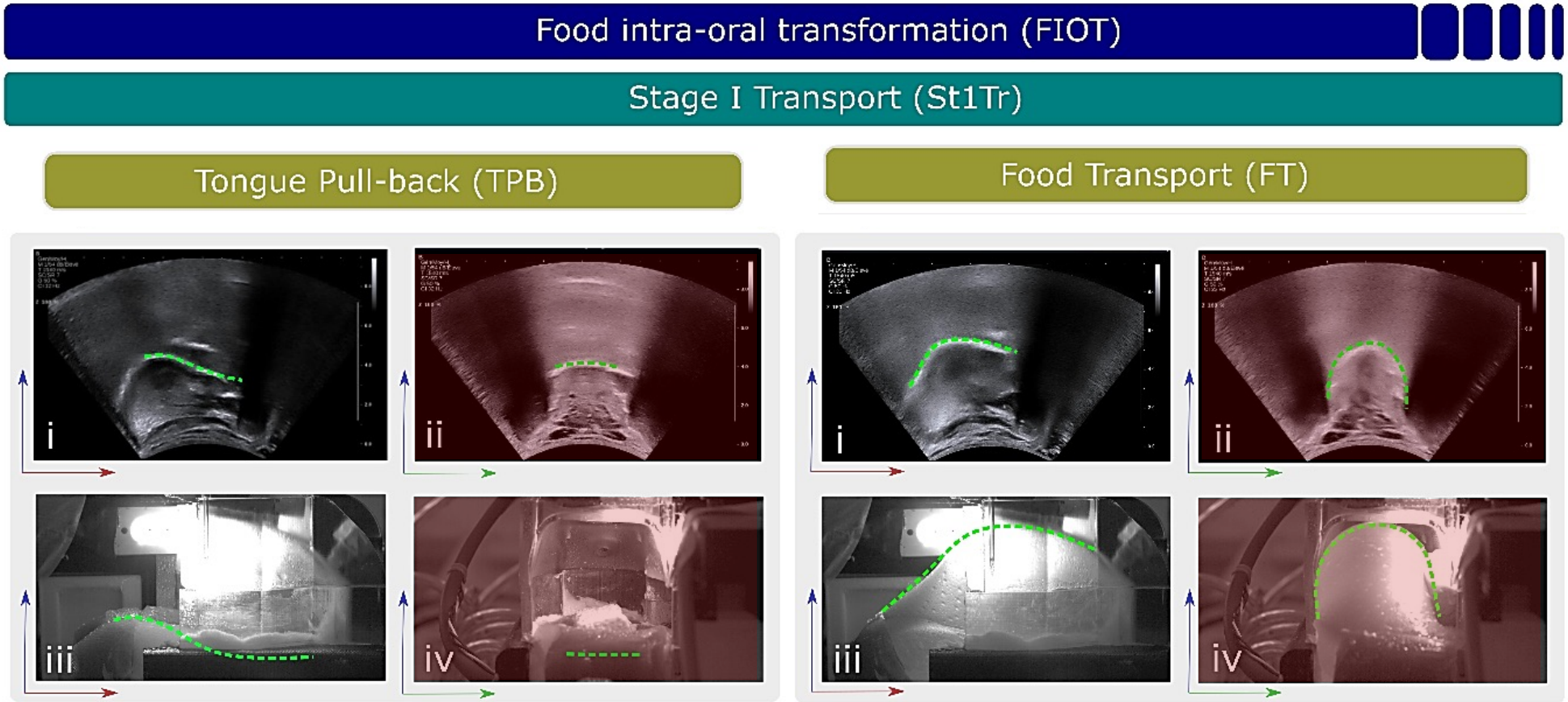
Stage I of Transport (St1Tr)



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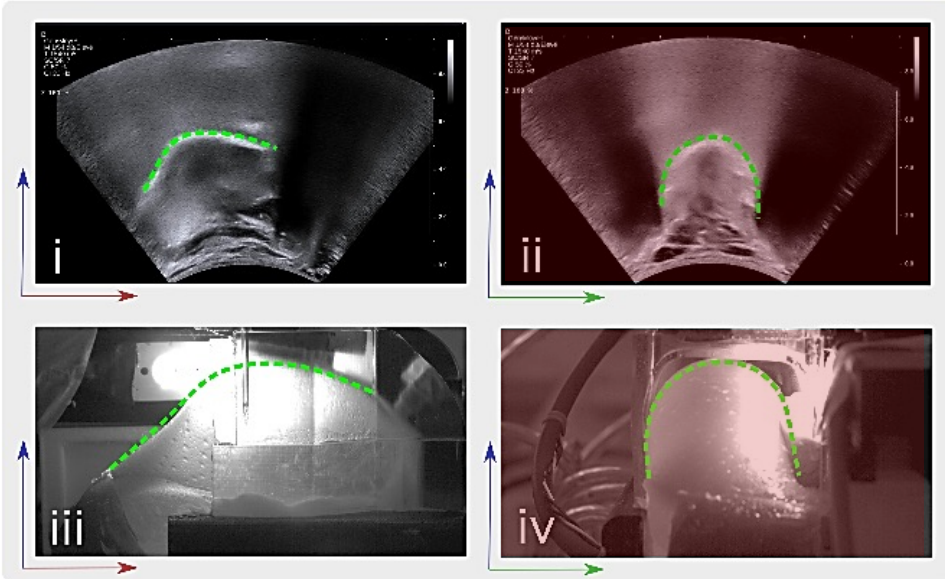
Stage I of Transport (St1Tr)

