

Perceived Realism of 3D-Printed Teeth, Extracted Human Teeth and Clinical Patient Cases in Endodontic Training: A Within-Subject Study

Elhassan Hassanein

`elhassan.hassanein@med.uni-duesseldorf.de`

Heinrich Heine University Düsseldorf

Sarah Krajan

Heinrich Heine University Düsseldorf

Mohamed Nagy

Izzeddin Abdi

Heinrich Heine University Düsseldorf

Research Article

Keywords:

Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10483823/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Perceived Realism of 3D-Printed Teeth, Extracted Human Teeth and Clinical Patient Cases in Endodontic Training: A Within-Subject Study

Elhassan Hassanein¹, Sarah Krajan¹, Mohamed Mokhtar Nagy², Izzeddin Abdi¹

Corresponding author:

Dr. Elhassan Hassanein

Department of Conservative Dentistry, Periodontology and Endodontology

Faculty of Medicine, Heinrich-Heine-University Duesseldorf

40225 Duesseldorf

Germany

Elhassan.hassanein@med.uni-duesseldorf.de

²Department of Conservative Dentistry and Endodontics

Galala University powered by Arizona State University

Galala Plateau Suez Gouvernante 8126014, Suez, Egypt

²Department of Conservative Dentistry and Endodontics

Ain Shams University, El Qobba Bridge, El Weili, Cairo Governorate, 4393005, Egypt

Sarah.krajan@gmx.net

Mohamed.nagy@gu.edu.eg

Izzeddinabdi01@gmail.com

Aim

To compare the perceived realism of two commercially available three-dimensional (3D)-printed tooth models with extracted human teeth, using clinical patient cases as the reference standard, during different stages of endodontic treatment, as evaluated by recent dental graduates.

Methodology

Twenty recent dental graduates who had completed undergraduate endodontic training participated in this cross-sectional comparative study. Three endodontic training modalities were evaluated: two 3D-printed tooth systems (TrainyDent® and Frasaco®) and

extracted human teeth, with clinical patient cases serving as the reference standard. Participants assessed eight stages of root canal treatment: access cavity preparation, canal orifice location, glide path creation, working length determination, cleaning and shaping, obturation, adhesive sealing, and occlusal adjustment. Perceived realism was recorded using a visual analogue scale (VAS; 0–10), with higher scores indicating greater similarity to the reference standard (clinical patient cases). Data were analysed using non-parametric tests for paired comparisons, with adjustment for multiple testing. Statistical significance was set at $P < 0.05$.

Results

Clinical patient cases were predefined as the reference standard (VAS score = 10) for all treatment stages. Extracted human teeth achieved the highest perceived realism scores (7.51 ± 1.53), followed by TrainyDent® (6.07 ± 1.74) and Frasaco® (5.55 ± 1.75). This ranking was consistent across all evaluated treatment stages. Significant differences were observed among the evaluated modalities ($P < 0.001$), particularly for procedures requiring tactile feedback.

Conclusions

Using clinical patient cases as the reference standard, extracted human teeth demonstrated the highest perceived realism among the evaluated training modalities. Although current 3D-printed tooth models do not fully reproduce the characteristics of natural teeth, they provide standardized, reproducible, and ethical adjunctive tools for preclinical endodontic education.

Introduction

Endodontic education is a fundamental component of dental training, requiring students to develop precise technical skills to perform root canal treatments effectively¹. Traditionally, pre-clinical endodontic training has relied on the use of extracted natural teeth, which provide anatomically accurate models for practicing procedures². However, the use of natural teeth presents significant challenges, including limited availability, ethical concerns, and substantial variability in tooth morphology that complicates standardized teaching and objective assessment - particularly in examination settings where consistency is paramount³.

The limitations of natural teeth have historically led educators to seek alternative training methods^{4, 5}. Before the advent of three-dimensional (3D) printed teeth, dental schools commonly used simulated canal blocks made of resin or acrylic⁶. While these models offered consistency in terms of availability and basic shape, they lacked the anatomical complexity of real teeth, featuring simplified canals that failed to replicate the challenges of natural root canal systems^{7, 8}. This artificial simplicity created a significant gap between pre-clinical training and clinical reality, leaving students poorly prepared for the complexities of actual patient cases⁹.

The introduction of 3D printing technology has provided new opportunities for developing standardized endodontic training models^{10, 11, 12, 13}.

These modern models provide numerous advantages: they replicate intricate root canal anatomy with consistent quality¹⁴, can be produced with specific pathological features (such as calcifications or curved canals), and eliminate the ethical and logistical issues associated with extracted teeth¹⁵. Particularly in examination contexts, 3D printed teeth ensure all students are evaluated on identical anatomical challenges, removing the variability inherent in natural tooth specimens¹⁰.

This shift to artificial models has become increasingly relevant in Germany, where successful public health preventive measures have significantly reduced the prevalence of caries and subsequent need for endodontic treatment¹⁰. While this positive trend reflects improved population oral health, it has created an educational challenge: university hospitals now struggle to provide sufficient root canal treatment cases for all dental students¹⁶. This scarcity of clinical experience makes high-fidelity simulation tools even more critical for ensuring graduates attain the necessary competence before treating patients¹⁷.

Several commercially available 3D-printed tooth models have been introduced for endodontic education, each aiming to provide standardized and reproducible training conditions.¹⁸ However, evidence comparing the performance and educational value of different 3D-printed systems remains limited. Although previous studies have investigated individual 3D-printed models, few have directly compared commercially available systems with extracted human teeth and clinical patient experiences. In particular, limited information is available regarding how closely these models reproduce the perceived realism of specific stages of root canal treatment, including access cavity preparation, canal negotiation, instrumentation, and obturation.

Furthermore, while these models address standardization needs, their ability to replicate the tactile feedback and unpredictable challenges of real patient cases requires thorough evaluation¹⁹.

