

# Can PEEK Be an Implant Material? Evaluation of Surface Topography and Wettability of Filled Versus Unfilled PEEK With Different Surface Roughness

Tarek Elawadly, BSc<sup>1\*</sup>  
 Iman A. W. Radi, MSc, PhD<sup>2</sup>  
 Amr El Khadem, MSc, PhD<sup>3</sup>  
 Reham B. Osman, MSc, PhD<sup>4</sup>

Polyetheretherketone (PEEK) composites are biocompatible materials that may overcome the esthetic and allergic problems of titanium dental implants. However, their potential for osseointegration with a subsequent survival rate is still questionable. The aim of this study was to evaluate the surface roughness and wettability of different surface-treated filled and unfilled PEEK specimens, which may be indicative of the osseointegration behavior and potential use of PEEK as an implant material. Unfilled, ceramic-filled (CFP) and carbon fiber-reinforced (CFRP) PEEK discs were prepared and left untreated or were surface treated with 50  $\mu$ , 110  $\mu$ , or 250  $\mu$  aluminum oxide particles. The roughness average (Ra) value of each disc was evaluated using a contact stylus profilometer. Their contact angles were measured to evaluate their wettability, which was compared among PEEK discs using ANOVA, followed by Bonferroni test for pairwise comparisons ( $P \leq .05$ ). Regarding the surface roughness, a significant difference was found between unfilled and filled PEEK when untreated and bombarded with 50 or 110 microns of aluminum oxide particles. For the contact angle, a significant difference was found only among the untreated PEEK materials. Among the evaluated PEEK materials, CFRP50, CFRP110 and CFP110 showed the most favorable Ra values with good wettability properties, thus being potential substrates for dental implants.

**Key Words:** dental implants, titanium, PEEK, surface topography, roughness average, wettability

## INTRODUCTION

Research and development in terms of implant materials, designs and surface modifications comprise the ongoing process for the production of the most optimal dental implant.<sup>1</sup> Titanium dental implants are considered the gold standard for replacing missing teeth because of their physical characteristics and biocompatibility.<sup>2,3</sup> However, esthetic concerns, increased demand for metal-free restorations, and reported allergic reactions associated with titanium have led to the search for alternative implant materials.<sup>4–8</sup>

Polyetheretherketone—commonly referred to as PEEK—was first introduced in the late 1990s as a high-performance thermoplastic polymer for replacing metal implant components. The material was initially used in orthopedics for the development of “isoelastic” hip stems and fracture fixation

plates, with a stiffness comparable to bone.<sup>9</sup> By April 1998, PEEK was commercially offered as a substrate for an implant material.

The implant material’s modulus of elasticity has an influence on the healing process, success, and survival rate of implant under different loading conditions. A modulus of elasticity that is close to that of bone will optimize the biomechanical load distribution between implant and surrounding bone and maintain bone implant contact (BIC).<sup>10</sup> Titanium alloys have a modulus of elasticity of 110 GPa compared to 3–4 GPa for natural unfilled PEEK. The modulus of PEEK’s elasticity can be tailored to reach 12–14 GPa, close to that of trabecular bone (10–14 GPa) and cortical bone (18–20 GPa). This can be achieved by impregnating PEEK with fillers such as ceramic particles and carbon fibers.<sup>9</sup> Furthermore, new PEEK composites of filled PEEK (as opposed to unfilled PEEK) are radiopaque, which is advantageous in the field of oral implantology.

Recent research focused on the bio-tribological properties of PEEK composites as bearing implant materials.<sup>11–14</sup> Although PEEK is biocompatible, chemically stable, and with an elastic modulus similar to that of normal bone, it is biologically inert.<sup>15</sup> A study comparing titanium, PEEK, and zirconia as implant materials revealed that PEEK has the lowest bone implant contact.<sup>16</sup> Recent efforts have focused on increasing the bioactivity of PEEK by impregnating bioactive materials into

<sup>1</sup> Prosthodontics Department, Faculty of Dentistry, Russian University, Cairo, Egypt.

