Understanding technology adoption by orthodontists: A qualitative study

Laura Anne Jacox,[a] Paul Mihas,[b] Christina Cho,[c] Feng-Chang Lin,[d] and Ching-Chang Ko[a]
Chapel Hill, NC, and Boston, Mass

Introduction: Orthodontics is evolving with advances in 3D imaging, additive fabrication, digital scanning, and treatment planning. With digital tools, orthodontic treatment may become more predictable, efficient, and effective while reducing side-effects. These technologies are affecting patient care, but knowledge of their adoption patterns and influence is incomplete. We aimed to identify adoption decision makers, information sources, perspectives, incentives, and barriers. **Methods:** Twenty-four privately practicing orthodontists were interviewed in a semistructured format following a topic guide. Interview transcripts were analyzed to identify factors in technology adoption and its perceived influence on practice. Thematic patterns were established through iterative systematic analysis, and qualitative validity was ensured with researcher triangulation. **Results:** Qualitative interviews revealed that orthodontists make purchasing decisions independently from staff, after consulting other dentists and company representatives. Meetings, residency training, and continuing education courses are influential information sources, whereas research literature is not. Early and middle adopters are integrating digital imaging, planning, and fabrication technologies into practice and view enhanced ease of use, capabilities, performance, and procedural efficiency as primary incentives to adoption. Improving outcomes and patient comfort are not frequently cited as incentives, and all interviewees view cost as the largest barrier. Orthodontists positively perceive the influence of technology on their practices, but are concerned that further innovation and direct-to-consumer products will cause loss of market share. **Conclusions:** CAD/CAM appliances, 3D imaging, and digital treatment planning are viewed as future standards of care and are increasingly being incorporated into the orthodontic office. Understanding the technology adoption process can guide innovation to improve treatment and ease the transition into a digital workflow. (Am J Orthod Dentofacial Orthop 2019;155:432-42)

Dentistry is undergoing significant changes due to digital technologies, which are influencing how dentists diagnose, plan treatment, and deliver care to patients.[1,2] Cone-beam computed tomography (CBCT), intraoral scanning, digital tooth setups, and custom computer-aided design/computer-aided manufacture (CAD/CAM) appliances are gaining acceptance among orthodontists. CAD/CAM appliances come in many forms, including clear aligner therapy (eg, Invisalign), robotically formed archwires (eg, Suresmile), and custom fabricated buccal or lingual brackets (eg, Insignia, Incognito, Harmony). With these tools, orthodontic treatment may become safer, more efficient, and more effective.[3-12]

The orthodontics office is moving toward a digital workflow with intraoral scans, digital tooth set-ups, 3D printers, and CAD/CAM appliances. In some studies, CAD/CAM appliances reduce treatment times and enhance patient experiences with equivalent or improved outcomes.[3,4,7,9,12] Lengthy treatment times are detrimental to patient compliance and dental health, because longer appliance wear is associated with increased external apical root resorption and white spot lesions.[5,6,8,10,11] Patients and orthodontists prefer shorter treatment times and are willing to pay up to 20% more to shorten duration.[13] For orthodontists, extended care adversely affects clinical operations, productivity, and revenue.[14,15] As technology evolves, it

[a]Orthodontics Department, University of North Carolina School of Dentistry, Chapel Hill, NC.
[b]Howard W. Odum Institute for Research in Social Science, University of North Carolina, Chapel Hill, NC.
[c]Harvard School of Dental Medicine, Boston, Mass.
[d]Department of Biostatistics, University of North Carolina, Chapel Hill, NC.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Funding: This work was supported by the National Institutes of Health (grant R01DE022816) and the University of North Carolina (UNC) Hale Professorship fund. Dr Jacox was supported by the Graduate School Masters Merit Assistantship for study in Dentistry awarded by the UNC Graduate School and the Masters Research Support Grant awarded by the Office of the Associate Dean for Research at UNC School of Dentistry and the Dental Foundation of North Carolina from the Dora Lee and John C. Brauer Dental Research Fund.
Address correspondence to: Ching-Chang Ko, Orthodontics Department, University of North Carolina School of Dentistry, 270 Brauer Hall, CB#270, Chapel Hill, NC 25799-7450; e-mail, ching-chang_ko@unc.edu.
Submitted, May 2018; revised and accepted, August 2018.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2018.08.018

Table I. Adopter demographics

Variable	*Early adopters (n = 9)**	*Middle adopters (n = 10)**	*Late adopters (n = 5)**
Mean age	42 years	49 years	66 years
Mean year practice was founded	1993	1982	1969
Mean year of practice transition[†]	2006	2001	1989
Mean total patient load	883 active patients	805 active patients	398 active patients
Mean total practice staff[‡]	16	11	7
Number of offices	Mean 2: 5 with 1 office, 2 with 2 offices, 2 with 3 offices	Mean 2: 7 with 1 office, 2 with 2 offices, 1 with 3 offices	Mean 1: 4 with 1 office, 1 with 3 offices
Sole owner, partnership, associate	6 sole owners, 2 partners, 2 associates	4 sole owners, 5 partners, 1 associate	4 sole owners, 1 partner
Practice setting	2 urban, 6 suburban, 1 rural	2 urban, 5 suburban, 3 rural	2 urban, 2 suburban, 1 rural
Practice location	4 Mass, 1 Calif, 4 NC	1 Mass, 9 NC	1 Mass, 4 NC
Price bracket[§]	6 high-end, 3 middle, 3 Medicaid	4 high-end, 4 middle, 2 Medicaid	2 high-end, 2 middle, 1 economy
Practice organization	7 ortho only, 1 ortho+pedo, 1 multispecialty	10 ortho only	5 ortho only
Primary appliance	6 twin/edgewise, 2 self-ligating, 1 clear aligners	6 twin/edgewise, 4 self-ligating	3 twin/edgewise, 2 self-ligating
Secondary appliance	7 clear aligners, 2 self-ligating	8 clear aligners, 1 twin/edgewise 1 self-ligating	4 clear aligners, 1 twin/edgewise