This study aimed to assess recent dental graduates' perceptions of endodontic training using two different brands of 3D-printed teeth compared with extracted natural teeth and

clinical patient experiences. We evaluated their perceived realism and educational experience across all treatment phases—from access cavity preparation to obturation.

To ensure comparable levels of procedural difficulty among the different training modalities, the Schneider angle of root canal curvature for the 3D-printed teeth, extracted natural teeth, and real patient teeth did not exceed 25 degrees, Figure (1). Our findings provide crucial insights for modern endodontic education, helping institutions optimize their training approaches in an era of changing disease patterns and advancing simulation technologies.



Figure 1: Virtual simulation of a molar demonstrating root canal curvature according to Schneider's method (25° in the mesio Buccal and distal roots and 18° in the palatal root)

Materials and Methods

Study Design and Ethical Approval

This within-subject observational questionnaire-based study was conducted at the Department of Endodontics, University Hospital Düsseldorf, Germany. The questionnaire was initially implemented as part of an internal quality assessment initiative to evaluate and improve undergraduate endodontic education and optimize preclinical training strategies. Following completion of the educational evaluation, ethical approval was obtained for the scientific analysis and publication of the anonymized questionnaire data (approval number: 2026-3612). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki, which served as the ethical standard for research involving human participants.

The study protocol was reviewed and approved by the responsible Ethics Committee (approval number: 2026-3612). All questionnaire data were collected and analyzed anonymously, and no personal participant information was collected or reported. This observational study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement.

Participants

Twenty recent dental graduates (18 females and 2 males; age range: 23–30 years) who completed their undergraduate dental education at Heinrich Heine University Düsseldorf were included in this study. All participants had successfully completed the complete undergraduate endodontic curriculum, including theoretical lectures, preclinical simulation training, and clinical root canal treatments under supervision.

The study population comprised all dental students who completed the final state examination in September 2025 and fulfilled the inclusion criteria. Participants were included only if they had performed endodontic procedures using all three evaluated modalities: TrainyDent® 3D-printed teeth, Frasaco® 3D-printed teeth, extracted human teeth, and clinical patient cases. The evaluation was performed immediately after completion of the final state examination to minimize recall bias and ensure comparable recent experience across all training modalities.

Study Objective

The primary aim was to assess the perceived realism and educational value of different training modalities in endodontics. Each participant performed a complete endodontic treatment sequence across all three modalities. The graduates completed a standardized questionnaire evaluating their experience. The questionnaire was developed specifically for this study based on the study objectives and previously published literature on endodontic simulation and training models. The questionnaire was reviewed by experienced endodontic educators for content validity, clarity, and clinical relevance before distribution. Internal consistency of the questionnaire items was evaluated using Cronbach's alpha coefficient.

As part of your training, you have already performed root canal treatment on extracted teeth, on a Frasaco® tooth, on a Trainy-dent® tooth, and on patients during the clinical phase of your dental education:

1) Trainy-dent®

How would you rate your experience with the above-mentioned company's tooth model during the following steps of root canal treatment?

Please rate each step on a scale from 1 (not at all realistic) to 10 (completely realistic) based on how realistically the procedure resembled treatment performed on patients.

Access cavity preparation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Identification of canal orifices

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Glide path preparation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Working length determination

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Canal instrumentation (Cleaning and shaping)

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Root canal obturation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Adhesive restoration (Coronal seal)

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Finishing and polishing

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

2) Frasaco®

How would you rate your experience with the above-mentioned company's tooth model during the following steps of root canal treatment?

Please rate each step on a scale from 1 (not at all realistic) to 10 (completely realistic) based on how realistically the procedure resembled treatment performed on patients.

Access cavity preparation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Identification of canal orifices

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Glide path preparation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Working length determination

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Canal instrumentation (Cleaning and shaping)

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Root canal obturation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Adhesive restoration (Coronal seal)

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Finishing and polishing

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

3) Extracted Teeth

How would you rate your experience with extracted teeth during the following steps of root canal treatment?

Please rate each step on a scale from 1 (not at all realistic) to 10 (completely realistic) based on how realistically the procedure resembled treatment performed on patients.

Access cavity preparation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Identification of canal orifices

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Glide path preparation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Working length determination

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Canal instrumentation (cleaning and shaping)

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Root canal obturation

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Adhesive restoration (coronal seal)

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Finishing and polishing

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Additional File 1: This questionnaire was developed specifically for this study to evaluate the perceived realism of different endodontic training modalities (TrainyDent®, Frasaco®, and extracted human teeth) compared with clinical patient cases across eight stages of root canal treatment.

3D-printed tooth model (Frasaco® GmbH, Germany), Figure (2).

1. 3D-printed tooth model (TrainyDent®, Unimir GmbH, Germany), Figure (3).
2. Extracted human teeth, Figure (4).
3. Clinical patient teeth.

One of the evaluated training modalities was the Frasaco® 3D-printed tooth model (Frasaco® GmbH, Germany; Figure (2)).

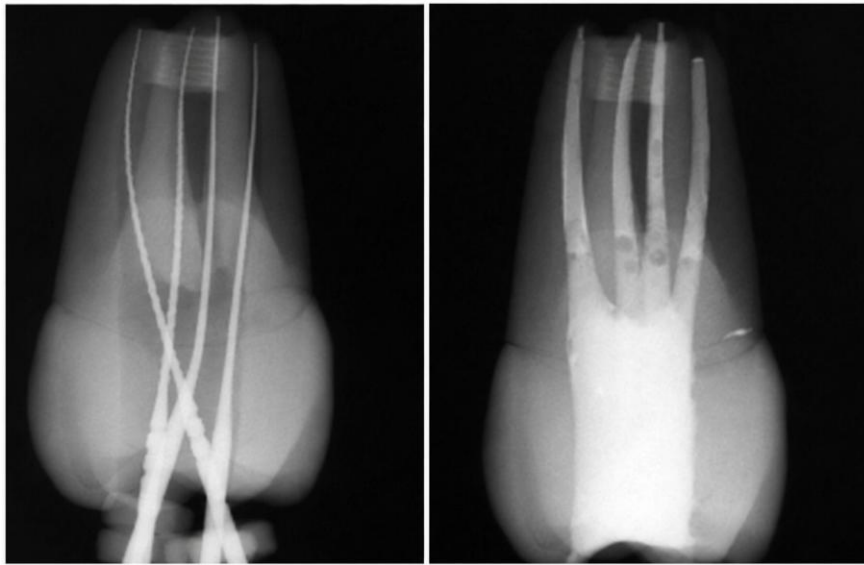


Figure 2: 3D-printed tooth model (Frasaco® GmbH, Germany), radiograph with handfiles ISO size 20 and obturation control

A representative radiograph of the TrainyDent® 3D-printed tooth model with ISO size 20 hand files and the post-obturation control radiograph is presented in Figure (3).