<sup>2</sup> Faculty of Dentistry, Cairo University, Egypt.

<sup>3</sup> Prosthodontics, Faculty of Dentistry, Cairo University, Egypt.

<sup>4</sup> Removable Prosthodontics Department, Faculty of Dentistry, Cairo University, Egypt; Department of Oral Function and Prosthetic Dentistry, Section of Oral Implantology, Universiteit van Amsterdam and Vrije Universiteit, Amsterdam, The Netherlands.

\* Corresponding author, e-mail: dr.tawadly@gmail.com

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its substrate.<sup>17</sup> Furthermore, a surface treatment—or a combination of a surface treatment and surface coating—are suggested to activate the surface of PEEK dental implants. Moderately rough implant surfaces with Ra value in the range between 1–1.5  $\mu\text{m}$  allow for adhesion of osteoblasts with a high proliferation rate and optimal osseointegration.<sup>18,19</sup>

Wettability is another important factor for any implant surface and is considered important for both healing and osseointegration.<sup>18</sup> It can be described through the evaluation of advancing and receding contact angles.<sup>20</sup> Advancing contact angle, opposed to receding angle can be defined as the initial angle measured when a droplet of liquid touches the surface and is larger than the receding contact angle. The larger the difference between the two angles, the more hydrophilic the surface. The initial healing process occurs through the adsorption of protein and flow of blood clot over the surface.<sup>21</sup> Wettability of the implant surface will partly determine adhesion of osteoblasts and bone generation. Implants placed in bone are preferred to be hydrophilic with contact angles below 90° and a high surface energy for improved osteoblastic adhesion and subsequent osseointegration.<sup>18,21</sup> Therefore, the aim of this study was to evaluate the surface roughness and wettability of unfilled (UFP) vs carbon (CFRP) and ceramic-filled PEEK (CFP) when untreated or sandblasted by 50, 110 and 250  $\mu\text{m}$  aluminum oxide particles.

## MATERIAL AND METHODS

Forty-eight discs, 10 mm in diameter and 2.5 mm in thickness (Figure 1) were milled from 3 different PEEK materials using a 5-axis milling machine (SHERA SD108159, Werkstoff-Technologie GmbH & Co, Lemförde, Germany) and resulting in 3 different groups with 16 discs per group: UFP, CFRP, and CFP PEEK. Each group was randomly divided into 4 subgroups based on their surface treatment, with 4 discs in each subgroup. The first subgroup had no surface modification and was considered the control group. The other 3 subgroups were sandblasted with 50  $\mu\text{m}$ , 110  $\mu\text{m}$  and 250  $\mu\text{m}$  aluminum oxide particles.

### Sandblasting process

According to random allocation, the discs were sandblasted continuously for 10 seconds with aluminum oxide particles of 50  $\mu\text{m}$ , 110  $\mu\text{m}$ , or 250  $\mu\text{m}$  under a pressure of 5 bars at a fixed distance of 50 mm between the nozzle and the disc (Figure 2). After sandblasting, all discs were ultrasonically cleaned for 20 minutes using distilled water to remove any adherent aluminum oxide particles.<sup>22</sup> Each disc was then picked up with tweezers, dried with an air syringe, and then placed in a coded nylon bag until assessment time.

### Measuring the surface topography

Surface roughness of PEEK discs was measured using a 2D contact stylus profilometer (Talysurf Version i60, Metek UK, Gloucestershire, UK; Figure 3). The profilometer involves a metal probe with ball diamond tip 2 microns in radius. The metal probe has a vertical resolution of 16 nm along 1 mm vertical range. A transverse surface scan of each specimen was

performed on eight 0.25-mm sections (cut-off wavelength) at medium speed of 0.25 mm/sec to analyze the surface roughness. The distance examined at each scan was 2 mm (0.25 mm  $\times$  8 sections). The irregular vertical movements of the tip were plotted against the profile of the surface explored. At least 3 profilometric scans were performed at different parts of disc. The mean surface roughness of the 3 scans was determined using the built-in Ultra software (Q-link SPC, Taylor Hobson Ltd, Leicester, UK).

