

## RESEARCH AND EDUCATION

### The use of smart glasses for remote or virtual instruction in CAD-CAM dentistry: A randomized controlled trial



Tim Hausdörfer,<sup>a</sup> Silke Kükemück,<sup>b</sup> Felix Marschner,<sup>c</sup> Jana Biermann,<sup>d</sup> Philipp Kanzow,<sup>e</sup> Annette Wiegand,<sup>f</sup> and Clemens Lechte<sup>g</sup>

Direct supervision of less experienced operators in performing practical skills and clinical procedures has been reported to improve educational outcomes and the quality of patient care.<sup>1-4</sup> The use of computer-aided design and computer-aided manufacturing (CAD-CAM) in restorative dentistry requires instruction and training to attain expertise in the design and fabrication of dental restorations, especially with regard to the various intraoral scanners or software program applications that can be used.<sup>5-12</sup> With an increasing variety of products and limited access to in-person instruction and supervision, alternative training and instruction methods are needed.

One option for remote instruction has been the use of head-mounted smart glasses that allow either a live streaming for remote supervision and guidance of the operator or placement of virtual

#### ABSTRACT

**Statement of problem.** The use of computer-aided design and computer-aided manufacturing (CAD-CAM) in restorative dentistry requires instruction and training. Given the increasing product diversity and limited availability of in-person instruction and support, it is unclear if alternative training methods are beneficial.

**Purpose.** The purpose of this randomized controlled trial was to analyze the use of smart glasses for remote or virtual instruction of digital scanning and crown design by using a CAD software program and to compare working time and quality of treatment with in-person instruction and with no instruction.

**Material and methods.** Sixty-six participants received an introduction to the use of an intraoral scanner and a CAD software program and were then randomly assigned to 1 of 4 groups, in-person instruction ( $n=16$ ), remote instruction via smart glasses ( $n=16$ ), virtual instruction (slidecast) via smart glasses ( $n=16$ ), or control (no instruction,  $n=18$ ). All participants made a digital scan of a training model, followed by the design of a ceramic crown. Total working time, as well as the quality of the scan, the virtual cast, and the crown design, were assessed. Additionally, self-rated knowledge gain, usability of the smart glasses as assessed by the System Usability Scale (SUS) and the overall satisfaction within each intervention group were assessed. Statistical analysis was performed by Welch ANOVA followed by post hoc tests, Kruskal-Wallis tests followed by post hoc tests, and the  $t$  test ( $\alpha=.05$ ).

**Results.** Remote instruction ( $26.2 \pm 5.9$  minutes) and in-person instruction ( $25.3 \pm 3.9$ ), but not virtual instruction ( $32.7 \pm 5.1$ ) significantly reduced the time need compared to the control ( $32.6 \pm 9.4$  minutes,  $P \leq .041$ ). Quality of performance was not significantly different among groups ( $P \geq .055$ ). Self-rated knowledge after the CAD-CAM training did not differ among groups ( $P = .723$ ) and overall satisfaction was higher for remote and in-person instructions than virtual instruction ( $P_{\text{adj.}} < .001$ ), but did not differ between both ( $P_{\text{adj.}} = .579$ ). SUS was not significantly different for remote compared to virtual instruction ( $P = .174$ ).

**Conclusions.** Remote supervision via smart glasses was found to be comparable to in-person supervision in terms of time requirements and workflow quality. (J Prosthet Dent 2026;135:393.e1-e6)

user instructions in an augmented-reality approach.<sup>13-15</sup> Smart glasses have been tested in industry,<sup>16,17</sup> while in

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<sup>a</sup>Senior Lecturer, Department of Preventive Dentistry, Periodontology and Cariology, University Medical Center Göttingen, Göttingen, Germany.

<sup>b</sup>Employee, G3-7 Information Technology, University Medical Center Göttingen, Göttingen, Germany.

<sup>c</sup>Senior Lecturer, Department of Preventive Dentistry, Periodontology and Cariology, University Medical Center Göttingen, Göttingen, Germany.

<sup>d</sup>Senior Lecturer, Department of Preventive Dentistry, Periodontology and Cariology, University Medical Center Göttingen, Göttingen, Germany.

<sup>e</sup>Professor and Head of Department, Department of Restorative Dentistry, Periodontology and Endodontology, University Medicine Greifswald, Greifswald, Germany.