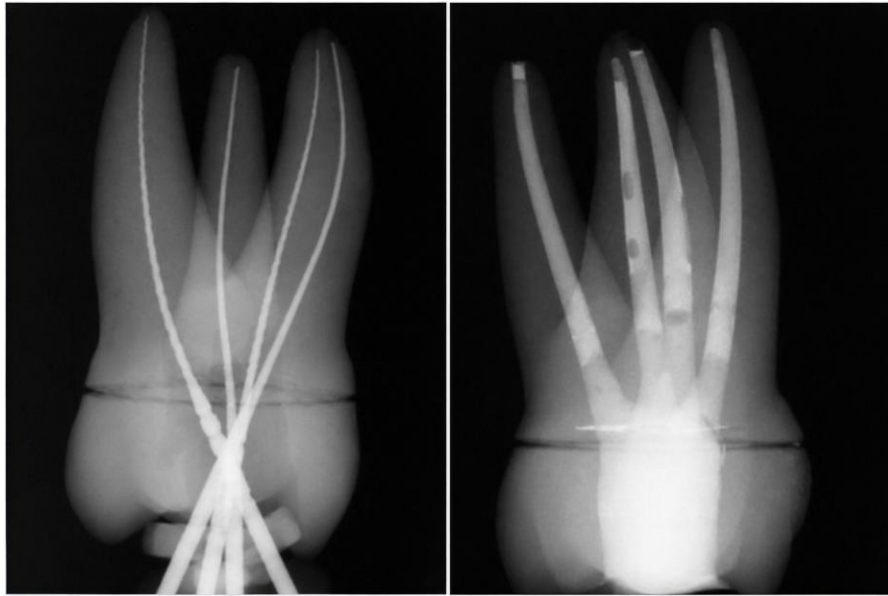


Figure 3: 3D-printed tooth model (TrainyDent®, Unimir GmbH, Germany), radiograph with handfiles ISO size 20 and obturation control

Representative radiographs of the extracted human tooth during instrumentation with ISO size 20 hand files and after obturation are shown in Figure (4).



Figure 4: Extracted Tooth radiograph with handfiles ISO size 20 and obturation control

Evaluation Protocol

Each participant performed a complete endodontic treatment sequence across all three modalities. Following each procedure, the graduates completed a standardized questionnaire evaluating their experience. The questionnaire was developed based on previously published studies evaluating endodontic simulation and training models. The selected items represented the major procedural stages of root canal treatment. The questionnaire was reviewed by experienced endodontic educators for content validity, clarity, and clinical relevance before distribution. Internal consistency of the questionnaire items was evaluated using Cronbach's alpha coefficient.

The following **eight endodontic steps** were assessed:

1. Access cavity preparation
2. Location of canal orifices
3. Glide path creation
4. Working length determination
5. Cleaning and shaping of the root canals
6. Obturation of root canals
7. Adhesive sealing of root canals and access cavity
8. Occlusal adjustment

Each item was scored on a **visual analogue scale from 0 to 10**, where 0 indicated "not realistic at all" and 10 indicated "identical to real clinical experience."

Procedure

3D Printed Teeth (Frasaco and TrainyDent):

Each brand's premolar and molar models were mounted in standard phantom heads and operated on using a high-speed handpiece, endodontic files, irrigants, and obturation systems under simulated clinical conditions.

Extracted

Teeth:

Ethically sourced extracted human teeth were mounted similarly in phantom heads. Standard access, instrumentation, and obturation techniques were performed.

Clinical patient cases:

During their final two clinical years of undergraduate dental training, each student performed endodontic procedures on clinical patients under faculty supervision. The treated cases included multi-rooted teeth. To standardize procedural difficulty and ensure suitability for undergraduate clinical training, only teeth with mild to moderate canal curvature were included. The Schneider angle of root canal curvature was assessed, and teeth with a curvature exceeding 25 degrees were excluded from treatment. Clinical patient

cases served as the reference standard for comparison with the extracted human teeth and 3D-printed teeth.

Sample Size Calculation:

The sample size was determined based on the findings of a previous study by Luz *et al.*²⁰, with an expected effect size of 1.02. Using an alpha (α) level of 0.05 and a statistical power of 0.95, the required sample size was calculated as 20 participants. As this study followed a within-subject comparative design, the same 20 participants evaluated all three training modalities (TrainyDent®, Frasaco®, extracted human teeth, and clinical patient cases) after performing endodontic procedures representative of each modality. Each participant thus generated 24 responses (8 steps $\times$ 3 modalities). Sample size calculation was performed using G*Power version 3.1.9.4.

Statistical Analysis:

Data were summarized using mean $\pm$ standard deviation (SD) or median and range, depending on data distribution. The normality of continuous variables was assessed using the Kolmogorov–Smirnov test. Differences in perceived realism scores among the three evaluated training modalities (extracted human teeth, TrainyDent®, and Frasaco®) were analyzed using the Friedman test for related samples. Clinical patient cases served as the predefined reference standard (VAS = 10) and were therefore not included in the statistical comparison.