### Measuring the contact angle

Two controlled volume (0.1 mL) droplets of distilled water were deposited onto the surface of each disc by micropipette. After each droplet deposition, images were captured with a micro video system (Scope Capture Digital Microscope, Brightwell Technology Ltd, Guangdong, China) at 5 and 45 seconds for measuring the advanced and receding contact angles, respectively (Figure 4). The acquired images were analyzed using Java-based Image J software (National Institutes of Health, Bethesda, Md).

### Statistical analysis

Data were collected, tabulated, and statistically analyzed using IBM Statistical Package for Social Sciences (SPSS, Version 21, SPSS Inc, Chicago, Ill). Ra values and contact angles were described as means and standard deviations. Data were explored for normality using Shapiro-Wilk tests. Comparison among the 3 groups was done using two-way ANOVA followed by Bonferroni posthoc test for pairwise comparisons. *P*-value less than or equal to 0.05 was considered statistically significant.

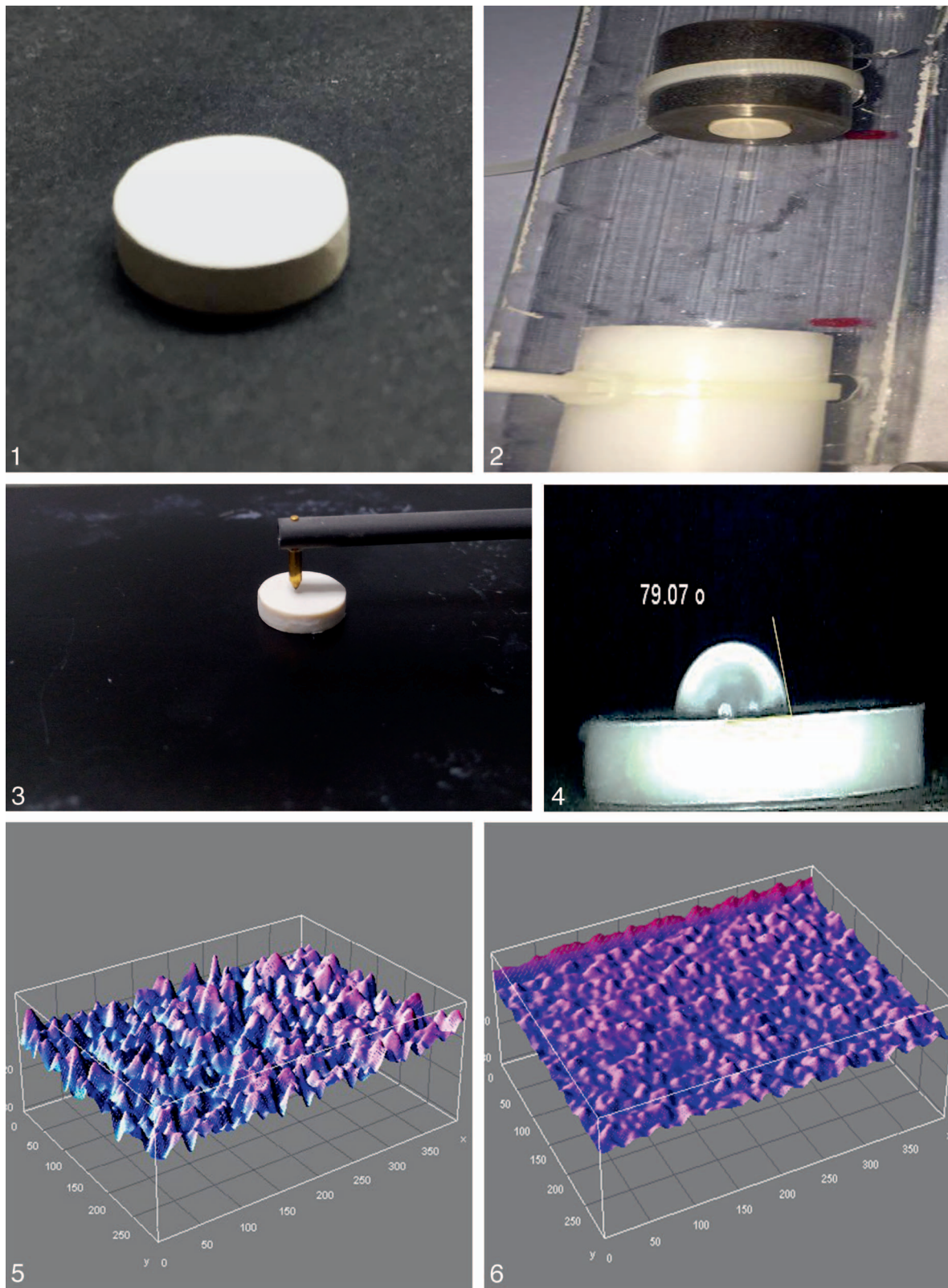
## RESULTS

### Surface topography

The recorded Ra values were in the range of 0.9  $\mu\text{m}$  to 2.14  $\mu\text{m}$ , as shown in Table 1. The highest and the lowest values were observed for CFRP250 (Figure 5) and UFP (Figure 6), respectively. In comparing the roughness average between UFP, CFRP, and CFP treated with similar particle sizes, a significant difference was found among groups—except for those treated with 250  $\mu\text{m}$  aluminum oxide particles. Pairwise comparisons revealed a significant