Food intra-oral transformation (FIOT)

Stage I Transport (St1Tr)

Food Transport (FT)

Coronal plane



Sagittal plane

Coronal plane

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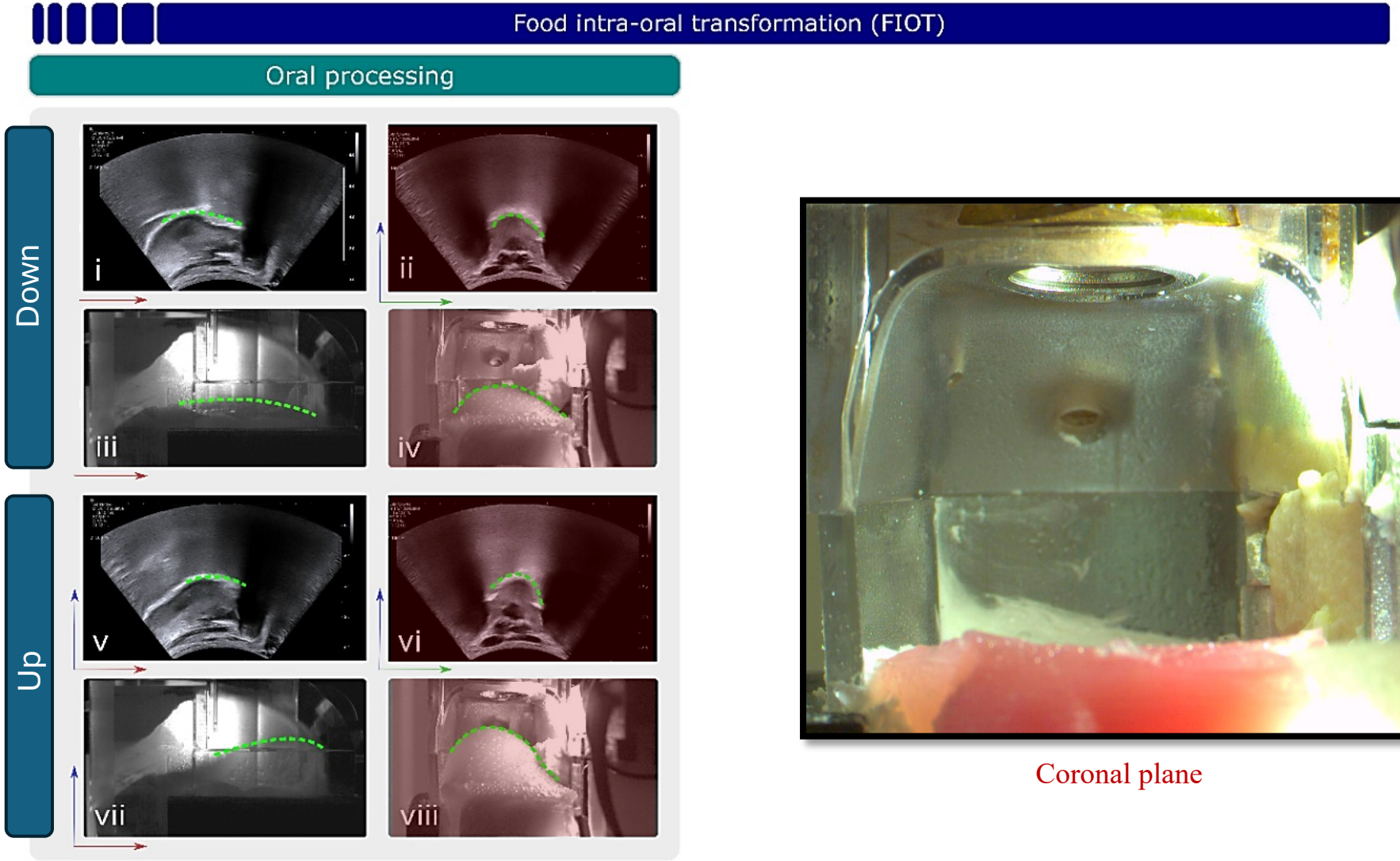
Oral Processing