*Criteria for assigning early, middle, or late adoption status is explained in the text; †Year of practice transition is the year the practice was acquired by the interviewee or current owner; ‡Total practice staff includes the orthodontists, other dentists, treatment coordinators, front desk staff, laboratory technicians, assistants, and any other staff employed by the practice; §The total is greater than the number of interviewees because some doctors owned 2 or more offices in different price brackets. A high-end practice charges fees >20% above the average for their area. A middle bracket practice charges fees ±20% of the average for their area. An economy practice charges fees <20% of the average cost for their area. A Medicaid practice has a majority of patients paying for treatment via Medicaid. A practice's price bracket was estimated by the interviewee.

may behoove patients and orthodontists to enter the digital age, where 3D imaging, digital treatment planning, and CAD/CAM appliances are standard of care.

Digital technologies hold promise for improving treatment, but for change to occur, orthodontists must effectively integrate them into practice workflows while providing feedback for improvement. Our current understanding of the adoption process is limited. To map the adoption landscape, we conducted semistructured qualitative interviews with 24 privately practicing orthodontists to identify decision makers, information sources, incentives, and barriers for technology procurement and to explore the influence of digital tools on practice. Clarifying how orthodontists adapt to changing technology can guide innovation and development of continuing education (CE) training.

MATERIAL AND METHODS

Twenty-four privately practicing orthodontists were enrolled in this qualitative study for participation in semistructured one-on-one interviews. Semistructured interviews promote an open environment, allowing participants to voice views and raise topics while addressing key questions.[16,17] Interviews were chosen as our primary approach because our study requires nuance and depth paired with flexibility to explore unexpected factors and perspectives.[17] Interviews encourage participants to discuss what matters most to them in their own words. Thematic patterns were established through iterative systematic analysis, and qualitative validity was ensured by researcher triangulation.[16-18]

From January to June 2017, orthodontists in North Carolina and Massachusetts were contacted for participation in our study. All contacted doctors are in our professional network or affiliated as adjunct faculty with University of North Carolina (UNC) School of Dentistry or Harvard School of Dental Medicine (HSDM). Each doctor was approached in person at the UNC or HSDM graduate orthodontic clinics or contacted via e-mail by the authors. Study information and consent forms were reviewed and signed by potential participants. Doctors were screened for inclusion and exclusion criteria (Appendix 1). Twenty-four qualifying participants were selected via purposeful sampling to include early, middle (the majority), and late adopters, along with doctors in early, middle, and late career phases (Appendix 2; Table I).[16,17]

Adopter status is based on technology utilization and involvement in product development, not on stage of

career, time of adoption, or years out of residency. Early adopters have adopted intraoral scanning and CBCT imaging (in-office or by referral) while incorporating digital treatment planning and CAD/CAM appliance modalities, including CAD/CAM wires (eg, Suresmile), CAD/CAM brackets (eg, Harmony, Insignia), 3D printing, and in-office aligner fabrication (eg, Orchestrate, ULab). Early adopters have explored acceleratory technologies (eg, Acceledent, Propel) as well. They have fully adopted, or at least tested, nearly all of the orthodontic technologies listed above. Engagement in product development through beta-testing and insider groups is a defining feature of our study's early adopters. Middle adopters have adopted intraoral scanning and CBCT imaging (in-office or by referral), while exploring acceleratory technologies, digital treatment planning with the use of CAD/CAM appliances, and 3D printing. For our study, middle adopters have tried some, but not all, of the listed orthodontic technologies. In addition, they do not beta-test products, belong to corporate insider groups, or otherwise develop new technologies. Late adopters have not adopted intraoral scanning, CBCT imaging, digital treatment planning, or CAD/CAM appliances, except for the use of clear aligners produced by off-site laboratories (eg, Invisalign). They have not explored most or even all of the listed orthodontic technologies. Late adopters do not beta-test products, belong to corporate insider groups, or otherwise develop new technologies.

Participants were sent a description of the study with consent and demographic forms to return before the interview. Ethics approval was given by the Institutional Review Board of UNC School of Dentistry (IRB 16-2743).

One-on-one interviews between the primary author and research participants were conducted in person (18 of 24 interviews) or remotely via telephone (6 interviews) and lasted 45-70 minutes. Each interview was in-depth and semistructured following a topic guide (Appendix 3). The topic guide included questions on observed and expected developments in digital dentistry, methods of usage, barriers and incentives to adoption, perceived influences of technologies on practice, and unmet technologic needs (Appendix 3). The topic guide was developed from a literature review of dental digital technology adoption and was revised after a pilot interview, not included in the study, and input from our qualitative research collaborator, Mr Mihas, several orthodontists, and an engineer specialized in personal fabrication.[19-21]

Interviews were audio-recorded, professionally transcribed, and deidentified. Transcripts were qualitatively analyzed with the use of MAXQDA12 software. A codebook with definitions was generated after analyzing 5 transcripts, and this was heavily revised after a consensus-coding meeting with our qualitative collaborator (Appendix 4).[22] The code list included deductive codes (eg, attitudes, values, decision making) and inductive codes (data-driven concepts of how doctors characterize, adopt, and use new technology),[22] MAXQDA12 software was used to calculate frequency and co-occurrence of codes and consolidate data from codes and demographic groups.[23] Co-occurrence maps allowed us to explore responses that are multidimensional, that is, coded to more than 1 topic. Co-occurrences capture narratives of shared meaning; for example, responses that illustrate a particular belief and a corresponding type of decision making would include two co-occurring codes.[23] In MAXQDA12, diagrams were generated to graphically display intersections and were redrawn in Adobe Illustrator software (Figs 1-3). Quotes from a code category or demographic were read by the first 3 authors independently to identify themes, incentives, and barriers to technology adoption.[22] Key themes were discussed, revised, and rechecked against the data, with representative quotations selected by all of the authors.

