How Does 3D Printing-Based Assistive Device Training Shapes Cognitive Flexibility and Professional Behavior in Occupational Therapy Students?

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Abstract

Aim: This study investigated the effectiveness of experience-based learning in 3D-printing-based assistive device training to shape occupational therapy students' cognitive flexibility and professional behavior skills.

Method: Sixty undergraduate occupational therapy students were involved in this study and were randomly allocated to control or training group. The training group received six weeks of hands-on training in 3D-printing-based assistive devices. Informative brochures related to each week's topics were provided to the control group for six weeks. Cognitive flexibility and professional behavior were measured with the Cognitive Flexibility Inventory and Professional Behavior Questionnaire before and after the training.

Results: A significant improvement in post-training cognitive flexibility scores was observed in both the control group (p=0.020) and the training group (p=0.003). However, a significant in-group change in professional behavior was found only in the training group (p=0.001). Post-training professional behavior scores were significantly higher in the 3D-G compared to the CG, with a medium effect size for the difference (p=0.006; Cohen's d=0.745).

Conclusion: 3D printing-based assistive device training has fostered students' professional behavior. Future studies are recommended to examine the short- and long-term effects of interdisciplinary and student-based training on cognitive flexibility and professional behavior.

Keywords: 3D printing, occupational therapy, assistive technology, cognitive flexibility, professional behavior.

3B Yazıcı Tabanlı Yardımcı Cihaz Eğitimi Ergoterapi Öğrencilerinde Bilişsel Esnekliği ve Profesyonel Davranışı Nasıl Şekillendirir?

Öz

Amaç: Bu çalışma, 3 boyutlu yazıcı tabanlı yardımcı cihaz eğitiminin deneyime dayalı öğrenme yöntemi ile ergoterapi öğrencilerinin bilişsel esneklik ve mesleki davranış becerilerini şekillendirmedeki etkinliğini araştırmayı amaçlamıştır.

Yöntem: Çalışmaya 60 lisans düzeyinde Ergoterapi öğrencisi katılmış ve rastgele şekilde kontrol veya eğitim grubuna atanmıştır. Eğitim grubu, altı hafta boyunca 3 boyutlu yazıcı tabanlı yardımcı cihaz eğitimi almıştır. Kontrol grubuna ise her hafta işlenen konularla ilgili bilgilendirici broşürler verilmiştir. Bilişsel

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esneklik ve mesleki davranış, eğitim öncesi ve sonrası Bilişsel Esneklik Envanteri ve Mesleki Davranış Anketi ile ölçülmüştür.

Bulgular: Hem kontrol grubunda (p=0,020) hem de eğitim grubunda (p=0,003) eğitim sonrası bilişsel esneklik puanlarında anlamlı bir artış olmuştur. Mesleki davranışta ise gruplar içindeki değişim sadece eğitim grubunda anlamlı bulunmuştur (p=0,001). Mesleki davranış, 3 boyutlu yazıcı eğitim grubunda, kontrol grubuna göre anlamlı derecede daha yüksek olup orta etki büyüklüğüne sahiptir (p=0,006; Cohen's d =0,745).

Sonuç: 3 boyutlu yazıcı tabanlı yardımcı cihaz eğitimi alan öğrencilerin mesleki davranışlarına ilişkin tutumları gelişmiştir. Gelecekteki çalışmaların, disiplinler arası ve öğrenci tabanlı eğitimlerin bilişsel esneklik ve mesleki davranış üzerine kısa ve uzun vadeli etkilerini incelemesi önerilir.

Anahtar Sözcükler: 3 boyutlu yazıcı, ergoterapi, yardımcı teknoloji, bilişsel esneklik, mesleki davranış.

Introduction

Occupational therapists (OTs) play a crucial role within multidisciplinary teams in utilizing, recommending, and designing assistive technologies to support individuals' participation in meaningful and purposeful occupations, promote independence, and enhance health. Assistive technology applications, addressed with a client-centered approach, fall under the "assistive devices/products" category and aim to eliminate barriers to participation and fulfilling roles[1]. Among these technologies, three-dimensional (3D) printing has emerged as one of the most preferred applications, offering personalized, cost-effective, and rapid production capabilities. Advances in customized manufacturing technologies provide OTs with significant advantages in assistive device applications but also necessitate mastery of these technologies in design and production[2].

