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AWARENESS AND PERCEPTION OF PEKK AS AN ADVANCED DENTAL MATERIAL AMONG DENTAL STUDENTS AND PRACTITIONERS

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ABSTRACT
Polyaryletherketones (PAEK) are high-performance thermoplastic polymers made up of polyetheretherketone (PEEK) and polyetherketoneketone (PEKK). Dental implants, frameworks of removable partial dental prostheses, frameworks of fixed partial dental prostheses and implant abutments are all being made with PEEK as an alternative material in the recent past. PEKK is a newer material that has an 80% stronger compressive strength and superior long-term fatigue capabilities than PEEK without reinforcement. Because of its light weight and compatibility with various veneering materials, PEKK has been employed as the framework material for Implant supported complete and fixed dental prostheses. Although it is gaining popularity due to its production adaptability, there are only a few clinical studies that support its usage. This survey aims to assess the awareness and perception of PEKK as an advanced dental material and spread awareness on its usage in dentistry among dental students and practitioners. A questionnaire containing 6 questions was prepared and distributed among Indian dental students and practitioners. Indian dentist knowledge on PEKK as advanced dental material was assessed through a series of specially designed proformas and corresponding results were calculated and tabulated. Among 100 samples enrolled in the study 55 were undergraduate students, 35 were postgraduate students, 5 were academicians and 5 were clinicians. 10% of the study population responded that PEKK was used in fabricating RPDs, 5% responded that PEKK was used to fabricate FPD, 5% for implant supported prosthesis and 80% responded that PEKK was used for all three purposes. Awareness should be spread among the students and practitioners on the benefits of using PEKK and also keep them updated on the advancements in PEKK as a dental material by conducting CDE and hands-on workshops.

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KEYWORDS: Polyetherketoneketone, PEKK, dental materials, High-performance polymer, frameworks, dental polymers, innovation

INTRODUCTION

Polymers, being one of the most key materials in dentistry, offer great physical and mechanical qualities, as well as good biocompatibility. Polymers are used to make a variety of removable appliances, restorations, and denture base materials. PEKK (polyetherketoneketone) is a novel polymeric material that has attracted researchers' interest due to its great qualities that can be applied to a wide variety of purposes. PEKK is a thermoplastic high-performance polymer that is free of methacrylates. Bonner initially introduced PEKK in 1962 [1], and it has subsequently been employed for a variety of industrial and military applications [2]. PEKK has recently gained popularity as a biomaterial with features that make it suited for dentistry and medicinal applications [3]. In restorative, prosthetic, and implant dentistry, the PEKK offers a wide range of uses. In the sphere of craniofacial and orthopedic implants, PEKK is a promising alternative [4, 5]. Because of its enhanced mechanical strength and the presence of the second ketone group, which allows for further surface modification, it has a wide range of biomedical applications.

The polyaryletherketone (PAEK) family includes the polyetherketoneketone (PEKK) and polyetheretherketone (PEEK), the two most well-known members. The PAEK family of thermoplastic polymers has been used in engineering since the 1980s, and they offer outstanding mechanical and chemical properties. Among all thermoplastic composites, the PAEK family exhibits ultra-high performance (better mechanical and chemical resistance) as a function of processing parameters. PEEK appeared as a semi-crystalline material in the late 1990s and demonstrated good biological, mechanical, and physical capabilities for biomedical applications [6]. Dental implants, temporary abutment and fixed prosthesis , removable denture [7], and finger prosthesis [8] are all promising applications of PEEK biomaterial.