<sup>f</sup>Professor and Head of Department, Department of Preventive Dentistry, Periodontology and Cariology, University Medical Center Göttingen, Göttingen, Germany.

<sup>g</sup>Senior Lecturer, Department of Preventive Dentistry, Periodontology and Cariology, University Medical Center Göttingen, Göttingen, Germany.

## Clinical Implications

The use of CAD-CAM systems could be taught via remote training by using smart glasses, as this saves time and personnel resources.

dentistry, the use of augmented-reality devices that present additional digital information, such as radiological data, onto the visual field of the operator, has been limited.<sup>18</sup> Also, remote supervision has been mainly tested in different medical settings,<sup>19–23</sup> partly indicating that remote supervision can be equally effective as in-person guidance.<sup>21,22</sup> The authors are aware of only 1 study that analyzed the use of remote instruction compared to face-to-face instruction in conventional impression making and reported a significant improvement in impression quality but no significant differences among groups.<sup>24</sup>

Consequently, this study aimed to analyze the use of smart glasses for remote or virtual instruction and to compare remote and virtual instruction with a negative (no instruction) and positive control (in-person instruction). The null hypotheses were that time, quality of performance, and self-rated knowledge gain would not differ among groups, that the usability of the smart glasses, as assessed by the SUS would not differ between the groups using smart glasses, and that overall satisfaction would not differ among each intervention group.

## MATERIAL AND METHODS

The study was performed at the University Medical Center Göttingen from November 2024 to April 2025. The study had been approved by the ethics committee of the University Medical Center Göttingen (approval number: 17/9/24) and registered in the German Clinical Trial Register (DRKS-ID: DRKS00035220). All participants had been informed about the aim of the study and the procedures and gave written informed consent before being enrolled in the study. The prospective randomized study was designed as a monocentric single-blinded controlled trial and was conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT) 2010 statement.<sup>25</sup>

Participants were recruited from fifth-year dental students at the University Medical Center Göttingen attending an Operative Dentistry course in the winter term 2024/25 ( $n=33$ ) and the summer term 2025 ( $n=33$ ). The participants were not experienced with the CAD-CAM system (CEREC; Dentsply Sirona) used in the study. Students that were repeating the Operative Dentistry course were excluded. Sample size calculation for 1-way Analysis of Variance (ANOVA) was

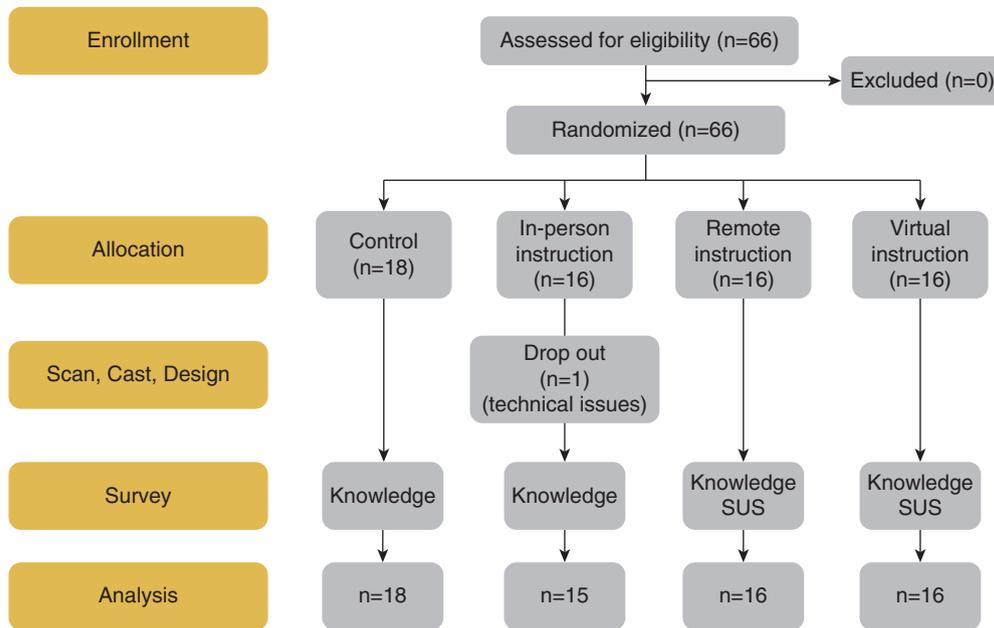
performed with a software program (G\*Power version 3.1 for Mac; Heinrich Heine University Düsseldorf). Based on preliminary data from the winter term 2024/25 showing an effect size of 0.5497 (required time), considering  $\alpha=.05$ , and 80% power, a sample size of  $n=11$  per group was calculated. After adjustment for pairwise comparisons ( $\alpha=.008$ ) a final sample size of at least  $n=15$  per group was determined. All eligible participants ( $n=66$ ) were included to counteract potential dropouts because of technical problems.