When significant differences were detected, post hoc pairwise comparisons were performed using Wilcoxon signed-rank tests with Bonferroni correction for multiple comparisons. The individual participant was considered the statistical unit of analysis. Associations between variables were assessed using Spearman's rank correlation coefficient where appropriate. All statistical tests were two-sided, and a P-value <0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics software (version 22; IBM Corp., Armonk, NY, USA).

Results

Twenty recent dental graduates from the Department of Endodontics at Heinrich Heine University were recruited for this study. The full survey evaluated eight endodontic procedural steps across three training modalities: extracted human teeth (ET), TrainyDent® (TD), and Frasaco® (F). Clinical patient cases served as the predefined reference standard (VAS = 10) against which all training modalities were evaluated.

Realism was rated using a visual analogue scale (VAS) from 0 (not realistic at all) to 10 (identical to real clinical experience). Table 2 summarizes the mean $\pm$ standard deviation (SD) of the perceived realism scores for each endodontic treatment stage across the three evaluated training modalities. Reliability analysis of the questionnaire demonstrated excellent internal consistency among the evaluated items, with a Cronbach's alpha coefficient of 0.94.

Clinical patient cases served as the reference standard for comparison with the extracted human teeth and 3D-printed teeth.

Both 3D-printed models (TD and F) were rated lower, with statistically significant differences noted in multiple domains.

Step-by-Step Analysis:

Access Cavity Preparation: Relative to the predefined clinical reference (VAS = 10), extracted human teeth received the highest realism score (7.85 ± 1.46), followed by TrainyDent® (6.55 ± 1.50) and Frasaco® (6.10 ± 1.48). Differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Location of canal orifices: Relative to the predefined clinical reference (VAS = 10), extracted human teeth achieved the highest realism score (7.70 ± 1.49), followed by TrainyDent® (6.20 ± 1.64) and Frasaco® (5.75 ± 1.59). Extracted human teeth were perceived as significantly more realistic than both 3D-printed tooth models, and differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Glide path creation: Relative to the predefined clinical reference (VAS = 10), extracted human teeth received the highest realism score (7.70 ± 1.66), followed by TrainyDent® (6.00 ± 1.86) and Frasaco® (5.45 ± 1.67). Differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Working length determination: Relative to the predefined clinical reference (VAS = 10), extracted human teeth received the highest realism score (7.95 ± 1.39), followed by TrainyDent® (6.25 ± 1.65) and Frasaco® (5.75 ± 1.86). Differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Cleaning and shaping of the root canals: Relative to the predefined clinical reference (VAS =

10), extracted human teeth received the highest realism score (7.60 ± 1.57), followed by TrainyDent® (5.85 ± 1.95) and Frasaco® (5.50 ± 1.85). Differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Obturation of the root canals: Relative to the predefined clinical reference (VAS = 10), extracted human teeth received the highest realism score (7.45 ± 1.64), followed by TrainyDent® (5.85 ± 1.84) and Frasaco® (5.45 ± 1.93). Differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Adhesive sealing of the access cavity: Relative to the predefined clinical reference (VAS = 10), extracted human teeth received the highest realism score (7.35 ± 1.54), followed by TrainyDent® (6.10 ± 1.68) and Frasaco® (5.05 ± 1.84). Differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Occlusal adjustment: Relative to the predefined clinical reference (VAS = 10), extracted human teeth received the highest realism score (7.45 ± 1.66), followed by TrainyDent® (5.95 ± 1.86) and Frasaco® (5.35 ± 1.88). Differences among the training modalities were statistically significant (Friedman test, $p < 0.001$).

Across all eight evaluated endodontic procedures, extracted human teeth consistently achieved the highest perceived realism scores, followed by TrainyDent® and Frasaco®. This ranking was maintained throughout all treatment stages, with extracted teeth receiving mean VAS scores between 7.35 ± 1.54 and 7.95 ± 1.39 , compared with 5.85 ± 1.84 to 6.55 ± 1.50 for TrainyDent® and 5.05 ± 1.84 to 6.10 ± 1.48 for Frasaco®. The highest realism score was observed for working length determination using extracted teeth (7.95 ± 1.39), whereas the lowest score was recorded for adhesive sealing of the access cavity using Frasaco® models (5.05 ± 1.84), Figure (5).

Figure 5: Perceived realism scores (VAS; mean $\pm$ SD) of extracted teeth, TrainyDent® and Frasaco® models across eight stages of endodontic treatment, showing significant differences among the three training modalities at each stage (Friedman test, $P < 0.001$).

Across all eight evaluated endodontic procedures, extracted human teeth consistently achieved the highest perceived realism scores, followed by TrainyDent® and Frasaco®