PAEK is an ultrahigh molecular weight polyethylene-based linear aromatic polyether ketone. The aromatic rings in the structure of PEEK and PEKK differ in the ratio of ether- and ketone- groups [9]. Between PEKK and PEEK, there are some distinctions. PEKK contains a second ketone group that improves polarity and backbone rigidity, resulting in a higher glass transition and melting temperature [10]. PEKK also has amorphous and crystalline properties, allowing for the creation of a variety of products. A PEKK with 60% straight and 40% kinked segments melts at 305°C, but a PEEK with 80% straight and 20% kinked segments melts at 360°C. Furthermore, PEKK's additional ketone group has strong polymer chains and therefore improved physical and mechanical properties, such as compressive strength [11]. PEKK is a linear thermoplastic polymer made up of benzene rings linked together by ether or ketone groups. PEKK can be manufactured by mixing aluminum chloride ($AlCl_3$) and nitrobenzene with diphenyl ether and iso- and terephthaloyl chlorides [10].

In comparison to other polymeric materials, PEKK has superior physical and mechanical qualities, such as melting temperature and compressive strength. PEKK also has better mechanical qualities than PEEK (pure and glass-reinforced) in terms of flexure, tensile, and compressive strength [12]. PEKK exhibits high biocompatibility and has been proposed as a viable alternative to titanium for long-term orthopedic applications [13]. The FDA has given it approval for oral maxillofacial and spinal surgery. In addition, PEEK is widely utilized as a prosthesis and implant biomaterial in dentistry. It provides metal-free restorations and is beneficial to allergy sufferers [14]. PEKK also shows antibacterial properties and is therefore being employed extensively in medical prostheses [8].Our team has extensive knowledge and research experience that has translated into high quality publications[15–34].

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PEKK has been used as a prosthesis and implant biomaterial in dentistry with great success. Conventional Titanium implants are highly unaesthetic owing to the metal threads being visible through the gingival tissue especially in patients with thin gingival biotype. PEKK, being tooth colored, overcomes this disadvantage and can be used in aesthetic zones effectively. PEKK, being highly porous, also evenly distributes stress and therefore is widely being used as an alternative material for implant supported prosthesis frameworks. PEKK has recently been used in a variety of dental applications due to its mechanical properties, fracture resistance, shock absorption, and superior stress distribution [35]. Because it provides metal-free restorations, the PEKK has high biocompatibility and is considered a viable alternative to metal and ceramics. PEKK is used in dentistry for dental implants, crown and bridge construction, removable denture frameworks, and endodontic posts because of its numerous advantages [14]. Hence, the aim of this study was to assess the knowledge of the dentists on the use of PEKK as an advanced dental material and application of the same in various fields of dentistry.

MATERIALS & METHODS

Following the approval of the institutional review board, anonymous survey forms **(Table 1**) were handed out to 100 dentists and a cross-sectional study was conducted among these Indian dentists. The dentists were assessed using a structured questionnaire comprising 5 closed-ended questions. Questions were explained whenever necessary with assurances on confidentiality of their identities and they were requested to mark their answers and complete it individually. The survey had questions containing the dentist's educational status and their knowledge on PEKK. Their awareness of PEKK as an advanced dental material was assessed and corresponding results were calculated and tabulated.

RESULTS

Among the 100 sample population enrolled in the study, 55 were BDS students, 35 were MDS students, 5 were clinicians and 5 were academicians as shown in **Figure 1**. Out of the respondents, 10% of the participants responded that PEKK could be used in RPD fabrication, 5% responded that PEKK could be used for FPD fabrication, 5% responded that PEKK could be used for implant prosthetic framework and 80% of the participants responded that PEKK could be used for all of the above mentioned uses. From **Figure 2**, it can be observed that most of those who responded correctly that PEKK can be used for all of the mentioned purposes belonged to the UG student group (45%) followed by PG student group (30%) and dental practitioners (5%) (statistically significant, $p=0.000 < 0.05$). 70% of the respondents thought that PEKK displayed better mechanical properties than PEEK, 20% thought that the mechanical properties changed depending on application, 5% thought that PEEK displayed better mechanical properties than PEKK and 5% thought that both PEKK and PEEK had similar mechanical properties. As observed in **Figure 3**, it can be inferred that most of those who responded correctly that PEKK displayed better mechanical properties belonged to the UG student group (40%) followed by PG student group (25%) and dental academicians (5%) (statistically significant, $p=0.000 < 0.05$). Out of the 100 respondents, 85% strongly agreed that PEKK can be used as an implant material, 5% thought that PEKK could be used medically but not for dental use, 5% wasn't sure and 5% strongly disagreed on the use of PEKK as an implant material. As seen in **Figure 4**, most of those who responded correctly that PEKK can be used as an implant material belonged to the UG student group (45%) followed by PG student group (30%) and dental practitioners (5%) and academicians (5%) (statistically significant, $p=0.007 < 0.05$). According to 55% of the sample population only PEKK had antimicrobial effect, 30% thought both PEEK and PEKK didn't possess antimicrobial properties, 10% thought both PEEK and