RESULTS

To understand technology adoption, we explored who is making purchasing decisions and where they learn about new technologies. For most doctors, orthodontic partners and associates participate in purchasing conversations, but adoption decisions are made with minimal staff input. Several doctors indicated that staff are resistant to change and therefore not consulted about adoption. However, training of staff and staff "buy-in" was considered important by most doctors.

> "The staff did not participate in the decision-making process. Not at all. No. We made the point that this was something we wanted to do and then we were very, very adamant about empowering them and giving them the training they need to excel with that, and that's been very successful. But no, as far as making the decision, that was all me."

When asked how long they considered a technology before adoption, some doctors made decisions in days or weeks whereas others would consider options for months or years. We hypothesized that early adopters make purchases more quickly than middle or late adopters, but no correlation appeared between adopter status and decision time. For the same doctor, time for adoption also varied significantly between technologies. For example, many orthodontists rapidly purchased

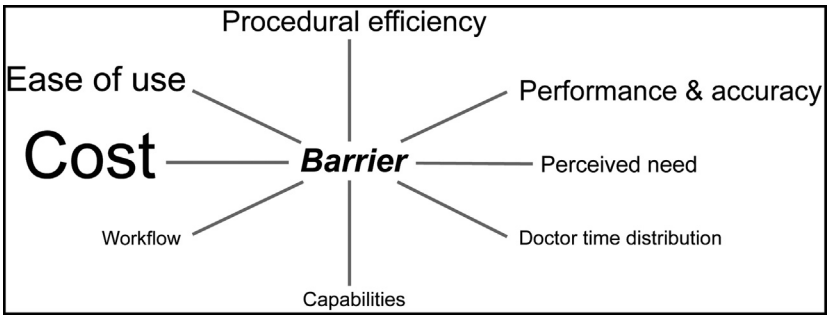

Fig 1. Barrier co-occurrence map. Co-occurrence of adoption barrier with overall cost (215), ease of use (114), procedural efficiency (95), performance and accuracy (92), perceived need for a product (75), doctor time distribution (66), capabilities (66), and workflow (64). Text size is proportional to frequency of co-occurrences. Threshold of 60 co-occurrences.

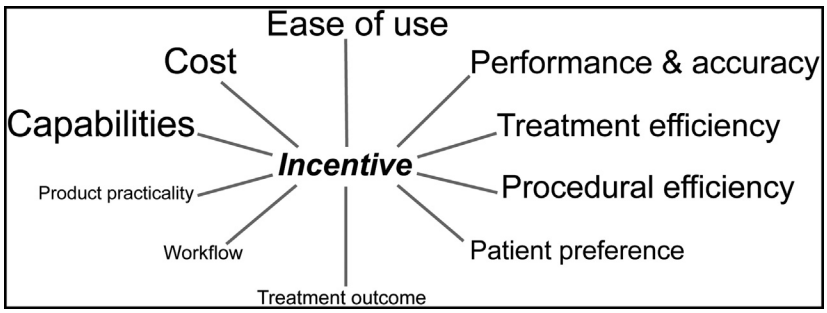

Fig 2. Incentive co-occurrence map. Co-occurrence of adoption incentive with capabilities (151), cost (147), ease of use (143), performance and accuracy (132), treatment efficiency (131), procedural efficiency (131), patient preference (109), treatment outcome (81), workflow (80), and product practicality (76). Text size is proportional to frequency of co-occurrences. Threshold of 75 co-occurrences.

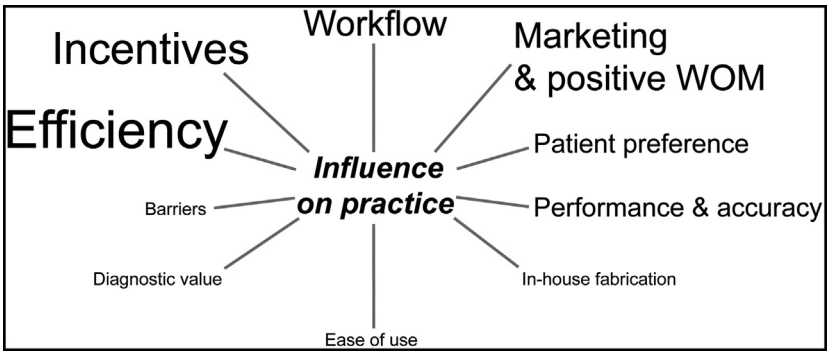

Fig 3. Influence on practice co-occurrence map. Results are based on orthodontists' responses to questions on how adopted technologies influence their practice. Co-occurrence of influence on practice with procedural efficiency (6), incentives (5), workflow (4), marketing and positive word of mouth (WOM) (4), patient preference (3), performance and accuracy (3), in-house fabrication (2), ease of use (2), diagnostic value (2), and barriers to adoption (2). Text size is proportional to frequency of co-occurrences. Threshold of 2 co-occurrences.

intraoral scanners but considered CAD/CAM technologies such as Suresmile or Insignia for much longer.

To identify information sources for adoption, orthodontists were asked how they first heard about technologies and what resources were consulted for more information (Appendix 3). Across all adopters, communication among dentists was the most frequently mentioned information source (Appendix 5). All interviewees described learning about products through orthodontic colleagues (Appendix 5).