Participants received a 2-hour lecture on the use of the intraoral scanner (CEREC Primescan; Dentsply Sirona) and the CAD software program (CEREC software 5.2.x; Dentsply Sirona) and were then randomized to one of the intervention groups: control ( $n=18$ ), in-person instruction ( $n=16$ ), remote instruction ( $n=16$ ) and virtual instruction ( $n=16$ ) using a sealed envelope (Fig. 1). Participants in the remote and virtual instruction groups were first trained in the use of the smart glasses by 1 operator (S.K.).

In all groups, participants had to perform a digital scan and the construction of a virtual crown on a typodont (frasaco; frasaco GmbH) with a right second maxillary premolar prepared for a ceramic crown with supragingival and equigingival margins. The scans included the complete maxillary and mandibular jaw and a jaw relation record. The typodonts were fixed in the phantom heads of simulation units (DSEclinical 5197; KaVo). The use of the CAD software program included the administration (for example, selection of tooth, restoration, or material), the acquisition of the scan files, the creation of a virtual cast including the editing of preparation margins, and the virtual design of the ceramic crown.

In the control group, participants received no supportive feedback or guidance in scanning or using the CAD software program, except the information gained in the introductory lecture. All in-person instruction was provided by 1 experienced operator (T.H.) and included simultaneous feedback to improve the scanning technique and the use of the CAD software program. All remote instruction was performed by another experienced operator (C.L.) and was conducted directly by connecting the supervisor with the participants via smart glasses (Real Wear Navigator 500 HMT-1; Barotec). Participants could interact with the supervisor via the microphone in the glasses and receive live feedback on the workflow via the integrated camera and screen. During the virtual instruction, a slide show was played via the monitor and speakers of the smart glasses, showing the complete CAD-CAM workflow in images and recorded voice-over instructions.

In each intervention group, 4 participants performed the study simultaneously.



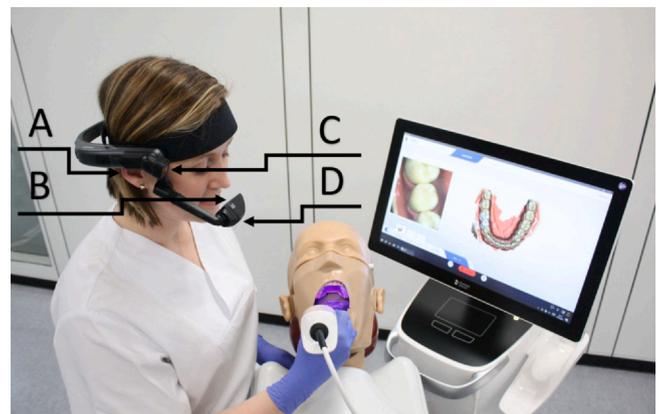
**Figure 1.** Study flowchart. SUS, System Usability Scale.

The time needed by the participants was assessed by measuring the total treatment time for administration, scanning, acquisition, virtual cast, and design. The time measured included all treatment steps, including any repetition of certain steps if required. In case that a participant in the control group or in the group with virtual instruction was unable to complete a step even after repetition, the step was performed by 1 of the supervisors (T.H., C.L.) and the quality assessment of this step was rated negative. The quality of the individual steps was independently assessed by 2 calibrated blinded examiners (J.B., F.M.) who assessed the scan, the virtual cast, and the design of the crown with a pretested spreadsheet that included 9 items for the scan, 5 items for the virtual cast, and 12 items for the crown design (Table 1). Each item was evaluated by using a 0 (negative) or 1 (positive) rating scale. In case of discrepancies, ratings were discussed between both raters until a consensus was achieved. For statistical analysis, item scores (percentage of positive ratings) in each category were averaged.