PEKK had antimicrobial properties and 5% thought only PEEK had antimicrobial properties. As depicted in **Figure 5**, most of those who responded correctly that only PEKK possessed antimicrobial property belonged to the UG student group (25%) and PG student group (25%) followed by dental academicians (5%) (statistically significant, p=0.000 <0.05). Among the participants of this study, 85% responded that manufacturing of PEKK could be done by milling, compression moulding as well as 3D printing, 5% responded that it could be manufactured by only milling, 5% responded that it could be manufactured by only compression moulding and 5% responded that it could be manufactured by only 3D printing alone. As seen in **Figure 6**, out of those who responded correctly that PEKK can be manufactured by all three methods; milling, compression moulding and 3D printing, 45% were UG students, 30% were PG students, 5% dental academicians and 5% dental practitioners (statistically significant, p=0.007 <0.05).

DISCUSSION

In the present study, it was observed that only 80% of the participants were aware of the extensive application of PEKK in manufacturing RPD, FPD and implant prosthetic framework whereas the rest thought that it could be used for single purpose dental use only. As depicted in **Figure 2,** most of those who responded correctly that PEKK can be used for all of the mentioned purposes belonged to the UG student group (45%) followed by PG student group (30%) and dental practitioners (5%) (statistically significant, p=0.000 <0.05). Owing to its low density, low elastic modulus, excellent strength, and adequate wear resistance, PEKK has a variety of dental applications. It has the potential to be used in fixed prosthodontics as a restorative material [36]. Computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies have improved the precision of current restorative and prosthetic materials and made fabrication easier. Individual ceramics created using CAD/CAM technology can be included into entire dentures to improve wear resistance [37]. PEKK prosthetic restorations have recently been made using CAD/CAM technology. PEKK (Pekkton® ivory) is a monolithic and bi-layered material with an indirect composite veneer [38]. PEKK's high performance and isoelastic properties has uses in oral implantology. PEKK has the advantages of being sufficiently strong, lightweight, wear resistant, and having an elastic modulus that is similar to that of dentin [36]. PEKK can be employed as implant abutments, implant framework material [39], prosthetic crown materials over the implant, and implant biomaterial in oral implantology[13]. PEKK can also be used in the treatment of maxillofacial injuries. The rehabilitation of a mandibulectomy patient with a fibula free flap and implant-supported prosthesis employing PEKK framework material was documented by Oh et al. [40]. PEKK has recently been employed for dental clasps and frameworks in removable partial dentures (RPD) employing digital technology [41].

70% of the participants of the current study responded that PEKK had better mechanical properties when compared to PEEK. Out of those 70%, most of those who responded correctly that PEKK displayed better mechanical properties belonged to the UG student group (40%) followed by PG student group (25%) and dental academicians (5%) (statistically significant, p=0.000 <0.05) (**Figure 3**). Literature shows that PEKK has better mechanical qualities than PEEK (pure and glass-reinforced) in terms of flexure, tensile, and compressive strength. When compared to unreinforced PEEK, Pekkton® ivory (Cendres + Métaux, SA, Switzerland) has an 80 percent better compressive strength [38]. PEKK's hardness and wear resistance are improved when titanium dioxide (TiO_2) is added [42]. PEKK's shock absorption, strength (65 MPa), and fracture resistance qualities make it a good candidate for use as a restorative material [14, 43]. When compared to dentin, the PEKK has a similar

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compression strength but a lower modulus of elasticity. PEKK's elastic modulus is comparable to that of bone, just like PEEK's [43]. PEKK has superior mechanical qualities and a better stress distribution, thus it has a wide spectrum of uses.