Within the orthodontic community, a hierarchy of information exchange emerged. Early adopters share information with each other and make recommendations to middle adopters. Early adopters communicate primarily with each other, individually and as members of corporate insider groups. At company-hosted insider group meetings, early adopters discuss products in beta-testing at their offices and learn from company representatives about new tech pipelines. The host company solicits input from doctors, while recruiting offices to run clinical trials and beta-test products. Early adopters experiment with new technologies at a reduced price by running trials and beta-testing, thus mitigating the largest barrier to adoption: cost (Fig 1). Despite discounts, early adopters acknowledge that new technology is, at times, costly and inefficient, but their curiosity and desire to remain on the cutting-edge fuel adoption.

> "I gravitate toward technology when I go to AAO. I think it's really cool and I'm kind of a techy. I'm a sucker for tech. I like being on the forefront and trying to see where it goes. It does not always work well because it does slow you down a little bit sometimes, but I think my staff likes that we're always trying to do the latest and greatest."

Most middle adopters seek advice from their "go-to" early adopter when considering new technology. The early adopter is seen as someone who tries the latest thing, although the middle adopter views herself as cautious, waiting for others to experiment to avoid wasting money on flawed or unnecessary products. Avoiding waste was a major concern for nearly all middle adopters.

> "He's one of our graduates that tends to buy things before I do. This is what happens. You have people that I say, "Well you do it and let me see how it works for you." He does stuff before I do, and then I kind of figure out whether I want to do it or not, but he's wasted a lot of money, too."

The importance of person-to-person exchange extends to company representatives. Many doctors investigate technology after representatives suggest it, especially when there is a well-established relationship. This occurred despite some doctors expressing distrust of representatives (Appendix 5). Other key information sources include continuing education and exposure during residency or on the job. Only 4 interviewees referred to published literature when considering technology adoption. The only resource consulted less than journals was office staff, consistent with orthodontists being primary decision makers.

Orthodontists can make beautiful smiles with traditional approaches, so why adopt digital tools? To understand key incentives and barriers to adoption, orthodontists were asked why they chose to adopt or forego technologies. Before the interviews, we hypothesized that clinical efficiency, patient preference, and treatment outcomes would be primary incentives, with cost as a major deterrent. Our results had some surprising departures from this hypothesis, although cost remained as the largest incentive and barrier.

Several key incentives emerged, with reduced cost, added capabilities, ease of use, improved performance, and increased efficiency coded the most (Fig 2). Patient preference was also a consideration, with some mention of a technology's practicality and effect on workflow and outcomes. Notably, the most frequently cited incentives did not include patient experience and comfort, but instead related to practice operations.

Many incentives were also barriers, including cost, capabilities, ease of use, procedural efficiency, workflow, performance, and accuracy (Fig 1). If a technology requires additional doctor time or is perceived to be unnecessary, it is less likely to be adopted. Major incentives and barriers co-occur because these factors are interrelated and considered together when making purchases. Across all doctors, cost was the largest incentive and barrier and substantially mentioned more than any other code; financial factors were mentioned 402 times. Practice economics and operations predominated the decision-making process.

Each adopter group had unique demographics and values. Early adopters tended to be younger and work in more recently founded or acquired practices than middle and late adopters (Table I). Early adopters had larger practices with more staff and patients, with most carrying large (800-900) to very large (1000-2000) patient loads; this sizable patient pool and gross income may be necessary to afford new technologies. Middle adopters also had large patient pools, but their average staff size was smaller. Late adopters had mean patient loads one-half the size of middle and early adopters and a much smaller staff. Across all groups, the majority were private practice orthodontics-only businesses that used twin/edgewise or self-ligating brackets as their primary appliance and clear aligners

Table II. Purchasing values by adopter group

Group	*Representative quotes*
Early adopter	"Patient experience is huge, because if you give the patients a great patient experience, that's actually a better assistant experience, because the patients are happy because you're doing something that's more comfortable or high tech and they're excited and they're pumped up; then whoever's working on them or working with them is just going to have a better experience. It just makes everybody happy. Versus let's try to take a PVS impression on this poor lady that has lower tori that are touching. We scanned that lady last week. She would have had a horrible impression experience. So I think it's high tech, high touch, high comfort for the patient." "I mean there's no question that you can see better [on CBCT]. You find things on there that you don't find on a PAN so now you know it's all the better benefits for the patients. 3D is better than 2D, period. There's no questions about it. It's just whether that benefit outweighs the risks. The risk of radiation to the patient now is so low and on that we've got literature. There's an AJO article that is like, "the i-Cat Flex machine has less dosage than the PAN," so well why wouldn't I if I've got a low dose? The other issue of what you see, it's like well you've got to learn how to read them and if you don't know what you're doing, send them out."
Middle adopter	"I think it's made things easier. I think the patients like it. They see it. If they've had braces before or they've been in braces or they've had impressions made, they understand the benefit there and they'll go out and tell their neighbors. Not just our office but people will tell—people are very quick on telling something negative about an experience, whether it's a physician, a dentist, or whatever, but if you have something good that you know is much better than it was before in orthodontics, it's a big boon and they'll tell people about it and we get a lot of referrals from it." "Oh heavens, yes. That was the main reason. We're trying to get every model out of the office. We don't have any models. We have a handful for teaching. We got some but not many."
Late adopter	"I'm pretty good at bending arch wires. I seldom had to intensively bend an arch wire, because we had an 0.022 slot and most often finished with an 0.018 × 0.025 wire. So only when I needed to do torque would I customize it. My question would be, why would someone explore that? Why would someone go to Suresmile saying this could be for me? Correct me if I'm wrong, but I think it's because they want to save my time, I don't like bending arch wires, I want to treat more patients and make more money. There hasn't been a great need. If we were super materialistic and did not enjoy the skills essential to being an orthodontist, we'd probably be gung-ho." "You've got to have space for technology. So you've got to have space and you've got to have that, and I did not." Question: "Have you considered doing custom-bent archwires or custom brackets?" Answer: "Shit no. That's why we went to school. Come on. I don't want a computer bending wire for me. I'm a wire bender. I'm an orthodontist."

as their secondary appliance. The practice setting and price bracket were not associated with adopter group. A national survey, currently being distributed, will test the generalizability of these trends.