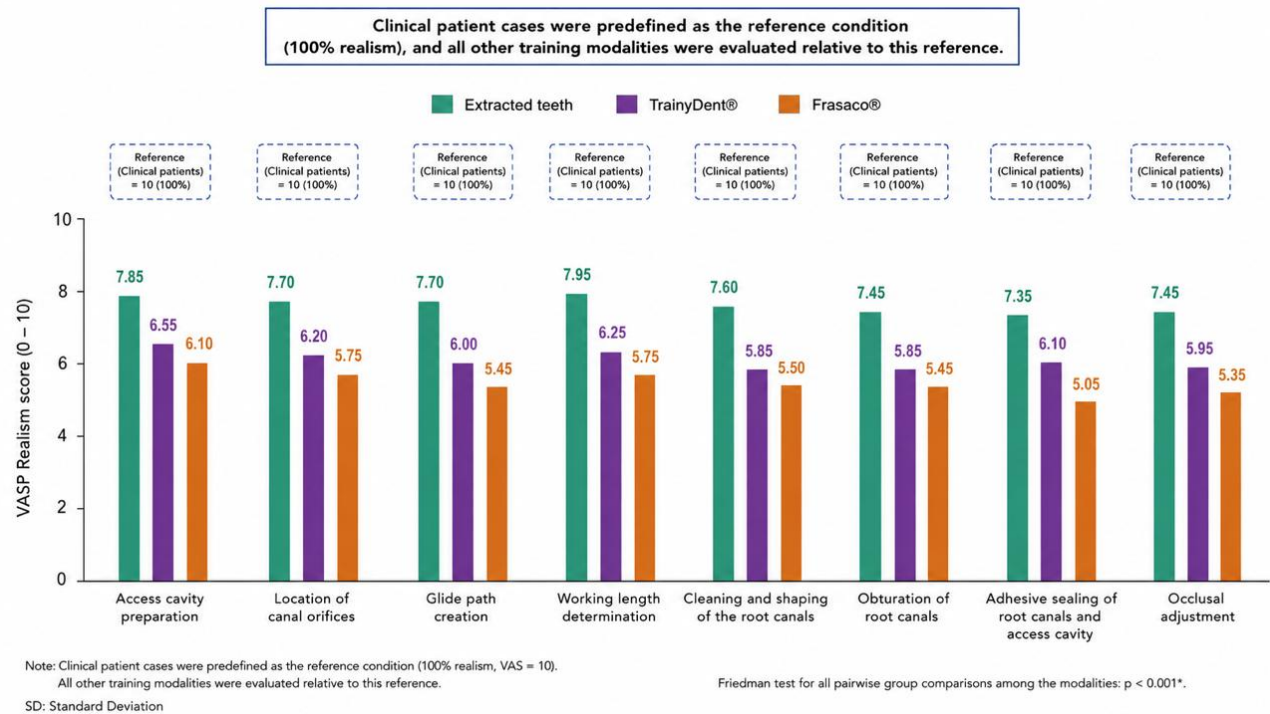


Figure 5. Friedman analysis revealed significant differences among the three training modalities for each procedural step (all $P < 0.001$). Pairwise comparisons showed that extracted human teeth were rated significantly more realistic than TrainyDent® and Frasaco® in several procedural steps, whereas no significant differences were observed between the two 3D-printed models after Bonferroni correction, Table 1.

Endodontic step	Comparison	Z	Bonferroni-adjusted P value
Access cavity preparation	F - TD	-0.029	0.977
Access cavity preparation	ET - TD	-3.445	0.006
Access cavity preparation	ET - F	-3.839	<0.001
Location of canal orifices	F - TD	-0.659	0.510
Location of canal orifices	ET - TD	-3.343	0.006
Location of canal orifices	ET - F	-3.564	<0.001
Glide path creation	F - TD	-0.958	0.338
Glide path creation	ET - TD	-2.062	0.240
Glide path creation	ET - F	-3.444	0.006
Working length determination	F - TD	-0.984	0.325
Working length determination	ET - TD	-1.076	0.282
Working length determination	ET - F	-0.357	0.721
Cleaning and shaping	F - TD	-1.378	0.168
Cleaning and shaping	ET - TD	-3.128	0.012
Cleaning and shaping	ET - F	-2.744	0.036
Obturation of root canals	F - TD	-2.102	0.232
Obturation of root canals	ET - TD	-3.369	0.006
Obturation of root canals	ET - F	-2.574	0.060
Adhesive sealing of root canals and access cavity	F - TD	-0.842	0.400
Adhesive sealing of root canals and access cavity	ET - TD	-2.585	0.060
Adhesive sealing of root canals and access cavity	ET - F	-2.172	0.180
Occlusal adjustment and polish	F - TD	-0.600	0.548
Occlusal adjustment and polish	ET - TD	-2.910	0.024
Occlusal adjustment and polish	ET - F	-3.580	<0.001

Table 1: Post hoc Wilcoxon signed-rank test results comparing extracted human teeth (ET), TrainyDent® (TD) and Frasaco® (F) across eight endodontic treatment stages. Values are Wilcoxon Z statistics with Bonferroni-adjusted P values. Clinical patient cases were predefined as the reference condition (VAS = 10) and were not included in the pairwise comparisons.

Endodontic Step	Training Modality	Mean $\pm$ SD (VASP Score)	Friedman test (p value)
Access cavity preparation	Extracted teeth (ET)	7.85 $\pm$ 1.46 ^a	< 0.001
	TrainyDent® (TD)	6.55 $\pm$ 1.50 ^b	
	Frasaco® (F)	6.10 $\pm$ 1.48 ^c	
Location of canal orifices	Extracted teeth (ET)	7.70 $\pm$ 1.49 ^a	< 0.001
	TrainyDent® (TD)	6.20 $\pm$ 1.64 ^b	
	Frasaco® (F)	5.75 $\pm$ 1.59 ^c	
Guide path creation	Extracted teeth (ET)	7.70 $\pm$ 1.66 ^a	< 0.001
	TrainyDent® (TD)	6.00 $\pm$ 1.86 ^b	
	Frasaco® (F)	5.45 $\pm$ 1.67 ^c	
Working length determination	Extracted teeth (ET)	7.95 $\pm$ 1.39 ^a	< 0.001
	TrainyDent® (TD)	6.25 $\pm$ 1.65 ^b	
	Frasaco® (F)	5.75 $\pm$ 1.86 ^c	
Cleaning and shaping of the root canals	Extracted teeth (ET)	7.60 $\pm$ 1.57 ^a	< 0.001
	TrainyDent® (TD)	5.85 $\pm$ 1.95 ^b	
	Frasaco® (F)	5.50 $\pm$ 1.85 ^c	
Obturation of root canals	Extracted teeth (ET)	7.45 $\pm$ 1.64 ^a	< 0.001
	TrainyDent® (TD)	5.85 $\pm$ 1.84 ^b	
	Frasaco® (F)	5.45 $\pm$ 1.93 ^c	
Adhesive sealing of root canals and access cavity	Extracted teeth (ET)	7.35 $\pm$ 1.54 ^a	< 0.001
	TrainyDent® (TD)	6.10 $\pm$ 1.68 ^b	
	Frasaco® (F)	5.05 $\pm$ 1.84 ^c	
Occlusal adjustment	Extracted teeth (ET)	7.45 $\pm$ 1.66 ^a	< 0.001
	TrainyDent® (TD)	5.95 $\pm$ 1.86 ^b	
	Frasaco® (F)	5.35 $\pm$ 1.88 ^c	

- VASP: Visual Analogue Scale of Perceived Realism (0 = not all realistic, 10 = extremely realistic)
- SD: Standard Deviation
- Different superscript letters (a, b, c within a column indicate statistically significant differences (p < 0.05)
- ET = Extracted teeth; TD = TrainyDent®; F = Frasaco®
- P < 0.05 was considered statistically significant
- Friedman test for related samples across the three training modalities for each step

Table 2: Comparison of perceived realism scores (VAS; mean $\pm$ SD) among the three training modalities across different endodontic treatment stages.