85% of the participants in the present study strongly agreed that PEKK could be used as implant material. As shown in **Figure 4,** out of those who responded correctly that PEKK can be used as an implant material belonged to the UG student group (45%) followed by PG student group (30%) and dental practitioners (5%) and academicians (5%) (statistically significant, $p=0.007 <0.05$). Yuan et al. [44] examined osteointegration in PEKK as an implant material in terms of chemistry and surface microstructure. The other ketone group in PEKK has been shown to boost the potential of surface chemical modification. The presence of -SO3H will be more on PEKK than PEEK as more ketone groups are added. This results in a more complex surface topography, a larger surface area, and a micro rough surface, all of which alter cell activity and osseointegration on the PEKK surface [45]. The osseointegration property is improved by increasing the porosity and incorporating HA into the surface. PEKK is a metal-free substance that can be used instead of titanium implants. PEKK abutments have the advantage of being customizable and compatible with a variety of veneering materials, as well as being able to serve as a framework for an implant-supported prosthesis [46]. Combining the PEKK attachment system with titanium could be a promising material for long-term implant prosthesis retention. Under compressive load, the PEKK framework causes less stress to the implant and tissue than under tensile stress [35]. Although PEKK has a wide range of applications in oral implantology, further research is needed to understand how to chemically modulate PEKK to improve implant-contact.

55% of the study population responded that PEKK had antimicrobial properties. Out of those that responded correctly that PEKK had antimicrobial properties, 25% belonged to the UG student group and 25% belonged to the PG student group followed by dental academicians (5%) (statistically significant, $p=0.000 <0.05$) (**Figure 5**). PEKK, owing to its extra porous microstructure, is bactericidal in nature. In terms of antibacterial activity, Wang [8] claims that PEKK has less bacterial adhesion on its surface than PEEK used in the orthopedic industry. On the surface of PEKK, Staphylococcus epidermidis adhesion was reduced by 37%. They discovered a 50% reduction in Pseudomonas aeruginosa adhesion and proliferation on PEKK after five days of culture as compared to PEEK without antibiotics. In a rat investigation, Moore et al. [47] discovered that PEKK had a lower inflammatory response than PMMA.

Out of the 100 participants in the current study, 85 dentists responded that PEKK can be manufactured by means of milling, 3D printing as well as compression moulding while the others thought it could be done by only one of the mentioned methods. Out of those who responded correctly that PEKK can be manufactured by all three methods; milling, compression moulding and 3D printing, 45% were UG students, 30% were PG students, 5% dental academicians and 5% dental practitioners (statistically significant, $p=0.007 <0.05$) (**Figure 6**). Sun et al. [48] presented a computerized method for using PEKK in removable speech bulb prostheses. The manufacturing process involved intraoral scanning, 3D printing, designing, digital milling of PEKK framework and delivery. The production of conventional complete dentures with polyetherketoneketone (PEKK) frameworks using computer-aided design and computer-aided manufacturing (CAD-CAM) is described in a clinical report by Ling Ding et al [49]. At the one-year follow-up, no biologic or prosthetic problems were discovered.

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In summary, PEKK displays suitable physical, mechanical, and chemical properties and can be used for various dental applications such as restorative material, crown and bridge work, endo crowns, framework material for an implant-supported fixed prosthesis, and as esthetic dental implant material. Furthermore, modifications and improving material properties can result in wider applications in clinical dentistry. Long term evaluations are needed as PEKK is a recent advancement in dentistry, and there are limited studies available.