Purchasing considerations varied greatly between groups (Tables II and III). Late adopters thought that new technologies take up too much space and are unnecessary because established methods work (Tables II and III). They feared that technology would negatively affect their practice and the field of orthodontics. Early adopters, in contrast, focused on a technology's diagnostic value and potential to reduce treatment time, increase treatment control, and improve efficiency. First-wave adopters frequently discussed a technology's impact on workflow, doctor time distribution, staffing, practice liability, and ease of use. Their own enjoyment and curiosity were also important. Surprisingly, early adopters focused on the patient experience more than other adopter groups (2-3 times as much), repeatedly discussing a technology's impact on patients' safety, preference, comfort, and customer service experience (Tables II and III). Middle adopters fell between early and late adopters in their consideration of these factors.

Middle adopters were most concerned with treatment outcomes, inventory needs, and storage space. Early and middle adopters effused about the "coolness" of new tools, the marketing opportunities, and advantages of in-house fabrication while considering return on investment. Middle adopters acknowledged their limited knowledge of some technologies, but hoped to learn more, whereas late adopters were uninterested. All groups were equally concerned with a technology's performance, capabilities, usefulness, and cost to the practice and patient (Table III).

Doctors' perceptions of adopted technologies varied by group, although all orthodontists tracked growth, efficiency, and workflow. Among early and middle adopters, technologies such as intraoral scanning and digital treatment planning were perceived to positively affect their practice by satisfying patient requests and providing positive word of mouth for marketing (Tables III and IV). These factors led to patient conversions and practice growth. Other perceived benefits included improved efficiency, office workflow, and ease of use (Fig 3). Most doctors reiterated the incentives that motivated purchase, whereas few focused on barriers (Fig 3). In contrast, late and nonadopters perceived minimal benefit at significant cost and felt that new tools were unnecessary or fads (Tables III and IV). Most late adopters

Table III. Adoption values as normalized code frequencies*

Domain†	*Adoption factors*	*Early adopters (n = 9)*	*Middle adopters (n = 10)*	*Late adopters (n = 5)*
Clinic	Space for device	2.77	4.29	6.42‡
	Storage of patient records	1.96	5.88‡	4.70‡
	Inventory of supplies	0	8.33‡	3.33
	Procedure efficiency	5.85‡	3.99‡	1.48
	Ease of use	5.75‡	3.60	2.43
	Workflow	5.64‡	4.00‡	1.84
	Staffing levels	5.75‡	4.29‡	1.07
	In-house fabrication	4.80‡	4.69‡	1.97
	Performance and accuracy	4.93‡	3.95‡	3.20‡
	Capabilities	4.54‡	4.14‡	3.53‡
	Practical and useful	3.96‡	4.79‡	3.26‡
	Unnecessary	2.92	3.87	7.00‡
	Influence on practice	3.33	4.00‡	6.00‡
Treatment	Diagnostic value	5.83‡	3.77‡	1.97
	Treatment outcome	3.96‡	5.54‡	1.79
	Treatment efficiency	5.71‡	3.49	2.75
	Treatment control	6.21‡	3.53	1.76
Patient	Patient preference	4.84‡	4.21‡	2.86
	Patient compliance	5.21‡	3.44‡	3.75
	Patient safety	7.32‡	2.68	1.46
	Patient comfort	5.78‡	3.73	2.13
	Customer service	6.17‡	3.33	2.22
Doctor	Doctor time	5.50‡	4.00‡	2.09
	Enjoyment	5.38‡	3.76‡	2.80
	Coolness factor	5.13‡	5.13‡	0.51
	Curiosity	5.29‡	3.33	3.81
	Liability	6.25‡	4.38‡	0
	Does not know enough to decide	1.01	7.27‡	3.64
	Desire to preserve specialty	0.74	6.00‡	6.66‡
Finances	Cost to the practice	4.76‡	4.04‡	3.33‡
	Cost to the patient	3.17‡	4.69‡	4.89‡
	Marketing	4.92‡	5.08‡	0.98
	Return on investment	4.52‡	4.57‡	2.71

*The numbers displayed are calculated by dividing the total frequency of a code within an adoption group (early, middle, or late) by the number of adopters in that category. For example, early adopters discussed "space for a device" an average of 2.77 times per interview. Interpretation of this table must be limited because frequencies are based on the total number of codes gathered from semistructured interviews in which not all interviewees were asked all of the probes or prompts. Traditional statistics cannot be applied. The adopter group with the largest frequency is underlined; †Adoption factors or values are grouped into conceptual domains; ‡The adopter group with the largest frequency or the group or groups with frequency values differing from the highest frequency by ≤35%, indicating a shared adoption value.

perceived new technology as having a neutral or negative impact on practice, reinforcing their disinterest in new digital tools.

Most orthodontists were aware of new market pressures and technologic innovations. The vast majority of doctors anticipated the standard of care to include an intraoral scan, a digital tooth setup, and fabrication of CAD/CAM appliances; 22 out of 24 doctors described this future workflow, whereas 2 outlying late adopters asserted that current approaches would continue. Most thought that the digital workflow will include in-office 3D printing for retainer and aligner fabrication. Doctors foresaw enhanced diagnostics and improved treatment efficiency and outcomes.