Sagittal plane

Coronal plane

Coronal plane

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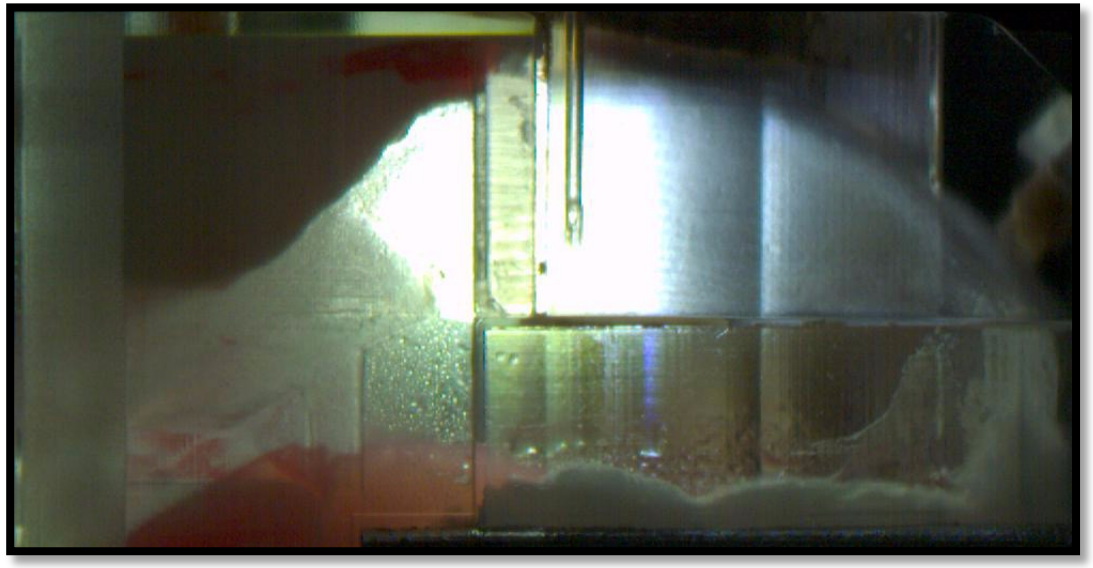
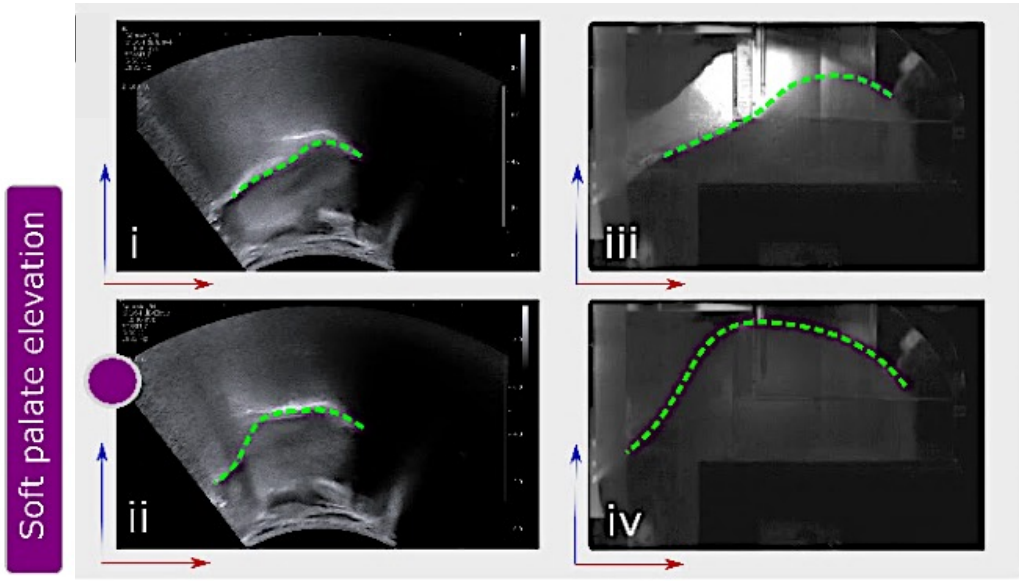
Stage II of Transport (St2Tr)

Food intra-oral transformation (FIOT)

Stage II Transport



Sagittal plane



Sagittal plane

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Assessment of in vitro food oral procesing