CONCLUSION

From the response obtained through our survey, it was found that the participants were not as aware of the uses and benefits of PEKK in dentistry. PEKK offers a wide range of advantages in terms of physical, mechanical and biological properties making it an advanced dental material. Awareness needs to be spread among the students, academicians and practitioners on the various benefits of using PEKK and also keep them updated on the advancements in PEKK as a dental material by conducting CDE and workshops.

APPENDIX

Table 1 shows the following questions asked in the survey

1. Qualification	A. Dental students UG (55%) B. Dental students PG (35%) C. Dental practitioners (5%) D. Dental academician (5%)
2. PEKK can be used for?	A. RPD (10%) B. FPD (5%) C. Implant prosthetic framework (5%) D. All of the above (80%)
3. Which statement regarding the mechanical property of PEKK is correct?	A. PEKK is better than PEEK (70%) B. PEEK is better than PEKK (5%) C. Both are the same (5%) D. They change depending on use (20%)
4. PEKK can be used as implant material. What do you think?	A. Strongly agree (85%) B. Strongly disagree (5%) C. May be but not sure (5%)

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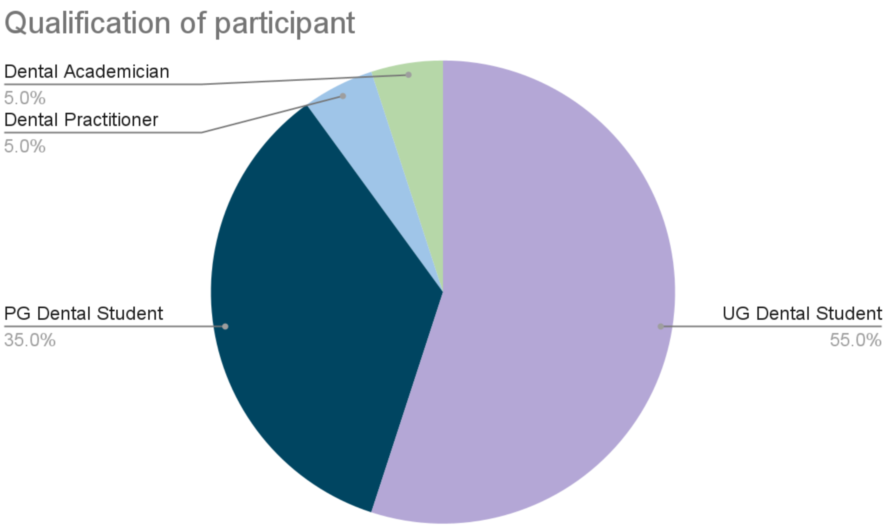
	D. For medical use NOT for dental use (5%)
5. Which material has an antimicrobial effect?	A. PEKK (50%) B. PEEK (5%) C. Both (10%) D. None of the above (30%)
6. Manufacturing of PEKK may be done through?	A. Milling (5%) B. 3D printing (5%) C. Compression moulding (5%) D. All of the above (85%)