difference between untreated UFP PEEK and the other two groups of untreated CFRP and CFP. Furthermore, a significant difference was found between CFRP and other 2 groups: CFP and UFP treated with 50 and 110  $\mu\text{m}$  (Table 2), where CFRP50 and CFRP110 showed the highest Ra values.

### Contact angle

UFP250 showed the highest advancing (95°) and receding (89°) contact angle values, while UFP50 revealed the lowest advancing (49°) and receding contact angle values (43.8°). For both contact angles, a statistically significant difference was found among the untreated PEEK groups (Tables 3 and 4).



**FIGURES 1–6.** **FIGURE 1.** Milled polyetheretherketone disc 10 mm in diameter and 2.5 mm thickness. **FIGURE 2.** Sandblasting done at a fixed distance (50 mm) between the nozzle and the disc. **FIGURE 3.** Measuring surface roughness using Talysurf. **FIGURE 4.** Measuring the advancing contact angle after 5 seconds. **FIGURE 5.** Surface plot of carbon fiber-reinforced polyetheretherketone (PEEK) treated with 250 microns aluminum oxide particles the highest roughness average value. **FIGURE 6.** Surface plot of unfilled PEEK the lowest roughness average value.

	CFRP		CFP		UFP		P value
	Mean	SD	Mean	SD	Mean	SD	
Untreated	1.27	0.15	1.46	0.14	0.91	0.14	.001*
50 $\mu\text{m}$	1.42	0.27	0.9	0.02	1.09	0.17	.01*
110 $\mu\text{m}$	1.71	0.25	1.55	0.25	1.23	0.14	.033*
250 $\mu\text{m}$	2.14	0.25	1.8	0.15	1.88	0.34	.207

\*Values that have statistically significant difference.

†CFRP indicates carbon fiber reinforced polyetheretherketone (PEEK); CFP, ceramic filled PEEK; UFP, unfilled PEEK.