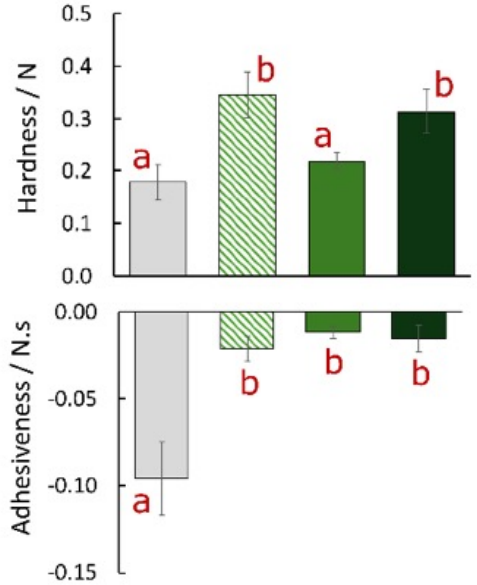
Programming

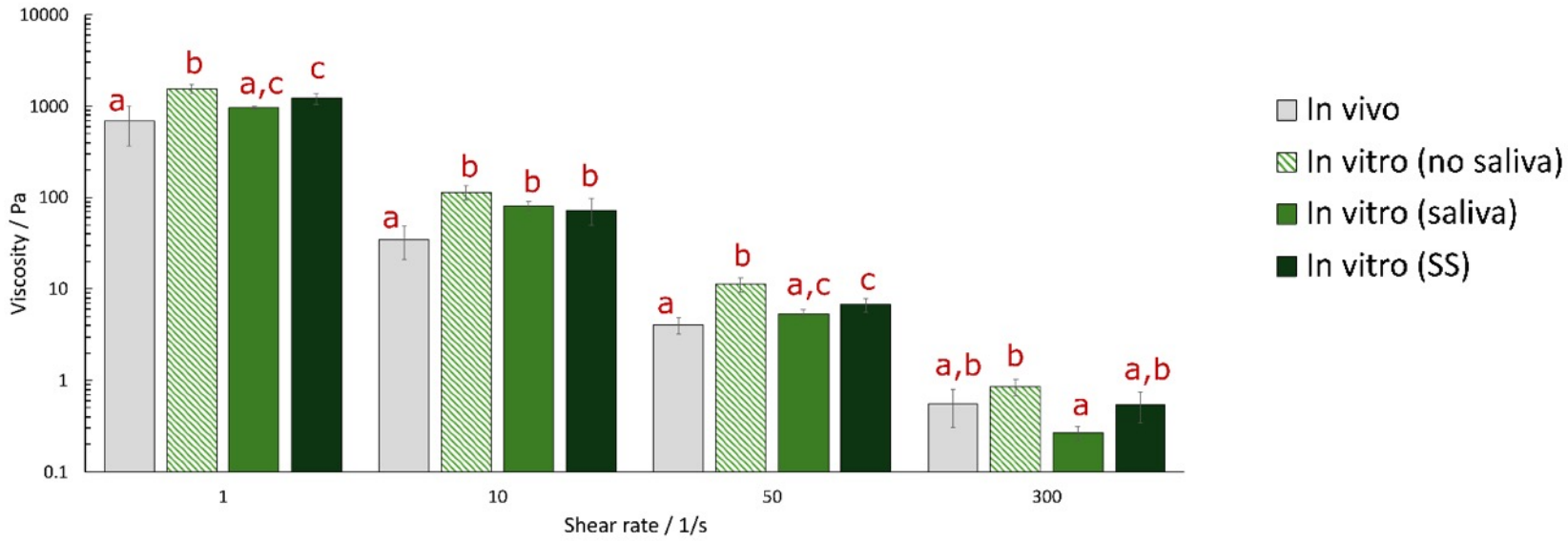
Number of chews = 9 (*in vivo*: 8 ± 2 chews)

Saliva flow rate = 15 mL/min

Oral lubrication conditions:

- **Dry mouth**
- **Healthy** salivary conditions (human saliva, 37°C)
- **Salivary substitute** (Boots®, 1gr)





Predictive testing for vulnerable populations without exposing them directly to unsuitable foods

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Take-home messages:

1. **First *in vitro* systems** including tongue biomechanics 
2. **First *in vitro* system simulating oral processing** of soft / viscous foods *(Tongue driven oral processing)* 
3. **Realistic *in vitro* simulation of oral processing** of solid foods *(Tongue-teeth coordination)* 
4. **Fist *in vitro* system capable of simulating** the **St2Tr** – critical for people with swallowing dysfunctions 

Reproducing how humans transform food before swallowing.

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The impact of our work

1. Industry

Faster innovation

Accelerating food formulation and reducing failed prototypes

2. Society

Safer nutrition

Reducing choking & swallowing risks for vulnerable populations

3. Science

Predictive food engineering

From trial-and-error to mechanistic design

Embodying the spirit of the Prix Marcel LONCIN 2025

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A 3D Biomimetic Artificial Mouth: Enabling the Predictive Design of Safer Foods

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merci !

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