Figure 1 shows the qualification of the respondents



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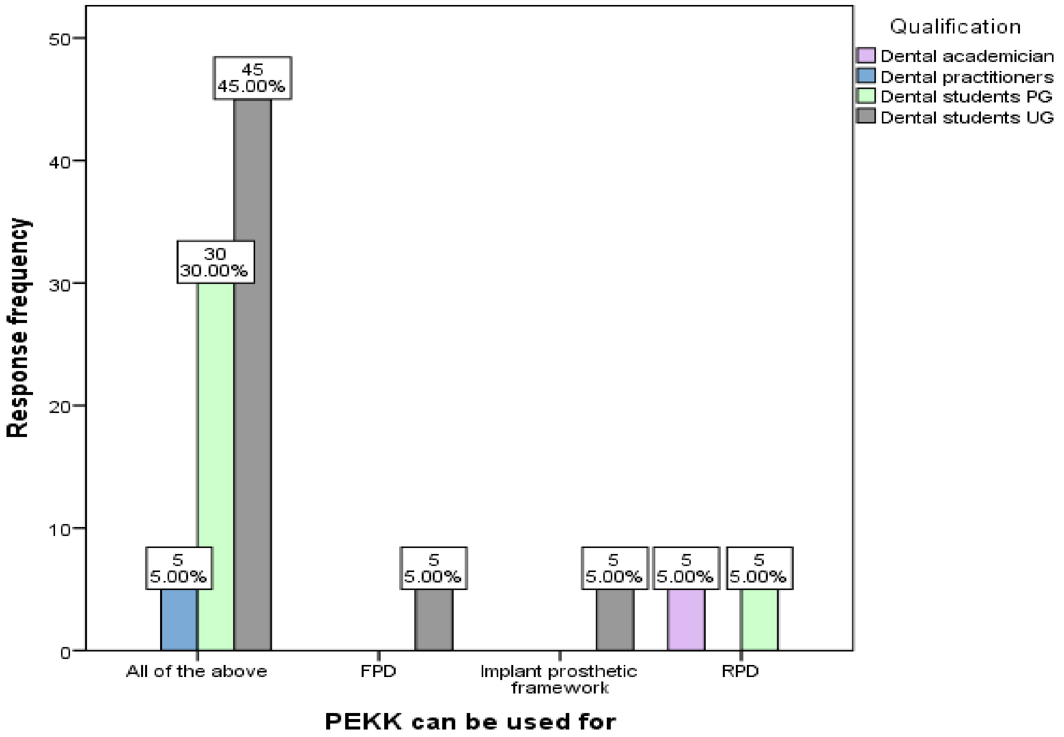

Figure 2: *Response to what PEKK can be used for among respondents. The association of their qualification and response was found to be statistically significant by Pearson's Chi-Square test. (Pearson's Chi-Square value=46.943, df=9, p=0.000 (p<0.05))*