Aggregate Scores:

When averaged across all eight endodontic procedures and expressed relative to the predefined clinical reference (VAS = 10), the overall perceived realism scores were:

- Extracted teeth (ET): 7.51 ± 1.53
- TrainyDent (TD): 6.07 ± 1.74
- Frasaco (F): 5.55 ± 1.75

When scores were averaged across all eight endodontic treatment stages, extracted human teeth showed the highest aggregate perceived realism score (7.51 ± 1.53), followed by TrainyDent® (6.07 ± 1.74) and Frasaco® (5.55 ± 1.75; Figure (6)).

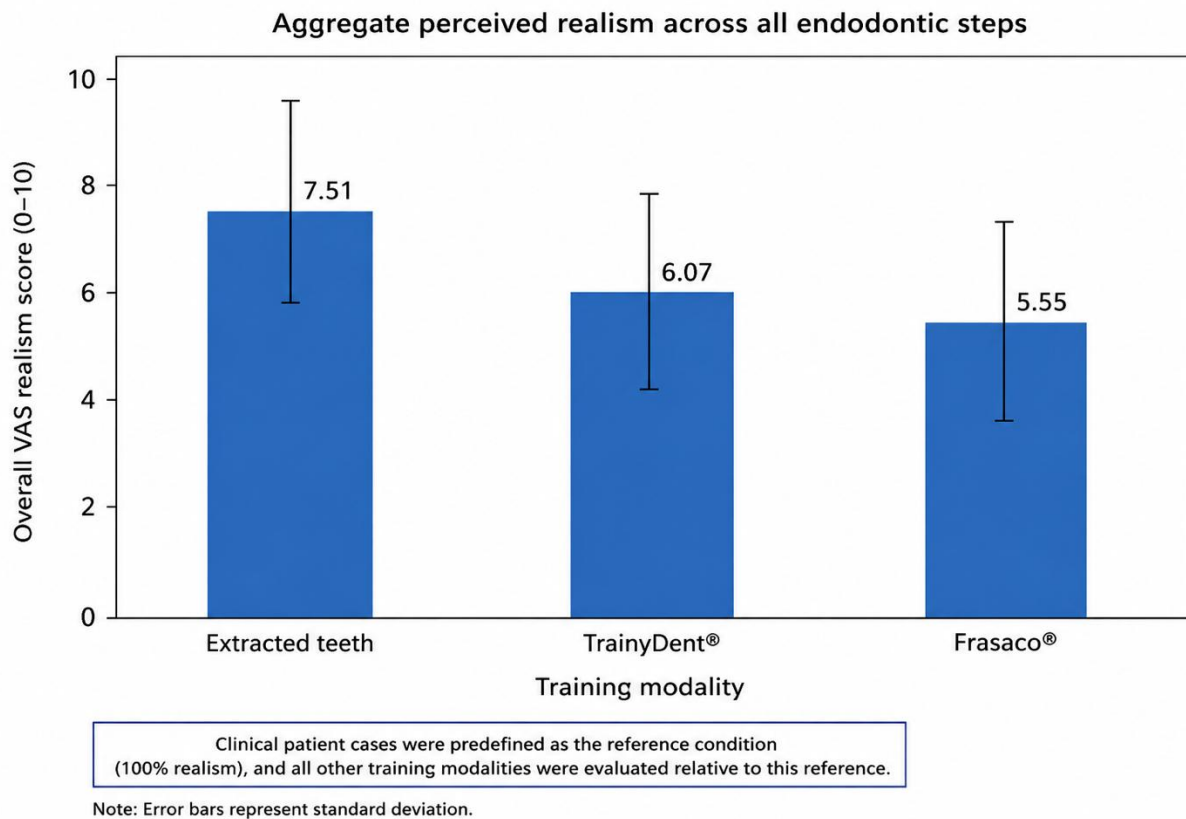


Figure 6: Aggregate perceived realism scores, expressed as overall visual analogue scale values (mean ± standard deviation), for extracted human teeth, TrainyDent® and Frasaco® across all eight endodontic treatment stages. Clinical patient cases were predefined as the

reference condition (VAS = 10). Error bars represent standard deviations. Differences among the three training modalities were statistically significant (Friedman test, $P < 0.001$).

Discussion

This study evaluated recent graduates' perceptions of extracted human teeth and two commercially available 3D-printed tooth models (Frasaco and TrainyDent) using clinical patient cases as the predefined reference standard for realism.

Consistent with expectations, the clinical (real patient) cases were rated highest for realism and educational authenticity. In line with established practice, hands-on training with extracted human teeth was also seen as highly realistic. Extracted teeth closely mimic clinical conditions, providing a "realistic training scenario" for endodontic practice. However, natural teeth have well-recognized limitations – they are scarce, raise infection-control and ethical issues, and lack standardization. Simulated models (typodonts and printed teeth) were used in part to overcome these drawbacks.

