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Digital Denture Fabrication in Pre- and Postdoctoral Education: A Survey of U.S. Dental Schools

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Abstract

Purpose: To survey chairs of prosthodontics or restorative departments and program directors of postdoctoral prosthodontic programs in the United States regarding digital denture fabrication. The key objectives of the survey were to identify the current trends in complete denture fabrication using CAD/CAM technology and to determine how and to what extent this technique is taught and used in U.S. pre- and postdoctoral prosthodontic programs.

Materials and Methods: An invitation to participate in an online survey was sent to 52 prosthodontics/restorative chairs of U.S. dental schools and to all of the 50 program directors of postdoctoral prosthodontics programs. A version of the survey with the same questions was sent to a national sample of prosthodontics/restorative chairs and program directors of postdoctoral prosthodontics. The 20-item survey took approximately 15 minutes to complete. Dependent samples paired *t*-test was run on items that were the same in both surveys.

Results: The response rate for the survey was 63% for department chairs and 44% for program directors. All respondents with the exception of one department chair were aware of CAD/CAM technology used for denture fabrication. More than half of the program directors (52.4%) compared to 12.1% of chairs have incorporated some aspects of CAD/CAM denture fabrication technology into their curriculum. When asked if the fabrication cost prevented introducing this technology in the predoctoral/postdoctoral curriculum, 52.4% of the department chairs affirmed this response compared to 12.1% of the program directors. There was a significant difference between groups when asked if they had incorporated the CAD/CAM denture fabrication technique into the postgraduate/predoctoral curriculum. Department chairs reported less usage of CAD/CAM technology. Only 12.1% of department chairs reported using some aspects of CAD/CAM technology in the predoctoral curriculum compared to 52.4% in the postdoctoral curriculum ($F = 13.528$, $p \leq 0.001$). While this technology is used in four predoctoral clinics, none of the chairs reported including CAD/CAM denture fabrication in their preclinical complete denture courses. For the schools using the technology, 33.3% of postdoctoral and 30.3% of predoctoral programs use it to make a denture with a try-in step; however, 19% of the postdoctoral and 18.2% of predoctoral programs process the dentures without a try-in appointment. Slightly less than half (42.9%) of graduate programs are using the technology to make just the denture bases. Only a small proportion (10% or less) of the total number of dentures processed in post- and predoctoral programs are made using CAD/CAM technology. The proportion of postdoctoral programs that process cases using CAD/CAM technology was significantly higher than in predoctoral programs ($F = 5.106$, $p \leq 0.028$). Many schools indicated that they are in a "trial phase" to evaluate the technique, especially at the predoctoral level. Also, 19% ($n = 4$) of postdoctoral and 15.2% ($n = 5$) of predoctoral respondents have created continuing education courses. Of postdoctoral programs, 38.1% ($n = 8$) plan to introduce this technology at some point in the near future (next 1 to 4 years); 27.3% of predoctoral programs plan to as well.

Conclusions: All program directors and department chairs who participated in the survey are aware of this technology with the exception of one department chair. More than half of the program directors reported that they have incorporated this technology in their curricula compared to only 12% of department chairs. Currently, only 10% or less of complete denture cases are processed using the CAD/CAM technology, at either the post- or predoctoral levels. Both groups reported that the main use of this technology is for the fabrication of denture bases and for processing dentures including the try-in step. The majority of respondents in both groups indicated they plan to add digital denture fabrication into their curricula within the next 1 to 4 years.

Fabrication of complete dentures using a compression molding technique has been the standard method since polymethyl methacrylate was introduced in 1936.[1] Although the use of CAD/CAM technology for denture fabrication was first described in the literature in 1994,[2] it has not been widely adapted for this purpose; however, CAD/CAM and rapid prototyping have been used successfully in maxillofacial prosthodontics[3] and fixed prosthodontics for the fabrication of crowns, inlays, onlays, implant abutments, and substructures for implant-supported prostheses.[4,5]

Currently, only two manufacturers in the United States offer the fabrication of complete dentures using CAD/CAM technology: Dentca® (Dentca Inc., Los Angeles, CA)[6] and AvaDent® (Global Dental Science, Scottsdale, AZ).[7] Both companies have established a clinical and laboratory protocol with the option of finalizing the complete dentures in two appointments. Kattadiyil et al[8] compared the two available systems, AvaDent® and Dentca®. AvaDent® uses laser scanning and computer technology. Teeth are arranged and bases formed using proprietary software. The bases are milled from prepolymerized pucks of resin. Dentca® uses computer software to produce virtual maxillary and mandibular edentulous ridges, arrange the teeth, and form bases.