Surface Treatment	G1	G2	P value
Untreated	Carbon	Ceramic	.272
	Carbon	Unfilled	.020*
50 $\mu\text{m}$	Ceramic	Unfilled	.001*
	Carbon	Ceramic	.010*
	Carbon	Unfilled	.098
110 $\mu\text{m}$	Ceramic	Unfilled	.557
	Carbon	Ceramic	1.000
	Carbon	Unfilled	.036*
250 $\mu\text{m}$	Ceramic	Unfilled	.189
	Carbon	Ceramic	.292
	Carbon	Unfilled	.558
	Ceramic	Unfilled	1.000

\*Values that have statistically significant difference.

†PEEK indicates polyetheretherketone.

ADV (5S) Surface Treatment	CFRP		CFP		UFP		P value
	Mean	SD	Mean	SD	Mean	SD	
Untreated	58.0	17.3	65.9	4.7	84.6	1.7	.016*
50 $\mu\text{m}$	66.3	17.2	67.8	10.7	49.1	16.6	.207
110 $\mu\text{m}$	89.3	26.1	63.8	25.4	88.3	6.3	.215
250 $\mu\text{m}$	87.4	9.2	91.1	8.6	95.3	6.0	.423

\*Values that have statistically significant difference.

†CFRP indicates carbon fiber reinforced polyetheretherketone (PEEK); CFP, ceramic filled PEEK; UFP, unfilled PEEK.

Receding 45S	CFRP		CFP		UFP		P value
	Mean	SD	Mean	SD	Mean	SD	
Untreated	51.6	17.2	59.3	6.2	80.4	0.8	.010*
50 $\mu\text{m}$	46.9	17.7	58.4	13.3	43.8	19.3	.467
110 $\mu\text{m}$	62.5	33.3	55.9	30.4	68.4	29.0	.850
250 $\mu\text{m}$	77.8	12.7	84.1	8.4	89.3	2.5	.241

\*Values that have statistically significant difference.

†CFRP indicates carbon fiber reinforced polyetheretherketone (PEEK); CFP, ceramic filled PEEK; UFP, unfilled PEEK.

## DISCUSSION

The aim of the current study was to evaluate the surface roughness and wettability of different PEEK materials with different surface treatments as potential indicators for future use in fabrication of dental implants. Surface roughness was evaluated using a 2D contact stylus profilometer. A 3D-white light interferometry was another option to evaluate the roughness average of the specimens; however, improper light reflection due to the color of PEEK samples hindered us from using this technique. Furthermore, the surface profiler readings are considered accurate due to the direct contact of the measuring stylus to the surface of the disc. Ra value was selected from among 16 other parameters to evaluate the specimens' roughness as it provides the average height of a set of individual measurements of the surface highest peaks and deepest valleys.<sup>18</sup> The disc dimensions of 10-mm diameter and 2.5-mm thickness were necessary to provide at least 3 profilometric measurements of the surface roughness each separated by 2 mm and to avoid disc fracture during the measurement procedures. Advancing and receding contact angles were measured for untreated and surface-treated PEEK specimens of different compositions. Chemical inhomogeneities due to cleanness of the examined surfaces were minimized by careful preparation and cleaning of each specimen prior to the experiment.<sup>22</sup> Further, random allocation and coding of the specimens as to surface treatment eliminated the possibility of performance bias due to improper handling. As shown in the results, Ra values ranged from 0.9–2.14  $\mu\text{m}$ . Surface roughness is influenced by many factors, including PEEK matrix, type of filler material, uniformity of material, size of sandblasting particles, and mechanical properties of the material.<sup>23</sup> These factors can explain the differences in the surface behavior of the specimens. The low Ra value of untreated UFP may be attributed to the uniformity of the material, which allows for easier machining compared to the other two groups. Untreated CFRP and CFP exhibit higher mechanical properties due to the presence of fillers with difficulty during machining and subsequent increase in surface roughness. The increased surface roughness observed in both UFP and CFRP following the surface treatment with 50  $\mu\text{m}$  aluminum oxide particles may be attributed to peaks and valleys created by the particles penetrating the specimens' surfaces. On the contrary, the decrease in the Ra values recorded for CFP can be explained by the hardness of the material, which is higher than both UFP and CFRP. Hardness of CFP may lead to difficulty during machining, creating an irregular surface with ceramic flecks. Sandblasting with 50  $\mu\text{m}$  particles results in removal of the ceramic flecks, but it could not penetrate deeper to create peaks and valleys responsible for the recorded surface roughness. After surface treatment with 110 and 250  $\mu\text{m}$  aluminum oxide particles, the specimens of 3 groups showed the same behavior with an increase in Ra values of treated specimens compared to the untreated samples. Nevertheless, the specimens of the CFP group showed the lowest increase in the Ra values that can also be explained by the material's hardness that resisted the sandblasting process. Scrutinization of the recorded Ra values reveals that the impregnation of filler particles results in a significant increase in the surface roughness compared to UFP. Furthermore, surface treatment of the UFP50, CFRP50, UFP110,

