Principles of Orthodontic Treatment and Current Research Status

Jiacen Han*
Elite preparatory academy, Hopatcong, Newjersey, US
*Corresponding author: valorie.han@eliteprepacademy.org

Abstract. Modern orthodontic treatment has gone from ancient simple devices to today's advanced digital tools such as CAD/CAM, three-dimensional imaging, and clear aligners like Invisalign. This article reviews the progress of orthodontics. It focuses on early tries at straightening teeth and the work of pioneers like Edward Angle who helped start the system of classification. The article also shows several big new ideas. These include cone-beam computed tomography (CBCT) for clear three-dimensional images of body parts and the use of artificial intelligence to make treatment planning work faster. Even though these steps have been made, there are still some problems. For example, Invisalign has a small range of use when treating hard cases of bad tooth bite, CBCT has a high risk of giving too much radiation, and the materials for 3D printing have limits. Current studies work to make treatment work better, to make materials work better, and to put digital tools together so care can be made just for each patient. This article looks at the many new advances in orthodontics in both clinics and in tech. It also points out how important it is to use many fields together to solve these problems. In the future, as tech keeps getting better, we can hope for patient care that is both safer and works better.

Keywords: Digital dentistry; Cone-beam computed tomography (CBCT); Edward Angle classification.

1. Introduction

Orthodontic treatment is a method that uses specific instruments (braces) to distribute the occlusal pressure evenly to all teeth, ensuring that each tooth exerts force uniformly. This helps to improve the uneven arrangement and uneven force distribution of teeth and also makes the teeth straight and aesthetically pleasing. Around 4000 BC, the wooden braces and other primitive devices of the ancient Egyptians indicated their attempts to solve the problem of tooth alignment. In the 19th century, orthodontic treatment began to be implemented, and Edward Angle made significant contributions to this treatment method. At the beginning of the 20th century, he proposed a classification system for tooth alignment and occlusion, which laid the foundation for the development of orthodontics. Currently, orthodontic treatment is widely used among teenagers to improve problems such as uneven tooth alignment and occlusion issues (excessive or insufficient tooth spacing). The orthodontic treatment method is constantly improving, and with the continuous progress of orthodontics, orthodontic materials and methods have gradually diversified. The arrival of Invisalign has further advanced orthodontics. The introduction of emerging technologies such as CAD, three-dimensional imaging technology, and digital scanning has made orthodontics more precise and efficient. Currently, emerging technologies being widely studied in this field include Invisalign, cone beam computed tomography (CBCT), 3D printing, and so on. These new technologies are now widely used, but they are not without drawbacks. For Invisalign, although it is more aesthetically pleasing than traditional metal braces and is more convenient and less noticeable when taken off and put on, its treatment recipients are relatively limited. For people with complex tooth misalignment or severe occlusion problems, it may not be as practical as traditional metal braces. Cone beam computed tomography, although a new and fast method, has problems such as radiation, poor image quality, and high cost. As for 3D printing, although it can help with personalized production and design and save materials, not all materials are suitable for it. Some specific materials cannot be used for production, which limits the production materials of braces and may affect their comfort and strength. This article will discuss the emerging technologies in orthodontic treatment and the problems they face.

2. Principles of Orthodontic Treatment and Current Research Status

The basic principle of orthodontic treatment is to use continuous biomechanical force on the periodontal tissue. This causes tooth movement and skeletal changes. This process has many biological reactions. It includes the rebuilding of the alveolar bone and the reorganization of the periodontal ligament [1]. When the orthodontic force is put on a tooth, the pressure side has bone resorption, and the tension side has bone deposition. This balance lets the tooth move while it still has healthy support [2]. Studies show that orthodontic treatment not only affects the alveolar process but also causes extra skeletal changes, including remodeling of the mandibular angle, mandibular ramus, and temporo-mandibular joint [3]. These findings widen the theory of orthodontic treatment and show that its effect goes beyond the traditional alveolar region.

Recent research focuses on the change of alveolar bone density during orthodontic treatment. The study by Yu et al. [4] shows that after 7 months of treatment, the alveolar bone density around the tooth drops by about 23% on average. But after the retention period, the lost bone density can return to the state before treatment. This result is very important to understand the biological process during treatment and to stop possible problems. However, about 10% of teeth cannot regain more than 80% of their original bone density, which suggests that doctors need to lengthen the retention period for some patients [5].