Both companies also offer the possibility of combining some classic steps into their protocols. Therefore, dentists can still set anterior teeth or do a tooth try-in before the dentures are milled.

Goodacre et al[9] and Infante et al[10] describe a method of recording the morphology of the intaglio and cameo surfaces of complete denture bases and identified the muscular and phonetic locations for the prosthetic teeth that could be used to scan the denture base morphology and tooth positions. After recording and importing this data into a virtual tooth arrangement program, the teeth are articulated. These data can be exported to a milling device for the fabrication of the complete dentures. A prototype three-dimensional tooth arrangement program serves as an example of how prosthetic teeth can be arranged virtually as part of the overall CAD/CAM fabrication of complete dentures. Hence, digital complete dentures can be fabricated in two appointments. The clinical protocol consists of a combination of conventional and digital steps for denture fabrication. The first appointment involves making impressions, obtaining maxillomandibular relationship (MMR) records, determining the occlusal plane orientation, choosing the tooth mold from the three available tooth size templates, selecting tooth shade, marking the midline and the smile line on the lip support flange, and delivering the dentures at a follow-up appointment.

The traditional/conventional approach to fabricating complete dentures requires at least five clinical appointments using the following steps: (1) Preliminary impressions; (2) final impressions; (3) MMR records; (4) wax/teeth try-in; and (5) insertion. Some disadvantages of the conventional method of fabricating complete dentures include the number of visits before the denture is delivered, the need for additional visits to adjust the denture, laboratory expenses and time based upon case complexity, lack of intimate fit of the denture bases with underlying tissues due to polymerization shrinkage, and the inability to easily create an optimal duplicate denture.[11,12] In contrast, some advantages of the CAD/CAM fabricated dentures, as noted by Bidra et al, are as follows:[12] reduced number of patient visits; superior strength and fit of dentures due to use of prepolymerized acrylic resin blocks for milling; reduced potential for Candida colonization and, therefore, healthier underlying tissues; reduced cost for the patient and the clinician based on time savings; easily reproducible (creation of duplicate dentures) due to stored digital data; improved potential for standardization in clinical research on complete dentures as well as implant-retained overdentures; and ability for better quality control.[9,12] Bidra et al[12] postulate that the ability to manufacture complete dentures using CAD/CAM technology has untold educational, investigational, and clinical possibilities that can affect not only individual patient care but public health around the world. The purpose of this study was to assess the level of digital complete denture fabrication using CAD/CAM technology at the pre- and postdoctoral level in U.S. dental schools.

Materials and methods

The University of Florida's Institutional Review Board approved the study (UFIRB-U-974-2013). The authors developed an initial survey instrument using educational research literature in prosthodontics and from their practice-based knowledge of the field. They selected the names and e-mail addresses of program directors and chairs from resources available through the American College of Prosthodontists. An online survey was sent to 52 prosthodontics/restorative chairs and 50 program directors of postdoctoral prosthodontic programs in the United States. The survey, composed of 20 multiple-choice questions for prosthodontics chairs and 18 multiple-choice questions for program directors, was designed to take approximately 15 minutes to complete (Appendices A and B). A pre-invitation e-mail announcement was sent to prospective participants followed by the actual survey and weekly reminders. A dependent samples paired *t*-test was run on items that were the same in both surveys (Table 1).