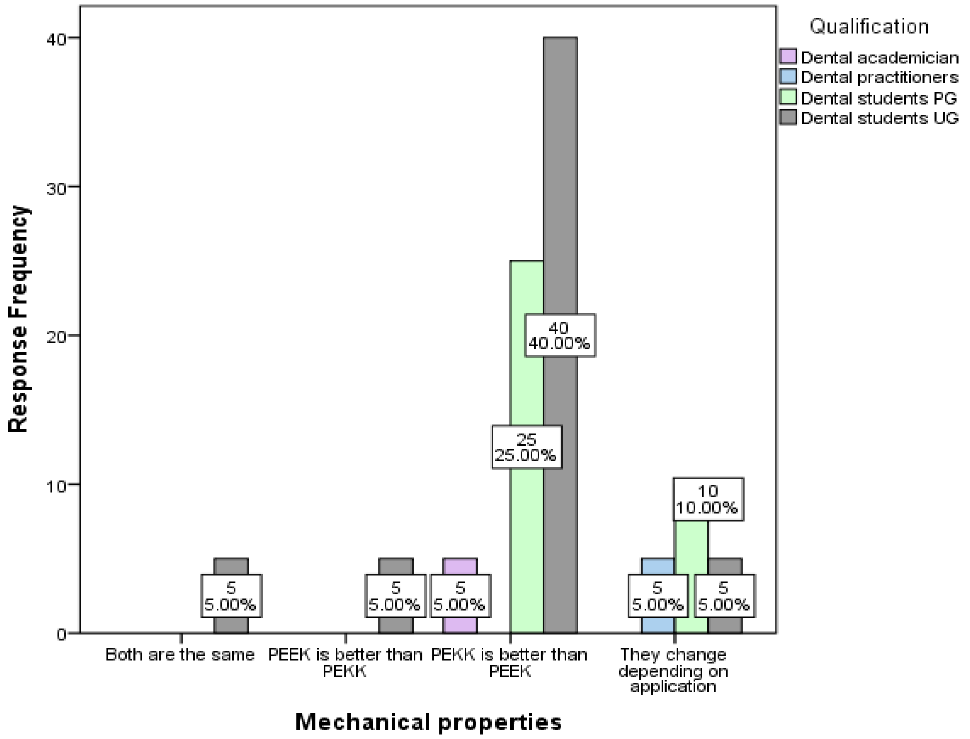

Figure 3: *Response to what the respondents thought about the mechanical properties of PEKK. The association of their qualification and response was found to be statistically significant by Pearson's Chi-Square test. (Pearson's Chi-Square value=34.935, df=2, p=0.000 (p<0.05))*

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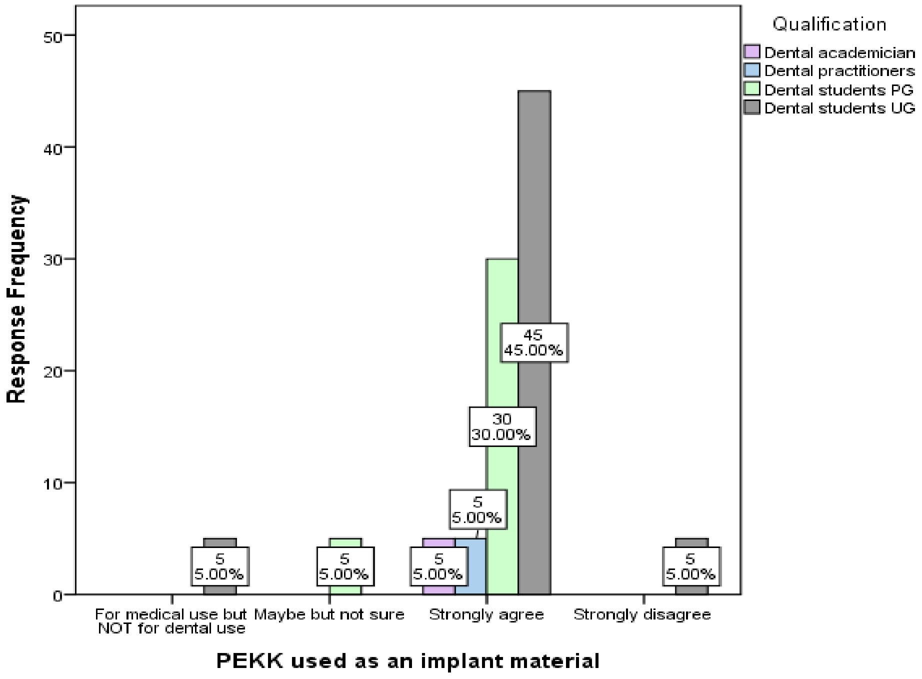

Figure 4: *Response to whether PEKK can be used as implant material among respondents. The association of their qualification and response was found to be statistically significant by Pearson's Chi-Square test. (Pearson's Chi-Square value=22.774, df=9, p=0.007 (p<0.05))*