> "Seemingly there's 2 gains from individualized treatment and one is increased efficiency. We kind of streamline things to make the treatment shorter. The second, hopefully more important one, is that you're increasing the precision of that outcome as well. Like both of those, the data is there."

Despite technology's promise, doctors were universally concerned with cost.

> "When I opened my office 16 years ago, my technology bill was $40,000. You can't even get a ceph/pan for $40,000. If you want a cone-beam scanner and 3D printer, I just spent 250 grand on technology that wasn't part of what you had 15 years ago. Then you add more education with that. Can you afford to do this? That's why ophthalmologists are the

Table IV. Perceptions of technology by adopter group

Group	*Representative quotes*
Early adopters	"I think the (intraoral) scanner has improved efficiencies. It's definitely helped with storage and space and cleanliness because you don't have plaster everywhere, alginate everywhere. Certainly patient comfort is a big issue. And then just reproducibility—if you have that digital file, you can give the printed model to the patient or you can reprint the digital file for them. If they need a new retainer or if you have a college student that needs one mailed to them, it just gives you a lot more flexibility in terms of providing better patient experiences." "People love technology. People want the latest and greatest. People are spending a lot of money for orthodontic treatment. They want to have everything top. If I can give you a service that's going to give you a better fitting aligner, which means it should stay on track and finish on time, or quicker, and I don't have to put this gooey crap in your mouth, then everybody wins."
Middle adopters	"Immensely—the [intraoral] scanner made a major impact. It made me go from doing no Invisalign to doing 100 Invisalign last year. It made it much simpler to have more accurate pretreatment study models and when I do surgical cases, my surgical study models, I think the accuracy is awesome." "It's a lot more efficient. It's easier on the patient. We get the appliances faster, and the gals that are doing the scanning are doing it faster. They do it pretty fast. Is it making the flow of the practice faster? Maybe a little quicker and cleaner."
Late adopters	"My God, yes! The [intraoral] scanner was horrible. It threw the whole afternoon and morning off. It really messed up the schedule." "I was appalled that Invisalign was taking hold. At first, it was on very tenuous grounds. It wasn't that embraced. It was expensive. You had to go through 20-25 aligners. They had limitations. Everything was nonextraction. One of the worse things in orthodontics is when the treatment dictates diagnosis. … Invisalign is … a wimpy technique designed by 2 nonorthodontist entrepreneurs who decided to have a business plan to solve some of these psychosocial problems of adults who complain about this 1-mm space or overlap. It's great for that. It could be 10% of our practice. And we'll use it. For real orthodontic challenges, there is no way. It's a compromise. It's a rationalization that's been foisted on the scientific clinical population by entrepreneurs."

most expensive doctors, because of those machines. Technology is very expensive."

Clear aligner therapy was seen as a growing trend in orthodontics and as a major threat to orthodontic jobs, owing to business models such as SmileDirectClub that bypass orthodontists to deliver aligners directly to consumers. A couple doctors were less concerned and considered SmileDirectClub to be "the McDonald's of orthodontics" and sought out by patients who would not pay for traditional braces. In fact, several doctors think patient numbers may increase in private practice, as cases are botched by direct-to-consumer products, teledentistry, and self-care. Self-treatment and its dental sequelae were a big worry for orthodontists.

Several doctors were concerned that algorithms and Invisalign's treatment database will make orthodontics so predictable that our careers will be obsolete, with general dentists or technicians managing all cases. Others predicted that orthodontists will persist, but that our work will include substantially more computer time. A common sentiment was, "I did not become an orthodontist to buy a computer screen and stare at it."

Late adopters are more optimistic; they felt confident in the viability and competitive advantage of orthodontists. This optimism may have stemmed from their proximity to retirement, their limited awareness of new technologies, or their decades of experience seeing trends come and go.

"Orthodontics is real low on the totem pole of important things, like periodontal disease. Brushing and all that has to be monitored. I don't see orthodontics getting out of our hands. As long as we can maintain professional end results, I don't fear the future at all."

DISCUSSION

Qualitative interviews reveal factors important to orthodontists deciding to adopt new technology. Orthodontists learn about new tools through other dentists, company representatives, and their residency and CE courses. Doctors make purchases independently from staff and research literature, suggesting that lectures at meetings and residency are more effective at disseminating knowledge to practicing doctors than journals. Early and middle adopters are integrating digital imaging, planning, and fabrication technologies into their practices. They view enhanced ease of use, capabilities, performance and accuracy, procedural efficiency, and reduced costs as primary incentives (Fig 2). The main incentives do not include patient outcome, experience, or comfort, but instead relate to a technology's benefit to practice operations and finances. Orthodontists care for their patients, but the business of orthodontics is a primary driver for technology adoption.

Cost is the ubiquitous barrier to adoption (Fig 1), despite most interviewees acknowledging that new tools could shorten treatment and improve outcomes.

Difficult implementation is a barrier, but when technology is user friendly, ease of implementation is a primary incentive, highlighting the importance of user interfaces, training, and customer support. Appropriate price points and smooth workflow integration are critical for adoption.

Early and middle adopters perceive positively the influence of intraoral scanners, CBCT imaging, digital tooth setups, and certain custom appliances after observing improvement in clinical efficiency and workflow and positive word of mouth. Satisfying customer requests and positive reviews may lead to patient conversions and practice growth. Intraoral scanning is associated with increased patient conversions and procedural efficiency, corroborating our interviewees' impressions.[19]

Late adopters view new digital tools as unnecessary, costly, and having a neutral or negative impact on practice. Late adopters' perception of technology reinforces their adopter status, whereas the positive experiences of middle and early adopters favor future exploration. Late adopters also have smaller staff sizes and patient pools compared with middle and early adopters; smaller practices may lack the income and staffing needed to invest in and manage new technology. As orthodontics becomes progressively more digital, the gap between adopter tiers will likely widen.