and CFP110 resulted in a moderately rough surface (1–1.5  $\mu\text{m}$ ) that is optimum for osseointegration of dental implants.<sup>18</sup> To further complement these findings, the specimens' wettability behavior was also evaluated. Both the advancing and receding contact angles of all the specimens were below 90° except for CFRP250 and CFP250. Contact angle below 90° indicates a good wettability of the surface, which is important for the processes of initial healing and osseointegration of the implant. The variation in contact angles recorded among the different groups can be attributed to the differences in chemical composition of the material and/or its surface roughness.

The results show that the contact angle decreases with the increase in the surface roughness but only to a certain limit, after which this relation was not observed. Water droplets cannot easily spread either on a low or a highly roughened surface. On smooth surfaces, there is lack of sufficient peaks and valleys for the liquid droplet to spread, while on highly roughened surfaces, the high peaks and deep valleys prevent the droplet from spreading on the surface.<sup>20</sup> Ra and contact angle values reveal that the wettability decreases when the Ra values are either below 1  $\mu\text{m}$  or above 1.7  $\mu\text{m}$ .

CFRP50, CFRP110, and CFP110 revealed moderately rough surfaces and low contact angles and are thus expected to exhibit favorable behavior in terms of osseointegration if used as an implant substrate. However, the results of this study should be considered preliminary due to limited number of specimens in subgroups. Larger scale in-vitro studies with increased specimen numbers are recommended as well as in-vivo animal studies to validate findings before these materials can be recommended for the fabrication of commercial dental implants.

## CONCLUSIONS

Among the evaluated PEEK materials, CFRP50, CFRP110, and CFP110 revealed the most favorable Ra values with good wettability properties and are thus potential substrates for osseointegrated implants. However, further in-vivo animal studies are recommended to confirm these findings.

## ABBREVIATIONS

CFP: ceramic filled PEEK  
 CFP110: ceramic-filled PEEK treated with 110 microns aluminum oxide particles  
 CFP250: ceramic-filled PEEK treated with 250 microns aluminum oxide particles  
 CFP50: ceramic-filled PEEK treated with 50 microns aluminum oxide particles  
 CFRP: carbon fiber reinforced PEEK  
 CFRP110: carbon fiber-reinforced PEEK treated with 110 microns aluminum oxide particles  
 CFRP250: carbon fiber-reinforced PEEK treated with 250 microns aluminum oxide particles  
 CFRP50: carbon fiber-reinforced PEEK treated with 50 microns aluminum oxide particles  
 PEEK: polyetheretherketone  
 Ra: roughness average

UFP: unfilled PEEK

UFP110: unfilled PEEK treated with 110 microns aluminum oxide particles

UFP250: unfilled PEEK treated with 250 microns aluminum oxide particles

UFP50: unfilled PEEK treated with 50 microns aluminum oxide particles

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#### NOTE

The authors declare no conflict of interest.

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