By contrast, both 3D-printed models (Frasaco and TrainyDent) received significantly lower realism scores. This finding echoes prior reports: for example, Kolling *et al.* found that students consistently rated 3D-printed root-canal models lower than human teeth in terms of tactile "feel" and engagement²⁰. In our data the 3D- printed models were perceived as less realistic, particularly in tasks like canal preparation and obturation. The lower perceived realism scores observed for both 3D-printed tooth models may be explained primarily by differences in material properties and internal canal design compared with natural teeth. Although current resin-based models reproduce external morphology and root canal anatomy with increasing accuracy, the mechanical characteristics of printing resins do not fully replicate the complex structure of natural dental tissues. Differences in hardness, elasticity, and cutting behaviour may influence tactile feedback during access cavity preparation, canal negotiation, instrumentation, and obturation, resulting in a less authentic clinical experience.

Furthermore, the initial canal dimensions of the investigated 3D-printed models may have contributed to the reduced perception of realism during canal preparation. The artificial canals presented with an initial apical size corresponding approximately to ISO size 20, resulting in a predefined apical stop and reduced difficulty during glide path creation and early instrumentation. In contrast, natural root canals frequently present with narrower, more variable anatomy, requiring progressive canal negotiation and enlargement. Therefore, although standardized canal dimensions improve reproducibility and allow comparable training conditions, they may reduce the ability of current 3D-printed models to reproduce the challenges encountered in clinical endodontic treatment.

Future development of 3D-printed endodontic training models should focus on optimizing resin properties and reproducing smaller initial canal diameters, variable canal anatomy, and more realistic tactile resistance to better simulate natural teeth.

Nevertheless, students still acknowledged positive aspects of the printed models. Notably, in other studies students gave high marks to 3D-printed tooth models for pre-clinical practice – they “received the highest approval” for simulating cavity preparation and were judged effective for learning theoretical and clinical skills²¹. In our cohort, despite the lower realism ratings, the 3D-printed models were regarded as useful practice tools. The interpretation of these results is that 3D-printed teeth, while not fully reproducing the authenticity of clinical patient teeth or extracted teeth, may serve as complementary training tools rather than complete replacements for patient-based experience²².

Students in prior research reported that 3D prints greatly improved their confidence and fine-motor skill development during endodontic practice²³. Similarly, our participants noted the practical benefits of the printed models’ consistency: the uniform anatomy, ease of handling, and repeatability were valued for perceived educational usefulness. Indeed, Fayyaz *et al.* concluded that 3D-printed teeth can serve as a “convenient and accessible alternative” to natural specimens in dental training, enhancing student confidence and clinical skill acquisition¹¹. In short, the standardized availability of 3D models – without the infection and ethical issues of extracted teeth – compensates for their somewhat lower haptic realism¹².

These findings align with the broader shift toward simulation-based learning in dental education. The contemporary trend is to integrate realistic simulations to supplement patient care, reflecting a consensus that simulators and printed models can offer safe, repeatable training¹¹. For example, Higgins *et al.* note the “widespread use of simulation in dentistry” and urge dental programs to develop simulation curricula to optimize student learning²⁴. Recent reviews specifically highlight 3D printing as a rapidly growing tool across preclinical disciplines. Karagkounaki *et al.* report that 3D-printed models enable the creation of diverse case scenarios resembling real-life conditions, while also offering greater availability and lower cost compared to traditional models²⁵. In other words, technology-enhanced simulation is viewed as a means to provide uniform, competency-based training opportunities. Our results support this view: even if printing materials must still be refined to fully mimic tooth tissues, 3D models are already proving to be valuable educational adjuncts.

This study has several limitations. The sample was relatively small (20 students) and drawn from a single institution, which may limit the generalizability of the findings. The within-subject questionnaire-based design and reliance on subjective VAS ratings should be considered when interpreting the findings, as responses may be influenced by individual perceptions and previous clinical experiences. We attempted to control for this by including recent graduates right after the final examination, but variability in previous clinical exposure is possible. Additionally, while a VAS allows fine-grained comparison of realism and value, it remains a subjective measure; future work could incorporate objective performance outcomes on these models. Furthermore, only two commercially available 3D-printed tooth systems were assessed; however, these models were selected because they represent widely used 3D-printed tooth systems in German dental universities for

endodontic education and provide sufficient radiopacity for endodontic training and radiographic assessment. Therefore, the findings cannot be generalized to all currently available or future 3D-printed tooth models, particularly as printing materials and technologies continue to evolve. Finally, our setting did not blind students to the modality type, and their perceptions might be affected by novelty or familiarity with certain models (e.g. if they had previously practiced on Frasaco typodonts).

In summary, despite these limitations, the results suggest that while live patient cases remain unsurpassed for realism, 3D-printed tooth models are seen as acceptable training substitutes when natural teeth are unavailable or impractical. The favorable student perceptions of the 3D systems in terms of consistency and accessibility underscore their educational utility. These findings fit within a growing body of evidence that 3D-printed models can bolster preclinical endodontic training. As materials and printing technologies improve, such models will likely play an increasingly prominent role in endodontic education, complementing traditional approaches and helping students transition safely to patient care.

Conclusion

Clinical patient cases and extracted teeth demonstrated the highest perceived realism during endodontic procedures. The evaluated 3D-printed teeth showed lower perceived realism, particularly regarding tactile aspects, but provide standardized and accessible adjunctive tools for preclinical endodontic education. Future studies should investigate whether improvements in material properties and simulation realism translate into improved educational outcomes.

Declarations

Funding:

The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical approval:

This study was approved by the Ethics Committee of Heinrich Heine University Düsseldorf (approval no. 2026-3612). Written informed consent was obtained from all participants prior to participation. All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki.

Conflict of interest:

The authors declare no competing interests.

Availability of data and material:

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Consent for publication:

Written informed consent for publication was obtained from all participants prior to their inclusion in the study.

Authors' contributions:

EH conceived and designed the study, collected and interpreted the data, and drafted the manuscript. SK supervised the students during their clinical examinations, prepared the ethics application for Heinrich Heine University Düsseldorf, contributed to the preparation of the figures, and critically revised the manuscript. MMN performed the statistical analysis, interpreted the data, and critically reviewed the manuscript. IA contributed to the writing and critical revision of the manuscript. All authors read and approved the final manuscript.