Orthodontic diagnostic technology has also made significant progress. Traditional two-dimensional cephalometry is now replaced by three-dimensional cone beam computed tomography (CBCT). The new method gives more complete anatomical information, lowers the radiation dose, and allows a more exact treatment plan [4,6]. Also, with deep learning and artificial intelligence, researchers can do automatic tooth segmentation and landmark recognition. This greatly makes diagnosis faster and more correct [7].

In terms of treatment methods, traditional fixed appliances and clear aligners each have their advantages. Studies show that fixed appliances work better for deep overbite, front-back jaw misalignment, and bite contact. Invisalign is more efficient for crowded teeth and incisor rotation [8]. Regarding treatment duration, study results are inconsistent. One study shows that Invisalign is on average 4 months faster than fixed appliances [9], while other studies have reached the opposite conclusion. These differences may be due to case selection, initial malocclusion severity, and doctor experience [10].

It is worth noting that orthodontic treatment has a significant impact on patients at the psychosocial level. A large-scale study in Korea found that dental esthetics have an important impact on self-esteem, social confidence, and mental health. This is often the main reason why adults seek orthodontic treatment [8]. In addition, factors such as age, gender, marital status, and education level have a strong impact on adult patients' decisions about orthodontic treatment. This shows that the need for treatment is affected by many social and psychological factors.

Even though there has been clear progress, orthodontic research still faces challenges. For example, more high-quality clinical studies are needed on the long-term stability of different orthodontic techniques, the predictability of various types of tooth movement, and the effect of treatment on the temporomandibular joint. In addition, as patients’ aesthetic expectations increase, developing orthodontic systems that balance treatment outcomes and aesthetics has become a research focus. Future research should integrate biomaterials, biomechanics, and digital technology to promote the development of personalized and precise orthodontic treatment.

3. Emphasizes Theory-to-innovation Transition

3.1. Invisalign

Invisalign, as one of the most revolutionary technological innovations in the field of orthodontics in the past twenty years, gradually moves teeth through a series of custom clear aligners, and has shaped the smiles of more than 5 million patients worldwide. This system is based on computer-aided design/computer-aided manufacturing (CAD/CAM) and three-dimensional imaging. It gives a new choice to patients who want a more aesthetic option than traditional fixed appliances [11]. Compared with traditional appliances, Invisalign gives better appearance, comfort, and ease of oral hygiene. It also reduces the number of visits and emergency treatments significantly [12].

However, research on Invisalign treatment results show some limits. A systematic review found that tooth extrusion and rotation are the hardest movements for Invisalign, with accuracies of only 30% and 36% [13]. Djeu et al. [14] compared Invisalign with traditional fixed appliances and saw that, under the American Board of Orthodontics (ABO) grading system, the Invisalign group lost 13 more points on average and had a 27% lower pass rate than the fixed appliance group. In detail, Invisalign did worse in bucco-lingual inclination, occlusal contact, occlusal relationship, and overbite, but did better in closure of space, marginal ridge height correction, and anterior rotation.

In recent years, Invisalign materials have undergone several updates, from the earliest Proceed 30 to the later Exceed 30 material, and then to Smart Track (LD30) introduced in 2013 [15]. Studies show that LD30 material has higher elasticity and better dental arch adaptability. Fang et al. [16] evaluated the changes of Invisalign material in the mouth. They found that after 2 weeks of use, some surface defects appeared, but the mechanical performance did not change much. It is worth noting that small amounts of elements such as aluminum may be released during use. This may pose a potential risk for patients with allergies.

Artificial intelligence technology is optimizing the evaluation of Invisalign treatment. Lee et al. [17] used deep learning for automatic tooth segmentation and landmark recognition. They found that a combined score of six degrees of freedom can predict treatment time better than a single factor. They also found that incisor misalignment has a significant impact on treatment time. Oh et al. [18] in a Korean study showed that patient choices are influenced by multiple factors, including demographic characteristics, oral health status, and psychological cognition. Those who seek orthodontic treatment usually pay more attention to dental examinations and have a more positive view of orthodontic treatment.