Table 1 Dependent samples *t*-test for responses by chairs (n = 33) and directors (n = 22) for common questions

Item	Mean	SD	F	Sig
1. Are you aware of the CAD/CAM technology for denture fabrication?	0.97	0.174	2.70	0.107
	1.00	0.00		
Yes 1				
No 0				
2. Have you incorporated the CAD/CAM dental fabrication technique into the postgraduate curriculum?	0.18	0.392	13.528	0.001*
	0.52	0.512		
Yes 1				
No 0				
5. How is the CAD/CAM denture fabrication used? (Select all that apply)	0.70	1.237	2.69	0.107
	1.14	0.854		
To make the denture base only				
To make the processed denture with no try-in				
To make the processed denture with the try-in step				
Electronic archive of completed dentures				
Does not apply				
8. What brand of teeth do you use?	0.88	0.331	3.571	0.064
	0.95	0.218		
Dentsply 1				
Ivoclar 1				
Other 1				
Does not apply 0				
10. What percentage of cases are processed using the CAD/CAM technique?	0.27	0.452	5.11	0.028**
	0.52	0.512		
Less than 10% 1				
11%-50 2				
51%-75% 3				
Over 76% 4				
Does not apply 0				
11. Have you incorporated CAD/CAM technology into a CE course?	0.15	0.364	0.531	0.469
	0.19	0.402		
17. Compared to conventional denture fabrication, how many appointments do you need for denture adjustments?	1.69	0.535	1.05	0.309
	1.81	0.512		
More 3				
The same 2				
Less 1				

*$p \leq 0.001$.
**$p \leq 0.05$.

Results

The response rate was 63% (n = 33) for department chairs and 44% (n = 21) for program directors. All program directors were aware of the CAD/CAM technology used for denture fabrication, whereas all but one of the department chairs was aware. Dependent samples *t*-test results showed no significant differences between the responses for department chairs and program directors with the exception of two questions: Have you incorporated the CAD/CAM denture fabrication technique into the post-or predoctoral curriculum? Only 12.1% of department chairs reported using CAD/CAM technology in the predoctoral curriculum; compared to 52.4% of postdoctoral programs (F = 13.528, *p* & 0.001; Fig 1). The other question where the groups showed significant differences was: Does the fabrication cost prevent you from introducing this technology in the pre-or postdoctoral curriculum? Of the department chairs, 52.4% responded yes to this question, whereas only 12.1% (n = 4) of the program directors replied the same (F = 13.528, *p* & 0.001; Fig 2).

Differences in how this technology is used for denture fabrication were reported for the programs. Respondents were able to select more than one of five choices so the data will add up to more than 100%. In the postdoctoral curriculum, 33.3% (n = 7) of the cases processed with this technology used the teeth try-in step before fabrication versus 19.0% (n = 4) with no try-in step (Table 2). In the predoctoral curriculum, 30.3% (n = 10) of the cases processed with this technology used the teeth try-in step before fabrication versus 18.2% (n = 6) with no try-in step. Also 12.1% (n = 4) of the respondents reported that electronic archival of the completed dentures is the most interesting aspect of digital denture fabrication (Table 3). In addition,

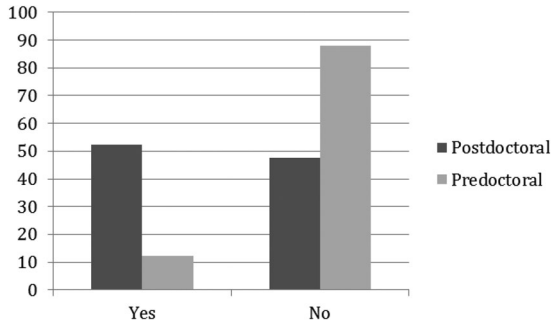

Figure 1 Percent distribution of responses to the question "Have you incorporated CAD/CAM denture fabrication in your current curriculum?"

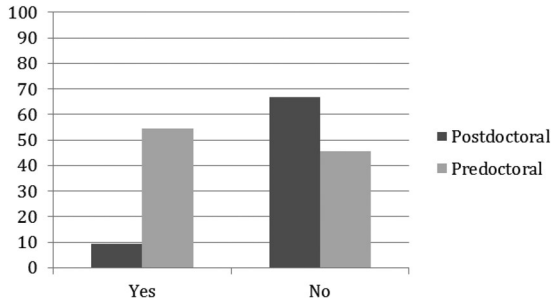

Figure 2 Percent distribution of responses to the question "Does fabrication cost prevent you from introducing this technology in your program?"

9.1% (n = 4) reported that they are using this technology to make the denture bases only, and then the dentures are processed using conventional denture fabrication steps, or after the teeth try-in appointment is verified and approved, the dentures are sent to the laboratory where they re-mill the entire prosthesis. Some of these variations of the digital technique have been done as a trial or pilot cases, and chairs agreed that digital preview has not been used for these cases. However, CAD/CAM technology for denture fabrication is used by 42.9% (n = 9) of the program directors to make the denture base only compared to 9.1% (n = 3) of the department chairs.