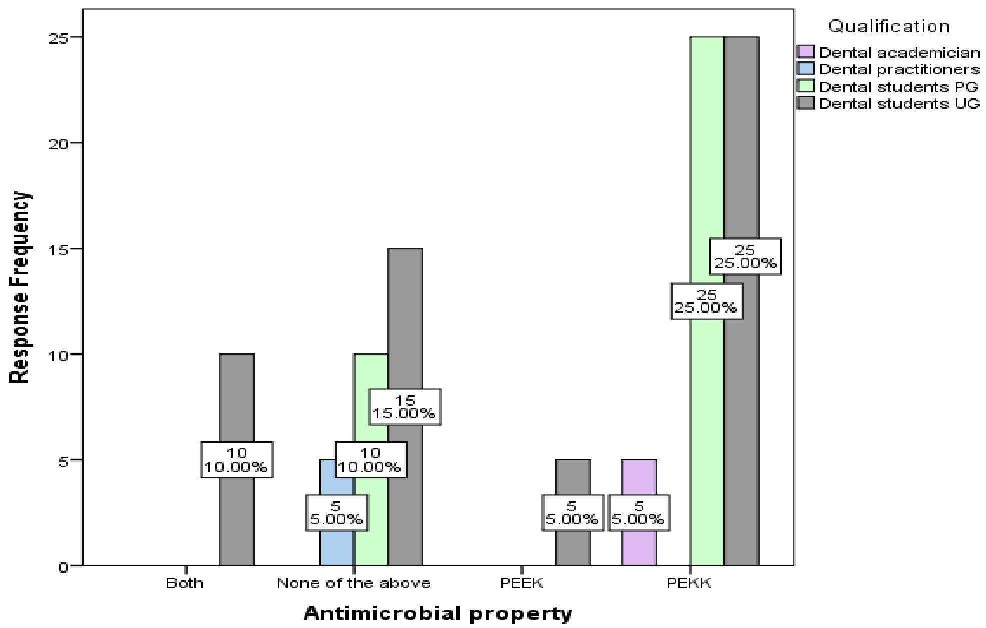

Figure 5: *Response to which material had antimicrobial activity according to the respondents. The association of their qualification and response was found to be statistically significant by Pearson's Chi-Square test. (Pearson's Chi-Square value=35.655, df=9, p=0.000 (p<0.05))*

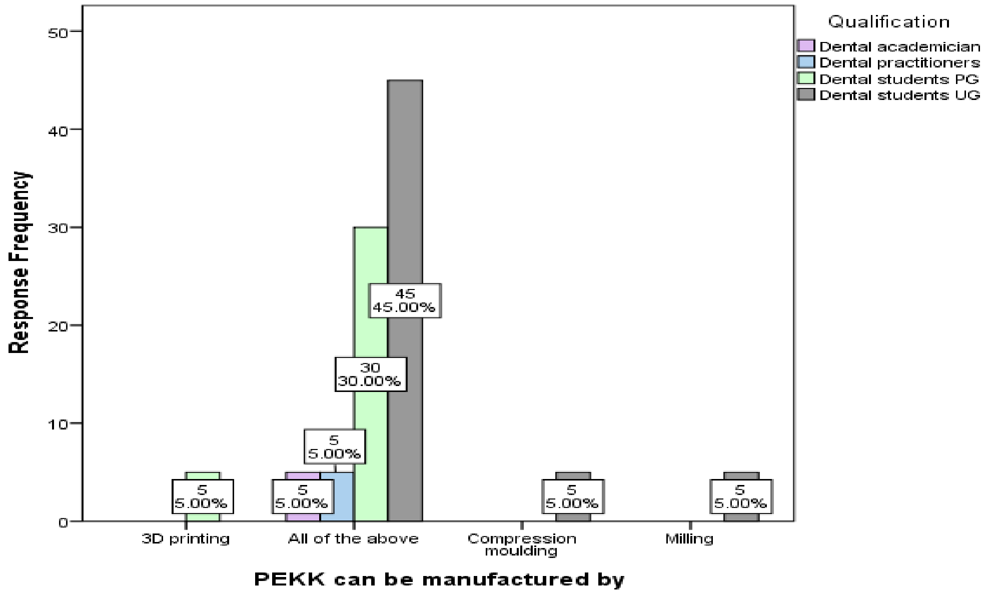

Figure 6: *Response to how PEKK can be manufactured according to the respondents. The association of their qualification and response was found to be statistically significant by Pearson's Chi-Square test. (Pearson's Chi-Square value=22.774, df=9, p=0.007 (p<0.05))*

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