Although Invisalign offers many advantages, clinicians should recognize its limitations. For complex malocclusions, especially in cases that require large anteroposterior adjustments or tooth extrusion, traditional fixed appliances may still be a more reliable choice. Future research should focus on improving Invisalign material performance, optimizing attachment design, and refining the mechanical system to increase the accuracy of complex tooth movements. At the same time, long-term follow-up studies are crucial for evaluating the stability and durability of Invisalign treatment, which will give clinicians a more complete basis for treatment decisions.

3.2. CBCT in Orthodontics

Cone-beam computed tomography (CBCT) is a way to make three-dimensional images that has greatly helped orthodontic diagnosis. Compared with the old plain X-ray that shows the whole jaw (panoramic X-ray), CBCT can show the body parts in more detail. It shows pictures of the teeth, the jaw bone, and the soft parts clearly. At the same time, the radiation the patient gets is lower than with a regular CT scan [19]. This better work makes CBCT very useful when checking for teeth that do not come in or problems with the jaw bone.

One big good point of CBCT is that it helps to plan the treatment more exactly. For example, when a patient has a tooth that does not come in (impacted tooth), the 3D view can show the tooth’s place very well. This helps the orthodontist to choose if the tooth should be taken out or moved to the right spot in another way. In addition, CBCT helps a lot when studying the structure of the joint in the jaw (TMJ) and when planning the needed surgery. Studies show that in many cases, using CBCT changes the way a case is seen and the plan for treatment. This is especially true when working with teeth that have not come in or with big problems at the root [20].

Even though CBCT has many good points, there are also some problems. One is the amount of radiation the patient gets. Even though CBCT gives less radiation than a regular CT scan, it still gives more than a normal panoramic X-ray or head image. Groups of experts such as the American

Association of Orthodontists suggest that CBCT be used only when it is clearly needed so that the good points in diagnosis are balanced with the risk from radiation [21].

Also, sometimes CBCT shows extra things that are not part of the original problem. For example, when scanning a jaw bone problem, the image might show small holes in the bone or other odd things. In many cases, these extra finds do not change the treatment plan but might lead to extra tests that are not needed. So, orthodontists must be very careful to decide which finds are important for the patient's treatment.

In the future, research on CBCT may work on lowering the radiation even more while keeping good picture quality. Researchers are also very interested in using artificial intelligence to read these pictures faster and more exactly. This may help to lower the chance of a wrong view and make the treatment go faster.

4. Problems

New tools in orthodontics bring many good things, but they also bring some challenges that can affect daily work in the clinic. In this section, we talk about these problems. We discuss problems in clinics, problems with equipment and technology, and ideas to make things better. We also focus on some studies that show these issues well.

4.1. Clinical Problems

One main clinical problem is the small changes in shape that can happen in 3D printed models and devices. These small errors may look unimportant at first, but they can affect how the treatment plan is made and how well the device fits in the end. For example, slight changes on the biting surfaces may change the force distribution on the teeth, lead to poor tooth movement, and even require the device to be reprinted, which delays the treatment process [22].

Another clinical worry involves the material issues used in 3D printing. Some 3D printing materials may release a small amount of elements during or after printing. For sensitive or allergic patients, these trace elements may cause local swelling or allergic reactions. For example, if a patient is slightly allergic to a certain metal or compound, even if the amount of material released from the 3D printed retainer is very little, it may cause discomfort or an allergic reaction [23]. This issue shows that although 3D printing has a huge benefit for personalized treatment, the safety of the materials used must be tested strictly over a long time.

Apart from the problems with 3D printing, cone beam CT (CBCT) also has some problems. Even though CBCT can offer detailed images of teeth and jaw bones to help plan treatment accurately, compared with regular 2D X-ray images, CBCT gives more radiation to patients. This is especially important for young patients or patients who need frequent scans [24]. For example, a young patient with many dental issues might need several scans during treatment. Each scan increases radiation, and over time the total may raise health risks. Although CBCT is very useful, orthodontists must balance its diagnostic benefits with the high radiation risk.

Modern orthodontic clinics face challenges. These challenges include the risk that 3D printed models have slight but clear deformations, the risk that printing materials may release trace elements, and the high radiation level from CBCT images. These problems require medical staff to be extra careful when using tools and materials and to keep watching safety.