The use of 3D printing in rehabilitation is rapidly expanding due to the absence of mold requirements and its cost-effectiveness compared to mass production[3]. However, the literature emphasizes the scarcity of professionals with the necessary technological expertise and the need for education to support widespread use[4,5]. In health sciences undergraduate education, studies on 3D printing primarily focus on medical and dental education for learning anatomical models and surgical practice, while vocational schools and nursing education use this technology for simulation and patient education purposes. Feedback and evaluations from students included in these studies indicate increased motivation for their professions and improved problem-solving skills[6-8]. These findings suggest that similar training could have positive effects on occupational therapy (OT) students, who play a role in supporting independence and participation.

Over the past five years, experiential learning processes involving 3D printing have gained momentum to enhance OT students' competencies in assistive device production. However, these studies report barriers to the adoption of new technologies, including technical inadequacies, difficulties in accessing technology in education, and failure to grasp its importance in professional practice[9,10]. A review by Yıldırım, Yıldırım, & Çelik on the instructional use of 3D printing highlights that while the technology has great potential in education and related subfields, it remains underexplored, with limited

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studies in Turkey. These studies are primarily concentrated on medical and nursing education[11].

OT interventions are conducted collaboratively with clients and require ongoing clinical reasoning. Clinical reasoning is a dynamic process that enables professionals to adapt to changing circumstances related to the client and the intervention plan by utilizing cognitive flexibility skills. Individuals with strong cognitive flexibility can replace challenging or maladaptive thoughts with more balanced and adaptive ones, generate alternatives, and evaluate difficult situations as more manageable. The integration of technological advancements into OT interventions and the preference for client- and situation-specific approaches/designs are part of the clinical reasoning process, requiring professionals with high cognitive flexibility[12-15]. Professional behavior development is also a crucial aspect of OT education that needs to be developed, including communication skills, empathy, and responsibility[16]. Studies highlight the need for a bridge between theory and practice to foster professional behavior in students, especially for Generation Z[17].

A review of the national core education curriculum for OT shows that assistive technology-related courses are primarily delivered through theoretical methods, case-based discussions, and article presentations. This emphasized the need for a method that actively involves students in the learning process[18]. 3D printing technology for designing and producing assistive devices in OT education is limited, only one study was found in Turkey[19]. Therefore, this study aims to investigate the effects of practical training in assistive device production using 3D printing technology on cognitive flexibility and professional behavior.

The study hypotheses are the following:

Hypothesis 1: 3D printing-based assistive device training would enhance cognitive flexibility in OT students.

Hypothesis 2: 3D printing-based assistive device training would foster positive professional behavior in OT students.

Materials and Methods

Research Type

This study used an experimental, randomized-controlled, and pre-test/post-test study design.

Study Population and Sample

The population of this study consisted of OT undergraduate students studying in the 2nd, 3rd, and 4th grades. The sample consists of students studying in the department of OT (except entry-level) at İstanbul Atlas University. Seventy OT students who could be included in the study were evaluated for eligibility for inclusion. A total of 68 participants were included in this study (Figure 1). The students were divided into two groups, the