At the end of the study, all participants were asked to fill out an electronic questionnaire (evasys; evasys GmbH) to self-rate their knowledge regarding CAD-CAM dentistry before and after completing the CAD-CAM training. Subsequently, the effectiveness of each intervention was calculated from the comparative self-assessments of the students.<sup>26</sup> In addition, participants from the intervention groups were asked to rate their overall satisfaction on a 5-point Likert scale (1: high, 5: low). The use of the smart glasses (remote and virtual instruction only) was assessed by the German language version of the SUS.<sup>27,28</sup> The SUS has been a widely used standardized questionnaire for the

assessment of perceived usability.<sup>27</sup> Participants who used smart glasses received a standardized questionnaire with 10 statements, which they rated on a 5-point scale based on their accuracy. By using a fixed formula, a score was calculated from the answers, which classified usability into grades: 100 to 78.9 grade A (excellent), 78.8 to 72.6 grade B (good), 72.5 to 62.7 grade C (satisfactory), 62.6 to 51.7 grade D (poor), and less than 51.7 grade F (very poor).<sup>29</sup>

The smart glasses (Real Wear Navigator 500 HMT-1; Barotec) (Fig. 2) were voice-controlled, head-mounted tablets that could be operated hands-free via voice recognition using the integrated microphone. A fully adjustable micro-display equivalent to a screen of approximately 854×480 pixels (corresponding to 15.5×8.7 cm) and a 16-megapixel (MP) camera enabling real-time



**Figure 2.** Use of smart glasses (Real Wear Navigator 500 HMT-1; Barotec) during intraoral scan (Cerec Primescan, Dentsply Sirona). A: speakers, B: screen, C: camera, D: microphone.

**Table 1.** Evaluation sheet for quality assessment

	Treatment step	Scoring
Scan	Maxillary jaw	87.7
	Mandibular jaw	92.3
	Jaw relation record	87.7
	Preparation mesial	100.0
	Preparation distal	98.5
	Preparation buccal	98.5
	Preparation proximal	98.5
	Neighboring tooth mesial to preparation	96.9
	Neighboring tooth distal to preparation	90.8
	Cast	Preparation margin mesial
Preparation margin distal		86.2
Preparation margin buccal		83.1
Preparation margin oral		84.6
Adjustment of virtual casts		76.9
Design	Minimum material thickness occlusal	87.7
	Minimum material thickness oral	87.7
	Minimum material thickness buccal	86.2
	Occlusion	90.8
	Proximal contact mesial	83.1
	Proximal contact distal	92.3
	Tooth axis	98.5
	Crown size and anatomy oral	92.3
	Crown size and anatomy buccal	96.9
	Marginal ridge mesial	56.9
Marginal ridge distal	0.0*	
	Occlusal surface (cusp and fissure relief)	93.8

Scoring in % of positive ratings.

\*For all participants the distal marginal ridge positioned too low, since the position suggested by software program not adjusted.

video chat in full high definition (HD) were integrated into the system. In the remote instruction group, the smart glasses were connected via wireless local area network (WLAN) to the internet. The remote instruction was delivered using a CE-certified medical device software program (XpertEye Software; AMA Xpert Eye GmbH) running on the smart glasses and also in the web browser (Google Chrome Desktop Version 13x.x; Google LLC) of the personal computer of the instructor. This software program complied with the General Data Protection Regulation. The supervisor was located in a separate room and was able to monitor 4 participants at the same time on 4 different screens (minimum resolution 1280×1024 pixels). Communication with individual participants was enabled by selective activation and deactivation of audio. In the virtual instruction group, a slide show showing the complete CAD-CAM workflow in 27 steps and including recorded voice-over instructions was displayed on the screen of the smart glasses using a software program (Proceedix; SymphonyAI).

**Table 2.** Total working time (minutes), quality (% of positive scores) of scan, cast, and design, self-rated knowledge gain, and overall satisfaction in different groups

	Control (mean ±SD)	In-person instruction (mean ±SD)	Remote instruction (mean ±SD)	Virtual instruction (mean ±SD)
Time (min)	32.6 ±9.4 <sup>a</sup>	25.3 ±3.9 <sup>b</sup>	26.2 ±5.9 <sup>b</sup>	32.7 ±5.1 <sup>a</sup>
Scan (%)	93.8 ±10.2	98.5 ±3.9	96.5 ±6.7	89.6 ±13.1
Cast (%)	77.8 ±26.5	86.7 ±18.0	85.0 ±21.3	81.3 ±24.7
Design (%)	75.9 ±15.3	86.7 ±6.1	82.8 ±8.9	77.6 ±17.9
Knowledge gain (%)	69.0 ±20.2	60.6 ±19.0	62.5 ±16.1	63.5 ±22.8
Overall satisfaction	n.a.	1.0 ±0.0 <sup>a</sup>	1.4 ±0.6 <sup>a</sup>	2.8 ±1.0 <sup>b</sup>

n.a., not applicable; SD, standard deviation. Different superscript letters indicate significant differences.