4.2. Equipment and Technology Problems

Equipment and technology faults cause many problems in modern orthodontic treatment. For example, invisible aligners (such as Invisalign) are very popular because of their good looks and easy use. However, research shows that compared with traditional fixed aligners, patients may feel more clear discomfort when they first use invisible aligners [25]. This discomfort comes mainly from the way the aligners apply force and the features of the materials. In the first few days, patients may feel sore or under pressure. This not only affects overall comfort but may also lower their willingness to continue treatment. This finding naturally raises an important question: do the beauty and convenience of invisible aligners really make up for the early discomfort? Some patients care a lot about looks, while other patients may find it hard to overcome the early discomfort, thus affecting the smooth progress of treatment.

Another big limit of modern orthodontics is that the types of materials for 3D printing are limited. Even if some new materials show excellent strength and flexibility, not all materials can match the current 3D printing technology perfectly. This mismatch actually restricts orthodontic clinics from choosing the best material for each case, and it may cause the quality of the devices to drop. This not only affects the patient's comfort, but also has a negative effect on the efficiency of treatment and the durability of the devices. At the same time, the high cost of integrated digital systems (such as computer-aided design, 3D imaging, and 3D printing) is also a barrier in terms of money and operation. Many clinics are still exploring how to use these technologies effectively, which leads to differences in the quality of treatment among facilities. This gap in technology and skills undoubtedly raises concerns about fairness in orthodontic care—can only clinics with enough money and advanced technology provide high quality treatment? In this case, the difference in treatment effects between urban and rural areas or between high-end and low-cost orthodontic services may grow further.

4.3. Suggestions

To overcome these challenges, we can take a series of measures. First, we must strengthen 3D printing technology. Researchers and doctors should work together to reduce the shape change of printed models, especially in the biting surface and other key parts. Using artificial intelligence (AI) to set print parameters can ensure each model is as accurate as possible [26]. For example, an AI system can automatically adjust print settings based on the tool design, so that errors are reduced and time is saved.

Another suggestion is to upgrade 3D printing materials. Future research should focus on developing materials that are safe, strong, flexible, and can be used stably in the mouth for a long time. These materials must be compatible with the human body and must not release any harmful micro elements. This kind of improvement will let doctors use a wider variety of materials with peace of mind, knowing these materials have already been through strict tests for safety and durability.

For cone-beam computed tomography (CBCT), lowering the radiation is a key goal. This can be done by optimizing the scanning steps and by using this kind of imaging only when it is really needed. Orthodontists should follow the guidelines of professional groups (for example, the guidelines proposed by Halazonetis [27]) to make sure they use the benefits of CBCT fully while lowering the risks as much as possible. For example, if a regular plain film is enough for a specific check, then a plain film should be chosen instead of CBCT. In addition, better training in reading CBCT images also helps to lower the risk of misdiagnosis, because accidentally found abnormalities may lead to unnecessary treatment.

Finally, improving the tools of invisible aligners is also a necessary step to make patients more comfortable. By developing new materials that can spread force more evenly, manufacturers can reduce the pain that some patients feel at the beginning. Ongoing research in this area may bring aligners that are easy to wear and can move teeth to the right positions effectively.

5. Conclusion

In short, new tools like 3D printing, CBCT, and invisible aligners have brought many positive changes to orthodontics. These new methods enable personalized treatment plans and more precise examinations, but there are still some challenges that need to be addressed. By following these suggestions, orthodontic treatment will become more precise and comfortable, and this will bring better treatment outcomes for patients. In the future of orthodontics, the balance between new tools and safety is very important. As clinicians become more skilled at using these advanced tools and researchers continuously introduce new technology, we can expect that the level of patient care will keep improving. This development will make modern orthodontic treatment more efficient, more widespread, and safer.

References

[1] Abramovitch, K., & Rice, D. D. (2014). Basic principles of cone beam computed tomography. Dent Clin North Am, 58(3), 463-84.

[2] Barnatt, C. (2014). 3D Printing. Wroclaw, Poland: ExplainingTheFuture.com.

[3] Breitner, C. (1941). Further investigations of bone changes resulting from experimental orthodontic treatment. American Journal of Orthodontics and Oral Surgery, 27(10), 605-632.

[4] Dawood, A., Marti, B. M., Sauret-Jackson, V., & Darwood, A. (2015). 3D printing in dentistry. British dental journal, 219(11), 521-529.