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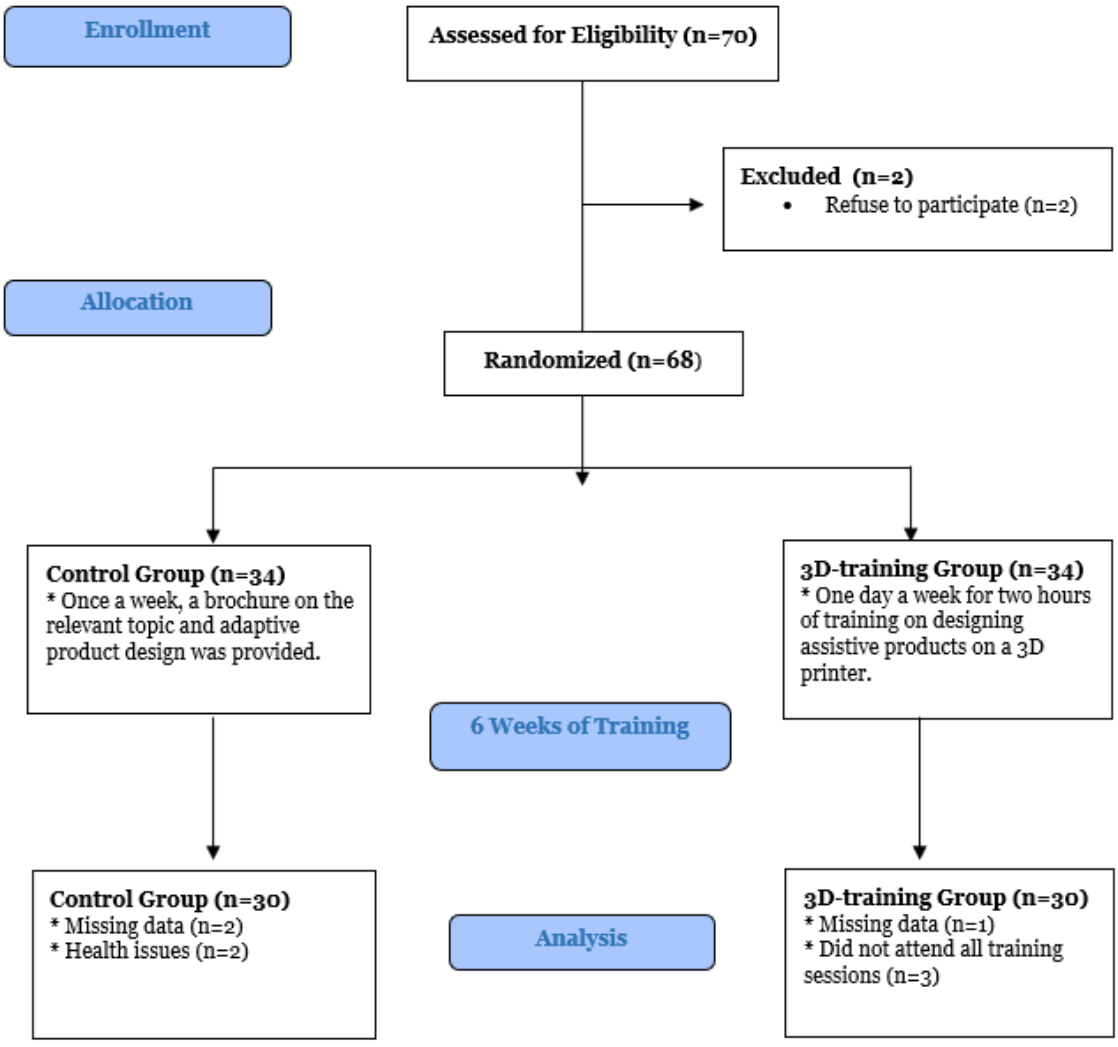
control group (CG) and the 3D-training group (3D-G), using the block randomization method through the website randomizer.org. Overall, 60 participants, 30 in each group, were completed the study.

Figure 1. Flow chart of the study



The inclusion criteria for participants were being a student in the OT department and not having received any training on 3D printing. The exclusion criteria were being an entry-level student and unable to participate in 6 consecutive weeks of training program.

Data Collection Tools

Demographic characteristics of the participants were recorded. Cognitive flexibility and professional behavior were evaluated with self-assessment tools, the Cognitive Flexibility Inventory, and the Professional Behavior Questionnaire, respectively. The assessments were collected before training and after training.

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Cognitive Flexibility Inventory (CFI): The Cognitive Flexibility Inventory (CFI) developed by Dennis and Vander Wal was used to measure the cognitive flexibility levels of students[20]. The CFI, whose Turkish validity and reliability study was conducted by Gülüm & Dağ is a 5-point Likert-type scale. The CFI aims to measure the ability of adaptive and problem-solving solutions that may arise in life. A high score indicates a good level of cognitive flexibility skill[14].