Statistical analysis was performed by using a software program (IBM SPSS Statistics for Macintosh, v29.0; IBM Corp). Inter-rater and intra-rater reliability of both raters was assessed using the Cohen  $\kappa$ . Data on working time (minutes), quality of scan, virtual cast, and design of the crown (%), self-rated knowledge gain (%), overall satisfaction, and SUS were submitted to Kolmogorov-Smirnov test and Shapiro-Wilk test to check normal distribution. Homoscedasticity (variance homogeneity) was assessed by the Levene test. As data on working time were normally distributed but failed variance homogeneity, the Welch ANOVA followed by Bonferroni post hoc tests was applied. Data on the quality of scan, virtual cast, and design of the crown, as well as data on the self-rated knowledge gain and overall satisfaction, were not normally distributed and analyzed by Kruskal-Wallis tests followed by post hoc tests. Normal distributed data on SUS were compared by 2-sided  $t$  test between remote and virtual instruction ( $\alpha=.05$  for all tests).

## RESULTS

All participants except one completed the study. One participant of the group receiving in-person instruction had to be excluded because of technical issues during the study (Fig. 1).

Inter-rater and intra-rater reliability of both raters amounted to 0.625 and 0.779, respectively. Based on these values, strength of agreement was regarded as substantial.<sup>30</sup>

Total mean ±standard deviation working time in the control group was 32.6 ±9.4 minutes. Virtual instruction was not significantly different from the control ( $P>.999$ ), while in-person instruction ( $P=.014$ ) and remote instruction ( $P=.036$ ) both required significantly less time and were not significantly different from each other ( $P>.999$ ). Qualities of the scan ( $P=.060$ ), the virtual cast ( $P=.738$ ), and the crown design ( $P=.055$ ) were not significantly different among groups. Self-rated knowledge gain varied between 60.6% and 69.0%, but did not differ between groups ( $P=.723$ ). Overall satisfaction did not differ between remote and in-person instruction ( $P_{\text{adj.}}=.579$ ), but virtual instruction resulted in a lower rating ( $P_{\text{adj.}}<.001$ ) (Table 2). SUS was scored 67.2 ±13.1 (grade C) for remote instruction and

59.8 ±16.5 (grade D) for virtual instruction but was not significantly different ( $P=.174$ ).

## DISCUSSION

This study analyzed a smart glasses-based instruction technique in a digital workflow, specifically intraoral scanning and CAD-based crown design in terms of total working time and quality of performance. The required time was reduced by remote or in-person instruction, but the performance quality and the self-rated knowledge gain did not differ significantly between the groups ( $P>.05$ ). Thereby, the null hypothesis that time, quality of performance, and self-rated knowledge gain would not differ among groups was partly rejected. The SUS did not differ between the groups using smart glasses; thereby, the null hypothesis that the usability of the smart glasses, as assessed by the SUS would not differ between the groups using smart glasses was not rejected. Since the overall satisfaction was lower among participants receiving virtual instruction compared to remote or in-person instruction, the null hypothesis that overall satisfaction would not differ among each intervention group was rejected.

Both remote and in-person instructions were performed by qualified trainers as instructor qualification has been reported to be related to student achievement.<sup>31</sup> Remote instruction was able to improve the working time to the level of in-person instruction, most probably as it allowed for real-time interaction and support similar to the face-to-face instruction. In-person and remote instruction of dental skills have different advantages. While in-person instruction allows for direct observation of the demonstrated practical skills, the use of smart glasses provides the same view for trainer and trainee, allowing the trainer to guide the trainee through the task.<sup>15,24</sup> Concomitantly, satisfaction ratings were rated equally positive for in-person instruction and remote instruction.