[5] Djeu, G., Shelton, C., & Maganzini, A. (2005). Outcome assessment of Invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system. American Journal of Orthodontics and Dentofacial Orthopedics, 128(3), 292-298.

[6] Dong, X. Y., & Others. (2020). Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation American Journal of Orthodontics and Dentofacial Orthopedics

[7] Fang, D., Li, F., Zhang, Y., Bai, Y., & Wu, B. M. (2020). Changes in mechanical properties, surface morphology, structure, and composition of Invisalign material in the oral environment. American Journal of Orthodontics and Dentofacial Orthopedics, 157(6), 745-753.

[8] Galan-Lopez, L., Barcia-Gonzalez, J., & Plasencia, E. (2019). A systematic review of the accuracy and efficiency of dental movements with Invisalign®. Korean Journal of Orthodontics, 49(3), 140-149.

[9] Haouili, N., Kravitz, N. D., Vaid, N. R., Ferguson, D. J., & Makki, L. (2020). Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign. American Journal of Orthodontics and Dentofacial Orthopedics, 158(3), 420-425.

[10] Halazonetis, D. (2012). Cone-beam computed tomography is not the imaging technique of choice for comprehensive orthodontic assessment. American Journal of Orthodontics and Dentofacial Orthopedics, 141(4), 403–405, 407 passim.

[11] Hodges, R. J., Atchison, K., & White, S. (2013). Impact of cone-beam computed tomography on orthodontic diagnosis and treatment planning. American Journal of Orthodontics and Dentofacial Orthopedics, 143(5), 665-674.

[12] Kravitz, N. D., Kusnoto, B., BeGole, E., Obrez, A., & Agran, B. (2009). How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. American Journal of Orthodontics and Dentofacial Orthopedics, 135(1), 27-35.

[13] Kumar, M., Shanavas, M., Sidappa, A., & Kiran, M. (2015). Cone beam computed tomography-know its secrets. Journal of international oral health: JIOH, 7(2), 64.

[14] Lee, J. Y., An, J., & Chua, C. K. (2017). Fundamentals and applications of 3D printing for novel materials. Applied materials today, 7, 120-133.

[15] Lee, S., Wu, T. H., Deguchi, T., Ni, A., Lu, W. E., Minhas, S., Murphy, S., & Ko, C. C. (2023). Assessment of malalignment factors related to Invisalign treatment time aided by automated imaging processes. The Angle Orthodontist, 93(2), 144-150.

[16] Littlewood, S. J., & Mitchell, L. (2019). An introduction to orthodontics. Oxford University Press.

[17] Miller, A. J., Maki, K., & Hatcher, D. C. (2004). New diagnostic tools in orthodontics. American Journal of Orthodontics and Dentofacial Orthopedics, 126(4), 395-396.

[18] Nasseh, I., & Al-Rawi, W. (2018). Cone beam computed tomography. Dental Clinics, 62(3), 361-391.

[19] Nikolai, R. J. (1997, September). Orthodontic wire: a continuing evolution. In Seminars in orthodontics (Vol. 3, No. 3, pp. 157-165). WB Saunders.

[20] Oh, M. H., Park, A. H., Kim, M., Kim, E. A., & Cho, J. H. (2021). Part II. What drives Korean adults to seek orthodontic treatment: Factors contributing to orthodontic treatment decisions. Korean Journal of Orthodontics, 51(1), 3-14.

[21] Peck, S. J. C. D. H. (2009). The contributions of Edward H. Angle to dental public health. Community dental health, 26(3), 130-131.

[22] Phan, X., & Ling, P. H. (2007). Clinical limitations of Invisalign. Journal of the Canadian Dental Association, 73(3).

[23] Phulari, B. S. (2011). Orthodontics: principles and practice. JP Medical Ltd.

[24] Phulari, B. S. (2013). History of orthodontics. JP Medical Ltd.

[25] Rogers, S. A., Drage, N., & Durning, P. (2011). Incidental findings arising with cone beam computed tomography imaging of the orthodontic patient. The Angle Orthodontist, 81(2), 350-355.

[26] Silva, X. Y., & Others. (2008). The Use of 3D Printers in Orthodontics - A Narrative Review

[27] Will, L. A. (2015). The history of orthodontic education: A century of development and debate. American Journal of Orthodontics and Dentofacial Orthopedics, 148(6), 901-913.