When asked "What percentage of cases are processed using the CAD/CAM technique?" 27.3% of the department chairs responded "less than 10%," and 72.7% selected "does not apply," while 52.4% of program directors responded "less than 10%," and 47.6% responded "does not apply." Program directors reported a strong preference for Ivoclar (61.9%, n = 13) and Dentsply (23.8%, n = 5) teeth. Chairs' preference for Ivoclar and Dentsply teeth was a little more evenly divided (42.4%, n = 14 and 39.4%, n = 13, respectively). When asked to describe advantages of using the CAD/CAM technique, members of both groups noted that in their experiences the dentures fabricated using this technique offer: decreased chair and appointment time for patients; more stability; better fit if impressions are accurate; simplified fabrication steps once the technique is understood; fabrication of prosthesis is done after polymerization shrinkage occurred, eliminating the possible deformation of the denture base and changes in denture teeth positions; reduced free monomer with healthier underlying tissues; repository of digital information for future replacements or simple denture duplication; multiple millings are possible. Furthermore, the chairs added a few more advantages to the list: great for geriatric patients and head and neck cancer patients with a history of radiation therapy to the oral cavity; workflow improves, but doubtful at predoctoral level; innovative and contemporary technology allows for digital tooth set-up, keeping up with emerging technologies; better method of vertical determination and CR record based on the gothic arch tracing concept. Chairs and program directors agreed that CAD/CAM is possibly the future of denture fabrication.

Members of both groups responded that in their experience, dentures fabricated using the CAD/CAM technique can present the following disadvantages: Frequently occlusal vertical dimension (OVD) is excessive; high level of training needed to estimate OVD, and esthetic plane; final esthetics unpredictable; learning curve; technique sensitive; customization of tooth angulation and characterization is limited; there is no mention of how posterior occlusal determinants are calculated in virtual tooth setting to achieve balanced occlusion; cost seems to be a disadvantage for both groups; it requires modifications of teaching techniques; lack of in-house laboratory support; lack of scientific evidence on this technique's outcomes and long-term success/durability; mistakenly, the dentist could rely on digital technology and not rely on basic principles of denture fabrication; limited flexibility for complex treatments like severe class II patients and "severely" resorbed ridges; and bonding of teeth to bases has had some known failures.

In addition, the chairs reported the following concerns: No mention of clinical remount in the CAD/CAM protocol; many steps of denture fabrication are condensed in this technique, thus requiring higher skills, without experience with traditional methods in the predoctoral level; some current methods do not employ good techniques for posterior plane of occlusion and wax try-in; the newness of the technology has not lead to determining whether it is worth incorporating into or replacing the current curriculum. The majority of the chairs and directors (63.6%, n = 21; 71.4%, n = 15, respectively), agreed that they needed the same number of appointments regardless of the technique used for the fabrication.

When asked to describe experiences in teaching the use of this technology, 66% of the chairs replied "none or NA," whereas a quarter of the directors replied "none or no experience." Less frequent replies were that CAD/CAM technology was more or less difficult or about the same, and that it was time consuming or hampered by poorly constructed trays.

Few of the chairs or directors (19%, n = 4; 15.2%, n = 5, respectively) reported incorporating this technology into an elective course in the predoctoral curriculum. A small number (12.1%, n = 4) of the chairs reported incorporating the technology into the predoctoral curriculum.

Discussion

Findings from the survey of department chairs and graduate program directors demonstrate that both groups are aware of digital denture technology. A larger percentage of the program directors compared to the chairs have more fully embraced the incorporation of CAD/CAM denture fabrication into their

Table 2 Percent distribution of responses to the question "How is the CAD/CAM denture fabrication used?" by postdoctoral directors

Digital Denture Grad Program Directors How is the CAD-CAM denture fabrication used? (Select all the apply) Answer Options	Response Percent	Response Count
To make the denture base only	42.9%	9
To make the processed denture with no try-in	19.0%	4
To make the processed denture with the try-in step	33.3%	7
Electronic archive of completed dentures	19.0%	4
Does not apply	23.8%	5
	answered question	21
	skipped question	1