Most doctors anticipate broad use of digital setups and CAD/CAM appliances as future standards of care, but are concerned that new technologies will cause loss of market share to general dentists and direct-to-consumer corporations. However, at this time, the orthodontist remains a critical factor in treatment outcomes.[24,25] This is consistent with studies comparing bracket systems, where the operator heavily influences outcome in terms of Peer Assessment Rating, treatment time, and total number of visits.[24,26] CAD/CAM appliances and digital treatment planning are valuable tools, but they do not replace the skill of the doctor.

Our sample included 24 orthodontists in Massachusetts and North Carolina, affiliated with University of North Carolina or Harvard School of Dental Medicine. The perspective of orthodontists in other geographic areas were not represented, and orthodontists affiliated with a university are likely more attuned to modern trends owing to their academic involvement. As a result, our sample is biased toward early and middle adopters. This was mitigated in part through purposeful sampling of late adopters, but more early and middle adopters were interviewed (9 early, 10 middle, 5 late). Women and minorities were also underrepresented in our sample, along with input from orthodontists working in group or multispecialty practices. A multispecialty or multidoctor practice may have different adoption practices and decision makers, which were not assessed here. The decision-making process between associates and partners was superficially explored, but too few employees (3 total) were interviewed to gain a representative perspective. Thus, key factors in technology adoption may be missed owing to geographic bias, sample bias, and the modest size of our interview cohort.

Exploratory qualitative interviewing does not yield quantitative statistical data. This methodology provides nuanced insight into people's experiences and opinions, which is useful as a psychologic and market research tool. The results of this qualitative study are the basis for a nationwide survey to quantitatively assess adoption, pairing the strengths of qualitative analysis (depth of information) with quantitative techniques (statistical generalizability). The qualitative data ensures that we identify and measure correct variables in our quantitative survey, which is to be completed in the coming year.

Orthodontic treatment has been successful for decades, so why enter the digital age? Digital models reduce physical storage, risk of breakage, and allow for easy transfer of records. Intraoral scanning is more comfortable for patients than traditional impressions, and CBCT imaging yields 3D diagnostic information for treatment of impacted teeth and facial asymmetries.[27-29] Studies also verify the accuracy and validity of intraoral scans and CBCT for orthodontic measurements and diagnostic purposes.[30-37] Widespread adoption of these imaging modalities is occurring and offering the accuracy of traditional methods with new advantages.

Although digital models offer benefits with few drawbacks, data supporting CAD/CAM appliances compared with traditional treatment is less robust. Suresmile's custom finishing wires reduce treatment time and improve outcomes, but published studies are nonrandomized, retrospective, and with small or poorly standardized samples.[3,7,9] Data in support of Insignia's CAD/CAM brackets and wires are even less clear cut. Two retrospective investigations indicate that Insignia reduces total treatment time while delivering results similar to conventional systems.[4,12] However, a recent prospective randomized trial found no significant difference in treatment duration and outcome between Insignia and traditional braces.[25] Insignia patients also filed more complaints, had increased debonds, and required more doctor planning time.[25] Although these results are concerning, the orthodontists in that study were "equally experienced" compared with each another, but not highly experienced with Insignia, introducing a confounder because the CAD/CAM learning curve is steep.[25] Future prospective randomized trials are needed to assess CAD/CAM appliances, although data suggest that treatment times can be reduced

with experienced doctors using certain products. Potential for CAD/CAM appliances is growing, but clinical evidence supporting manufacturers' claims is necessary to justify costs and guide improvements.

In the words of William Gibson, "The future has arrived—it's just not evenly distributed yet." The digital revolution in orthodontics has begun, but orthodontists represent a wide spectrum with some leading the charge and others plan to retire before change is necessary. Among adopters, technology is changing how orthodontics diagnose, plan treatment, and fabricate appliances, akin to the innovation of the Andrews Straight-Wire Appliance in 1976. CAD/CAM brackets, aligners, and prebent finishing wires may realize the "straight-wire" goal to eliminate chairside bending, improve accuracy, and reduce treatment times. Though substantial research and development are still necessary, CAD/CAM appliances and digital setups were seen as the future of orthodontics by our sample of orthodontists. Identifying decision makers, information sources, incentives, and barriers to adoption can guide innovation and training to improve treatment and smooth the transition into digital orthodontic workflows.

CONCLUSIONS

Our semistructured qualitative interviews of privately practicing orthodontists revealed the following.

1. Purchase decisions are made by practice owners, influenced by other dentists, company representatives, and educational experiences. Research literature and staff input rarely affect adoption decisions.
2. The largest incentives to adoption include capabilities, ease of use, performance and accuracy, patient preference, efficiency, and reduced costs. The largest barrier to adoption is cost. Patient comfort and treatment outcome are not frequently cited as incentives or barriers.
3. Early and middle adopters positively perceive new technology's influence on their practices through increased efficiency, positive word of mouth, and satisfying patient requests.
4. Orthodontists anticipate broad adoption of intraoral scanning, digital treatment planning, and CAD/CAM appliances as future standards of care, although there is concern about self-treatment trends and direct-to-consumer products.

ACKNOWLEDGMENTS

The authors thank all the participating orthodontists for their honesty, humor, and willingness to spend time participating in our study. The authors also thank Mr Ilan Moyer for his input on questions regarding technology adoption and in-house personal fabrication.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajodo.2018.08.018.