In contrast, virtual instruction by placement of user instructions into the screen of the smart glasses did not lead to time improvement. Studies<sup>16,17</sup> on assembly tasks also reported no improvement in completion time by virtual instruction compared to paper-based or tablet instructions. Potential explanations include additional time and cognitive resources for operating the smart glasses, visual or mental fatigue, ergonomics, distraction, or different information processing.<sup>16,17</sup> The additional time need and cognitive resources might also account for the relatively low SUS found in the present study. As all participants used smart glasses for the first time, their repeated use might improve SUS. Experience with the devices or software program has been reported to lead to an increase in SUS of up to 15% compared to inexperienced users.<sup>16,17,28</sup>

Limitations of the study included that participants wore the smart glasses for only approximately 30 minutes, and

no comparisons were made with other types of glasses. As a result, it remains unclear how extended use or the use of lighter, more compact smart glasses might have influenced the SUS scores. Additionally, the study was confined to a single scenario within a more complex treatment process. Important factors such as tooth preparation or crown cementation were not considered, which may limit the generalizability of the findings.

Further reasons for the similar quality between the groups might be attributed to the design of the study and the CAD software program used. All participants received an introductory lecture addressing the use of the intraoral scanner and the CAD software program so that basic knowledge was achieved in all groups, limiting a potential beneficial effect by further instruction. Moreover, the CEREC system used in this study provided step-by-step guidance, which might even allow inexperienced users to perform the different tasks. In a previous study, the CEREC system was rated as easier to use, more user-friendly, functional, and effective compared to other systems.<sup>12</sup> These reasons might also explain why no differences in the performance were observed among the different instruction groups.

Remote supervision via smart glasses was found to be comparable to in-person supervision regarding time efficiency and workflow quality. Therefore, the use of CAD-CAM systems might be successfully taught via remote training by using smart glasses, as this saves time and personnel resources. Beyond educational use, smart glasses offer potential in clinical dental applications. Their use in medical fields, including emergency care and nursing has shown improvements in communication, situational awareness, and decision-making under pressure.<sup>23,32</sup> In dentistry, these capabilities could support live remote supervision during intraoral scanning or preparation assessment, providing experienced input without requiring the physical presence of instructors.

The present findings also suggest that smart glasses may enable effective delegation of digital tasks. Beyond dental assistants or dental laboratory technicians, even semi-skilled personnel could perform intraoral scans or other CAD-related steps under real-time supervision, relieving clinical workload and optimizing team-based workflows, particularly in settings where personnel resources are limited.

Patient perception may present a barrier to the clinical implementation of smart glasses. Experimental and qualitative findings suggest that such devices can reduce perceived warmth, trustworthiness, and competence—particularly when the smart glasses appear bulky or unfamiliar.<sup>33</sup> However, these concerns have been reported to have limited influence on clinicians' willingness to adopt the technology in practice,<sup>34</sup> suggesting that while patient-facing concerns should not be overlooked, clinical implementation may still be feasible when supported by

careful introduction and design considerations. Patient-focused research in dentistry is needed to better understand acceptance and guide implementation.

Future research should also investigate long-term learning effects, clinical implementation, and the integration of smart glasses with artificial intelligence; for example, for real-time error detection or scan quality assessment. Aspects such as hygiene and cost-efficiency also need to be addressed.

## CONCLUSIONS

Based on the findings of this randomized controlled trial, the following conclusion was drawn:

1. Remote instruction via smart glasses was found to be a promising support method because it was comparable to personal instruction in terms of time requirement and workflow quality.

## PARTICIPANT CONSENT

All participants were informed about the aim of the study and the procedures and gave written informed consent before being enrolled in the study.

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### Corresponding author:

Dr Tim Hausdörfer  
Department of Preventive Dentistry, Periodontology and Cariology  
University Medical Center Göttingen  
Robert-Koch-Straße 40  
Göttingen 37075  
GERMANY  
Email: tim.hausdoerfer@med.uni-goettingen.de

### CRedit authorship contribution statement

**Tim Hausdörfer:** Conceptualization, Methodology, Writing – Original draft, Supervision, Investigation, Data curation; **Silke Kükemüick:** Conceptualization, Methodology, Supervision, Resources; **Felix Marschner:** Investigation, Writing – Review & Editing; **Jana Biermann:** Investigation, Writing – Review & Editing; **Philipp Kanzow:** Formal analysis, Writing – Review & Editing; **Annette Wiegand:** Conceptualization, Writing – Original draft; **Clemens Lechte:** Conceptualization, Methodology, Writing – Original draft, Investigation.

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