References

1. Longridge NN, Dutta A, Fox K. Endodontic education - present status and future directions. *Br Dent J.* 2025;238:567-572.
2. Madfa AA, Almansour MI, Al-Zubaidi SM, et al. Assessment of the quality of root canal fillings performed on extracted teeth by undergraduate dental students in a sample from Saudi Arabia. *BMC Med Educ.* 2024;24:1-9.
3. Holden ACL, Dracopoulos SA. Owning the tooth: exploring the ethical and legal issues relating to the use of extracted human teeth in dental education in Australia. *Aust Dent J.* 2017;62:146-151.
4. Iacopino AM. The Influence of “New Science” on Dental Education: Current Concepts, Trends, and Models for the Future. *J Dent Educ.* 2007;71:450-462.
5. Decurcio DA, Lim E, Chaves GS, Nagendrababu V, Estrela C, Rossi-Fedele G. Pre-clinical endodontic education outcomes between artificial versus extracted natural teeth: a systematic review. *Int Endod J.* 2019;52:1153-1161.
6. Dobroś K, Hajto-Bryk J, Zarzecka J. Application of 3D-printed teeth models in teaching dentistry students: A scoping review. *European Journal of Dental Education.* 2023;27:126-134.
7. Versiani MA, Martins JNR, Ordinola-Zapata R. Anatomical complexities affecting root canal preparation: a narrative review. *Aust Dent J.* 2023;68:S5-S23.
8. Tchorz JP, Brandl M, Ganter PA, Karygianni L, Polydorou O, Vach K, Hellwig E, Altenburger MJ. Pre-clinical endodontic training with artificial instead of extracted human teeth: does the type of exercise have an influence on clinical endodontic outcomes? *Int Endod J.* 2015 Sep;48:888-93.
9. Khattak O, Ganji KK, Iqbal A, Altassan M, Khan FH, Anis R. Beyond labs: unveiling dynamics of dental students’ transition from pre-clinical to clinical training in a Saudi dental school. *PeerJ.* 2024;12:e18019.
10. Reis T, Barbosa C, Franco M, et al. 3D-Printed Teeth in Endodontics: Why, How, Problems and Future—A Narrative Review. *International Journal of Environmental Research and Public Health* 2022, Vol 19, Page 7966. 2022;19:7966.

11. Fayyaz Y, Ali M, Ullah R, Shaikh MS. Applications of 3D-printed teeth in dental education: A narrative review. *J Taibah Univ Med Sci.* 2024;19:816-822.
12. Meglioli M, Mergoni G, Artioli F, Ghezzi B, Manfredi M, Macaluso GM, Lumetti S. A Novel Self-Assessment Method for Training Access Cavity on 3D Printed Endodontic Models. *Dent J (Basel).* 2023 Jun;11:152.
13. Kucher M, Dannemann M, Modler N, Böhm R, Hannig C, Kühne MT. Determination of a Representative and 3D-Printable Root Canal Geometry for Endodontic Investigations and Pre-Clinical Endodontic Training-An Ex Vivo Study. *Dent J (Basel).* 2023 May;11:133.
14. Reymus M, Fotiadou C, Kessler A, Heck K, Hickel R, Diegritz C. 3D printed replicas for endodontic education. *Int Endod J.* 2019;52:123-130.
15. Ahmed HMA. A critical analysis of laboratory and clinical research methods to study root and canal anatomy. *Int Endod J.* 2022;55:229-280.
16. Pieper K, Lange J, Jablonski-Momeni A, Schulte AG. Caries prevalence in 12-year-old children from Germany: results of the 2009 national survey. *Community Dent Health.* 2013;30:138-142.
17. Jon A, Bsc CB. 3D Printing of Teeth from X-Ray Microtomography for the Purpose of Research and Training. Published online March 31, 2021. Accessed June 18, 2025. <https://qmro.qmul.ac.uk/xmlui/handle/123456789/86698>.
18. Anderson J, Wealleans J, Ray J. Endodontic applications of 3D printing. *Int Endod J.* 2018;51:1005-1018.
19. Lahoud P, Jacobs R, Boisse P, EzEldeen M, Ducret M, Richert R. Precision medicine using patient-specific modelling: state of the art and perspectives in dental practice. *Clinical Oral Investigations* 2022 26:8. 2022;26:5117-5128.
20. dos S Luz D, de S Ourique F, Scarparo RK, Vier-Pelisser FV, Morgental RD, Waltrick SB, de Figueiredo JA. Preparation time and perceptions of Brazilian specialists and dental students regarding simulated root canals for endodontic teaching: a preliminary study. *J Dent Educ.* 2015 Jan;79:56-63.

21. Ramírez-Muñoz A, Escribano-Capdevila M, Navarrete N, Vieira GCS, Salamanca- Ramos M, Ortolani-Seltenerich PS, Aranguren J, Pérez AR. Comparative Micro-CT Analysis of Minimally Invasive Endodontic Systems Using 3D-Printed Replicas and Natural Teeth. *Materials* (Basel). 2024 Oct;17:5279.
22. Dosch M, Schwendicke F, Tseng PC, Spies BC, Keßler A. 3D-Printed Multi-Coloured Teeth Comprising Material Gradients for Dental Education-A Pilot Study. *Eur J Dent Educ*. 2026 Feb;30:197-204.
23. Bürklein S, Schäfer E, Donnermeyer D. Evaluation of a 3D-Printed Model as Complete Case Scenario in Undergraduate Dental Education-Diagnosis, Treatment Planning and Clinical Practice. *Eur J Dent Educ*. 2026 Feb;30:133-147.
24. Higgins D, Hayes M, Taylor J, Wallace J. A scoping review of simulation-based dental education. *MedEdPublish* (2016). 2020 Feb;9:36.
25. Karagkounaki A, Manoukakis T, Margariti I, Pavlou C, Hadjichristou C. 3D Printing in Dental Education: A Review of Its Use across Disciplines. *J Dent Educ*. 2025 Oct;89:1479-1486.