Professional Behavior Questionnaire (PBQ): Professional behavior was assessed with the "Professional Behavior Questionnaire (PBQ)" which was developed by Yuen, Azuero, Lackey, Brown, & Shrestha and validated for reliability and validity in Turkish among occupational therapy students[21,22]. This instrument is reported to be useful for educators to monitor the affective domain of professional behaviors of health professions students, which is essential for success in clinical placements. The PBQ consists of 28 items and questions related to willingness to learn, learning skills, and cultural competence. Higher scores indicate higher levels of professional behavior.

3D Printing-Based Assistive Device Training (3D-T)

The students in the 3D-G completed the practical training of assistive device production with a 3D printer (Printer model: Creality Ender-3 V3 SE) (Figure 2), which was planned for 1 day and 2 hours per week for 6 weeks. Within the scope of the training, a program was created based on “learning by doing” and “peer learning” approaches, with examples from the studies conducted in this field in the literature[2].

Figure 2. 3D printer and bag holder assistive device

In the 1st and 2nd weeks of 3D-T, technical knowledge of 3D printer technology, usage and materials, the concept of assistive device and its production with 3D printer were covered and prototypes were made. During weeks 3 and 5, students were divided into groups to research and print assistive technology for various case studies (experiences from summer internships) and problems in the fields of neurological, pediatric, geriatric, and hand rehabilitation. In the last session of the training (6th week), students were encouraged to create an original design by taking 3D images of real objects or body parts through a mobile application (3D scanner app). Feedback was received and questions were answered after each training session. The assistive device examples are taken from

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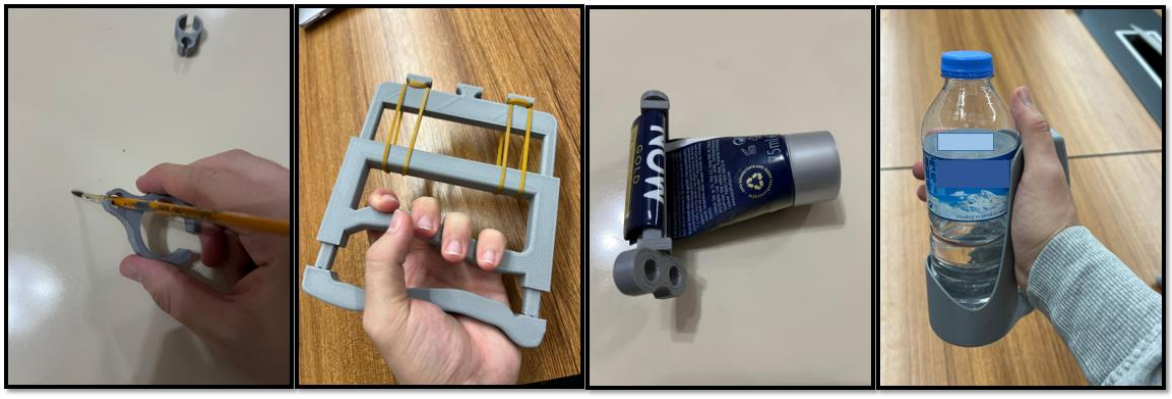
the thingiverse.com website. The meshmixer application, a computer program, was used when students created a customized design. Some of the examples of assistive devices are given in Figure 3.

Figure 3. 3D printed assistive device examples.



The students in the CG received weekly (for 6 weeks) hand-out brochures where general information about 3D printer technology and its usage areas in OT interventions (see Figure 4).

Figure 4. An assistive-technology brochure

Ethical Statement

This study was carried out at Istanbul Atlas University. Ethics committee approval for this study was obtained from the Non-Invasive Scientific Research Ethics Committee at Istanbul Atlas University (Decision No: E-22686390-050.99-46601, Approval Date: 22.07.2024). The study was conducted following the Declaration of Helsinki and informed consent was obtained from all participants before data collection.