Table 3 Percent distribution of responses to the question, "How is the CAD/CAM denture fabrication used?" by department chairs (predoctoral)

Digital Denture Chair Survey How is the CAD-CAM denture fabrication used? (Select all the apply) Answer Options	Response Percent	Response Count
To make the denture base only	9.1%	3
To make the processed denture with no try-in	18.2%	6
To make the processed denture with the try-in step	30.3%	10
Electronic archive of completed dentures	12.1%	4
Does not apply	69.7%	23
	answered question	33
	skipped question	0

programs. A small number of the responding schools included CAD/CAM denture fabrication in their clinical courses; however, this technology has not yet been integrated into the preclinical complete denture courses.

Schools using this technology to make a denture with a try-in step include about a third of the pre- and postdoctoral curricula. Both groups were more hesitant to fabricate dentures without a try-in appointment. Slightly less than half of the graduate programs reported using the technology to make just the denture bases compared to less than a tenth of the predoctoral programs. Therefore, the data suggest that program directors are more willing to use this technology in denture fabrication. Both groups have created CE courses that present CAD/CAM technology, although those efforts were reported in less than one-fifth of the graduate and predoctoral programs.

Looking to the future, the majority of graduate programs and predoctoral departments expressed plans to introduce this technology at some point in the future. Chairs expressed more reluctance to incorporate this technology, not surprisingly because of concerns related to costs involved in implementation and ongoing costs versus conventional processing. In contrast, only a small minority (less than one-tenth) of graduate program directors expressed concern about cost. Graduate directors identified "accuracy" and "consistent base density" as the major advantages of this technology and "unknown long-term durability," "bonding of teeth to the denture base," and "limited flexibility for complex cases," as disadvantages. Department chairs expressed a different perspective, identifying "better fit," "fewer appointments," and "efficient/faster" as advantages. The chairs listed "cost," "difficulty," and "technique sensitive" as disadvantages of the digital approach. Some respondents raised philosophical concerns about whether this approach would be effective in a predoctoral curriculum. Frequently, respondents felt that schools might use digital technology at the expense of learning the basic steps in denture fabrication, and that "many steps (are) consolidated in one visit, which is difficult for a novice practitioner."

One limitation of this study is the response rate. Although nonrespondents were invited several times after the initial administration of the survey, only 44% of department chairs and 63% of graduate program directors responded. Thus, the findings reported here are limited to this current dataset and should not necessarily be considered to be transferable. Another limitation is related to the perspective of the respondents. The respondents were administrators, thus it is unknown to what degree their perspectives coincide with faculty viewpoints. Several chairs and directors responded directly to the principal investigator by e-mail, expressing opinions about digital dentures; however, they did not complete the electronic survey and thus their perspectives are not represented in the analysis of the data. Since this study was exploratory, additional clinical and educational research is likely to elucidate the long-term outcomes of digital denture treatment and its contribution in dental education.

Conclusions

On the basis of the results of this study, the following conclusions can be drawn:

1. All program directors and department chairs who participated in the survey are aware of this technology with the exception of one department chair.
2. More than half of the program directors reported that they have incorporated this technology in their curricula, compared to only 12% of department chairs.
3. Currently, only 10% or less of complete denture cases are processed using CAD/CAM technology, at either the post- or predoctoral levels.
4. Both groups identified the main use of this technology as for the fabrication of denture bases and for processing dentures including the try-in step.

The majority of respondents in both groups indicated that they are planning to add the digital denture fabrication into their curricula in the next 1 to 4 years.

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Appendix A: CAD/CAM program directors survey

1. Are you aware of the CAD-CAM technology for denture fabrication?

   Yes_____
   No_____

2. Have you incorporated the CAD-CAM denture fabrication technique into the postgraduate curriculum?

   Yes_____
   No_____

3. If you answered "yes" to Question #2, skip this question. If you answered "no" to Question #2, please respond to the following question.
   Are you planning to introduce this CAD-CAM technology for denture fabrication in your postgraduate program?
   Yes_____
   No_____
   Unsure_____

4. If you are not planning to introduce it next year, do you plan to introduce it in the next two to four years?

   Yes_____
   No_____
   Unsure_____

5. How is the CAD-CAM denture fabrication used? (Select all the apply)

   To make the denture base only_____
   To make the processed denture with no try-in____
   To make the processed denture with the try-in step_____
   Electronic archive of completed dentures_____
   Does not apply_____

6. If your response to Question #5 was "does not apply," skip this question. If your response to Question #5 was one of the first four responses, please respond to the following question.
   Are you using the digital preview to substitute the teeth try-in appointment?
   Yes_____
   No_____

7. If your response to Question #6 was "no," skip the following question. If your response to Question #6 was "yes," answer the following question.
   Describe your experience with the denture digital preview.