REFERENCES

1. Bauer JC, Brown WT. The digital transformation of oral health care. Teledentistry and electronic commerce. J Am Dent Assoc 2001;132:204-9.
2. van der Zande MM, Gorter RC, Wismeijer D. Dental practitioners and a digital future: an initial exploration of barriers and incentives to adopting digital technologies. Br Dent J 2013;215:E21.
3. Alford TJ, Roberts WE, Hartsfield JK Jr, Eckert GJ, Snyder RJ. Clinical outcomes for patients finished with the Suresmile method compared with conventional fixed orthodontic therapy. Angle Orthod 2011;81:383-8.
4. Brown MW, Koroluk L, Ko CC, Zhang K, Chen M, Nguyen T. Effectiveness and efficiency of a CAD/CAM orthodontic bracket system. Am J Orthod Dentofacial Orthop 2015;148:1067-74.
5. Fox N. Longer orthodontic treatment may result in greater external apical root resorption. Evid Based Dent 2005;6:21.
6. Khalaf K. Factors affecting the formation, severity and location of white spot lesions during orthodontic treatment with fixed appliances. J Oral Maxillofac Res 2014;5:e4.
7. Sachdeva RC, Aranha SL, Egan ME, et al. Treatment time: Suresmile vs conventional. Orthodontics (Chic) 2012;13:72-85.
8. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: Part II. Treatment factors. Am J Orthod Dentofacial Orthop 2001;119:511-5.
9. Saxe AK, Louie LJ, Mah J. Efficiency and effectiveness of Suresmile. World J Orthod 2010;11:16-22.
10. Segal GR, Schiffman PH, Tuncay OC. Meta analysis of the treatment-related factors of external apical root resorption. Orthod Craniofac Res 2004;7:71-8.
11. Tufekci E, Dixon JS, Gunsolley JC, Lindauer SJ. Prevalence of white spot lesions during orthodontic treatment with fixed appliances. Angle Orthod 2011;81:206-10.
12. Weber DJ 2nd, Koroluk LD, Phillips C, Nguyen T, Proffit WR. Clinical effectiveness and efficiency of customized vs conventional preadjusted bracket systems. J Clin Orthod 2013;47:261-6.
13. Uribe F, Padala S, Allareddy V, Nanda R. Patients', parents', and orthodontists' perceptions of the need for and costs of additional procedures to reduce treatment time. Am J Orthod Dentofacial Orthop 2014;145(4 Suppl):S65-73.
14. Clark J. Increasing practice efficiency and profitability using In-Ovation Self-ligating Brackets. Dentsply GAC 2007:1-5.
15. Phipps GS. Seven keys to on-time finishing. J Clin Orthod 2004;38:155-8.
16. Matthews DC, McNeil K, Brillant M, et al. Factors influencing adoption of new technologies into dental practice. JDR Clin Transl Res 2016;1:77-85.
17. Rubin HJ, Rubin I. Qualitative interviewing: the art of hearing data. 3rd ed. Thousand Oaks, Calif: Sage; 2012.
18. Carter N, Bryant-Lukosius D, DiCenso A, Blythe J, Neville AJ. The use of triangulation in qualitative research. Oncol Nurs Forum 2014;41:545-7.
19. Mackay MM, Fallah M, Danyal T. Acquisition of a digital intraoral scanning device: an examination of practice volume changes and

the economic impact via an interrupted time series analysis. J Clin Dent 2017;28:1-5.
20. Noble J, Hechter FJ, Karaiskos NE, Lekic N, Wiltshire WA. Future practice plans of orthodontic residents in the United States. Am J Orthod Dentofacial Orthop 2009;135:357-60.
21. Park JH, Laslovich J. Trends in the use of digital study models and other technologies among practicing orthodontists. J Clin Orthod 2016;50:413-9.
22. Saldaña J. The coding manual for qualitative researchers. 3rd ed. Los Angeles and London: Sage; 2016.
23. Silver C. Using software in qualitative research: a step-by-step guide. 2nd ed. Thousand Oaks, Calif: Sage; 2014.
24. Anand M, Turpin DL, Jumani KS, Spiekerman CF, Huang GJ. Retrospective investigation of the effects and efficiency of self-ligating and conventional brackets. Am J Orthod Dentofacial Orthop 2015;148:67-75.
25. Penning EW, Peerlings RHJ, Govers JDM, et al. Orthodontics with customized versus noncustomized appliances: a randomized controlled clinical trial. J Dent Res 2017;96:1498-504.
26. Kattner PF, Schneider BJ. Comparison of Roth appliance and standard edgewise appliance treatment results. Am J Orthod Dentofacial Orthop 1993;103:24-32.
27. Proffit WR, Fields HW, Sarver DM. Contemporary orthodontics. Elsevier Health Sciences; 2014.
28. Wismeijer D, Mans R, van Genuchten M, Reijers HA. Patients' preferences when comparing analogue implant impressions using a polyether impression material versus digital impressions (intraoral scan) of dental implants. Clin Oral Implants Res 2014;25:1113-8.
29. Yuzbasioglu E, Kurt H, Turunc R, Bilir H. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. BMC Oral Health 2014;14:10.
30. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop 2009;136:19-25 [discussion 25-8].
31. Berco M, Rigali PH Jr, Miner RM, DeLuca S, Anderson NK, Will LA. Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull. Am J Orthod Dentofacial Orthop 2009;136:17.e1-9: [discussion 17-8].
32. Costalos PA, Sarraf K, Cangialosi TJ, Efstratiadis S. Evaluation of the accuracy of digital model analysis for the American Board of Orthodontics objective grading system for dental casts. Am J Orthod Dentofacial Orthop 2005;128:624-9.
33. Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. Orthod Craniofac Res 2011;14:1-16.
34. Hilgers ML, Scarfe WC, Scheetz JP, Farman AG. Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am J Orthod Dentofacial Orthop 2005;128:803-11.
35. Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J Orthod 2005;32:282-93.
36. Quimby ML, Vig KW, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 2004;74:298-303.
37. Zilberman O, Huggare JA, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod 2003;73:301-6.