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Data Analysis

Statistical analysis was conducted using SPSS v.26 (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was applied to evaluate the distribution of variables. Descriptive statistics are reported as mean ± standard deviation or percentage (%). Categorical variables were compared between groups using the χ2 test. Variables with normal distribution were compared using independent-sample t-test and paired-sample t-test. Wilcoxon signed-rank test and Mann-Whitney U test were used to compare variables that did not show normal distribution. Cohen's d effect sizes were calculated for between-group differences. Effect size benchmarks were categorized as <0.30, 0.30–0.80, and >0.80, representing small, medium, and large effect sizes, respectively[23]. The difference between the mean values was calculated by taking the difference of the mean values obtained from the pre- and post-training values and showed by the symbol **Δ** in the tables. The results were considered significant with p values <0.05.

Post Hoc Power Analysis

A post hoc power analysis was conducted to assess the statistical power of the independent samples t-test used to compare professional behavior scores between two groups estimated using the software program G*Power (version 3.0.10)[24]. The analysis was performed using the following parameters: a two-tailed test, an alpha error probability (α) of 0.05, a sample size of 30 participants per group (total n=60), and an effect size (Cohen's d) of 0.745, achieving a statistical power of 81%.

Results

The study sample consisted of 60 students in the CG (n=30) and 3D-G (n=30), with mean ages of 20.92±1.32 and 21.63±1.37 years, respectively. A comparison of the demographic data and baseline values for these individuals is presented in Table 1. No significant difference was found between the two groups' baseline characteristics.

Table 1. Demographics and baseline values of the participants.

	CG (n=30)	**3D-G (n=30)**	**t**	**p**
Age (years±SD)	20.92±1.32	21.63±1.37	-1.970	0.054
Gender, n (%)				
Male	23 (85.2)	26 (86.7)		0.872
Female	4 (14.8)	4 (13.3)		
Body composition				
Weight (kg)	58.22±8.39	60.53±9.62	-.961	0.341
Height (cm)	165.22±6.22	165.53±5.34	-.203	0.840
BMI (kg/m2)	21.31±2.65	22.14±3.00	-1.095	0.278
Study Year, n (%)				
2nd Year	9 (33.3)	8 (26.7)		0.804

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3rd Year	14 (51.9)	16 (53.3)		
4th Year	4 (14.8)	6 (20.0)		
Place of Residence, n (%)				
Dormitory	5 (18.5)	3 (10.0)		0.648
Family Home	19 (70.4)	23 (76.7)		
Student House	3 (11.1)	4 (13.3)		
Self-academic Performance Rating, n (%)				
Very Good	-	1 (3.3)		0.360
Good	12 (44.4)	17 (56.7)		
Mid-level	15 (55.6)	12 (40.0)		
CFI (mean±SD)	74.48 ±6.46	74.03±5.88	.274	0.785
PBQ (mean±SD)	90.07±12.49	90.40±12.10	-.100	0.921

Data are presented as mean±standard deviation or n (%)

Abbreviations: cm: centimeter; kg: kilogram; COI: Cognitive Flexibility Inventory; PBQ: Professional Behavior Questionnaire

The comparison of in-group and inter-group changes in the assessment of the 3D-T on cognitive flexibility and professional behavior between the groups is shown in Table 2. A significant difference was found in the post-training values of cognitive flexibility score in both the CG (p = 0.020) and 3D-G (p = 0.003) compared to the pre-training values. Professional behavior in in-group change was significant only in the 3D-G (p = 0.001). There were no significant differences in cognitive flexibility scores between groups after training (p = 0.270). The positive shift in the professional behavior was significantly higher in the 3D-G compared to the CG, having a medium effect size for the difference (p = 0.006; dcohen = 0.745).

Table 2. Comparison of in-group and inter-group changes in cognitive flexibility and professional behavior before and after 6 weeks of training

	CG (n=30)				**3D-G (n=30)**				**Inter-group change (Δ) p**	**Effect Size Cohen's d**
	Pre-training	**Post-training**	**In-group change (Δ)**	**p**	**Pre-training**	**Post-training**	**In-group change(Δ)**	**p**		
CFI	74.48±6.46	76.96±7.06	2.48±5.21	**0.020**	74.03±5.88	78.46±6.70	4.43±7.63	**0.003**	0.270	0.298
PBQ	90.07±12.49	87.88±13.28	-2.18±13.26	0.400	90.40±12.10	96.30±12.48	5.90±7.68	**0.001**	**0.006**	**0.745**