8. What brand of teeth do you use?

   Dentsply_____
   Ivoclar_____
   Other_____
   Does not apply_____

9. Please explain your reasons (such as cost, convenience, administrative, or personal preference) for selecting the brand of teeth

10. What percentage of cases are processed using the CAD-CAM technique?

    Less than 10%_____
    11% to 50%_____
    51% to 75%_____

Over 76%_____
Does not apply_____

11. Have you incorporated the CAD-CAM technology into a CE course?

Yes_____
No_____

12. Are you planning to introduce this CAD-CAM technology for denture fabrication in your postdoctoral program?

Yes_____
No_____
Unsure_____

13. Does the fabrication cost prevent you from introducing this technology in the postdoctoral curriculum?

Yes_____
No_____
Does not apply_____

14. Describe advantages of using the CAD/CAM technique.
15. Describe disadvantages of using the CAD/CAM technique.
16. Describe your clinical experiences in using this technology. For example, is the try-in appointment easier? Is postoperative care easier for you compared to conventional denture fabrication?
17. Compared to conventional denture fabrication, how many appointments do you need for denture adjustments?

More_____
The same_____
Less_____

18. Describe your teaching experiences in using this technology. For example, has it been easier, or more difficult to teach this type of technology compared to conventional denture fabrication? If so, please describe your experiences.

Appendix B: CAD/CAM department chairs survey

1. Are you aware of the CAD-CAM technology for denture fabrication?

Yes_____
No_____

2. Has your school incorporated the CAD-CAM technology when teaching complete denture fabrication?

Yes_____
No._____

3. Have you incorporated the CAD-CAM denture fabrication technique into the predoctoral curriculum?

Yes_____
No_____

4. Do you use the CAD-CAM denture fabrication in the preclinical complete denture course?

Yes_____
No_____

5. Do you use the CAD-CAM denture fabrication in your predoctoral clinic?

Yes_____
No_____

6. How is the CAD-CAM denture fabrication used? (Select all that apply)

To make the denture base only_____
To make the processed denture with no try-in____
To make the processed denture with the try-in step_____
Electronic archive of completed dentures_____
Does not apply_____

7. If your response to Question #6 was "does not apply," skip the following question. If your response to Question #6 was any of the first four choices, please answer the following question. Are you using the digital preview to substitute the teeth try-in appointment?

Yes_____
No_____

8. What percentage of cases is processed using the CAD-CAM technique?

Less than 10%_____
11% to 50%_____
51% to 75%_____
Over 76%_____
Does not apply_____

9. What brand of teeth do you use?

Dentsply_____
Ivoclar_____
Other_____
Does not apply_____

10. Please explain your reasons (such as cost, convenience, administrative, or personal preference) for selecting the brand of teeth.
11. Have you incorporated this technology into an elective course?

Yes_____
No_____

12. Have you incorporated this technology into a CE course?

Yes_____
No_____

13. Are you planning to introduce this CAD-CAM technology for denture fabrication in your predoctoral program?

    Yes_____
    No._____

14. Are you planning to introduce it in the next year?

    Yes_____
    No._____

15. Does the fabrication cost prevent you from introducing this technology in the predoctoral curriculum?

    Yes_____
    No_____

16. Describe advantages of using the CAD/CAM technique.
17. Describe disadvantages of using the CAD/CAM technique.
18. Describe your clinical experiences in using this technology. For example, is the try-in appointment easier? Is postoperative care easier for you compared to conventional denture fabrication?
19. Compared to conventional denture fabrication, how many appointments do you need for denture adjustments?

    More_____
    The same_____
    Less_____

20. Describe your teaching experiences in using this technology. For example, has it been easier, or more difficult to teach this type of technology compared to conventional denture fabrication? If so, please describe your experiences.