Data are presented as mean±SD. Bold font indicates statistical significance. Abbreviations: COI: Cognitive Flexibility Inventory; PBQ: Professional Behavior Questionnaire

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Discussion

This study indicated that compared to education only delivered by the theoretical method and brochures, the 3D-ADT with the learning-by-doing method may positively contribute to professional behavior but not cognitive flexibility. This improvement has a medium effect size, pointing out that teaching in an experience-based way may provide a significant change in positive attitudes towards the occupation in students when introducing them to new technology related to their major field. Also, both methods increased cognitive flexibility, a skill needed for critical thinking and problem-solving, in each group. However, this result was limited only to within-group changes.

In recent years, 3D technology has gained prominence in OT practices, enabling professionals to adopt a client-centered approach and enhance the participation of individuals with various conditions[25,26]. Interestingly, while OTs show enthusiasm for assistive device solutions with 3D printing, they reported a lack of knowledge and time constraints[1]. This could be achieved by integrating appropriate and profession-related technology into the learning content and enabling experiential learning.

Experiential learning has been suggested as an effective educational method to increase cognitive flexibility in students for the challenges of the 21st century[27,28]. In this study, we faced OT students with designing and 3D printing assistive technology specific to problems in different areas of rehabilitation by introducing them to evidence-based experiential learning or only theoretical methods. The current study found that both methods were successful in promoting cognitive flexibility in students assigned to study groups. The findings of the current study are consistent with those of Veneri, who compared the results of two different methods (experiential learning with computer-assisted learning vs videotape) in physical therapy neurologic education and showed both methods were efficient in developing cognitive flexibility[29].

Prior studies have drawn attention to multidisciplinary approaches and end-user-involved designing methods to increase the cognitive skills necessary for critical thinking and clinical reasoning, especially to provide successful implementation of new technology and concepts in healthcare students[30-32]. In this study, hands-on 3D-T did not provide superiority compared to the theoretical method in terms of cognitive flexibility at the end of the six-week training program. It seems possible that these results are due to a lack of collaborative design solutions with other students studying in other health, art and design, and engineering departments. In addition, in some weeks of the training, OTs with expertise in different fields could have been invited, and a design could have been made through case discussions. Further studies that take these variables into account are needed to be undertaken to understand the determinants of cognitive flexibility in such training programs.

A comprehensive review by Kahlke, McConnell, Wisener, & Eva highlighted the gap between knowing and acting in health professions education and practice results in difficulty in demonstrating an effective attitude in professional life[33]. In this study, we aimed to build a bridge and found significant improvement in professional behavior at the end of the training in the 3D-G compared to the CG. Our results are in line with

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Değerli's findings, which showed the effectiveness of an 8-week assistive technology 3D printing course in OT students' acceptance of technology while cultivating a positive attitude toward one's profession[19]. Even short-term assistive device training with 3D printer had positive effects on students' self-efficacy and understanding of the role of OTs in this field[34].

Overall, most of the students in our study shared positive feedback about the training program and expressed their gratefulness to build confidence when working with new technologies. We hope that this study will help other researchers and educators when designing research and educational curricula.

Limitations

One of the limitations of our study is that, although there are studies in this field, we could not perform a priori sample size calculation due to the absence of a study directly including the parameters we used. Another limitation of the study was the instructor in this study (first author) was familiar to all students in both groups, which may have introduced bias in their adaptation to the program and their self-reported tools.

Conclusion

The evidence from this study suggests that technology-enhanced experiential learning helps develop professional behavior in OT students as they can relate to their future professional occupation. We believe that if we face our students' challenges of the future, they can feel confident to overcome most of the problems in their profession. In addition to this, working in healthcare requires cooperation with other disciplines, so this should be taken into consideration when designing educational programs to enhance cognitive flexibility which is needed for this century and critical thinking. More research is needed to better understand the long-term consequences of the effectiveness of these programs following up with students in professional life.

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Conflict of Interest: The authors have no conflict of interest to declare.

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