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Short Review

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POLYMER MATERIALS FOR ORTHODONTIC USE: AN UPDATE ON THE PROPERTIES AND CRITICAL ISSUES

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Abstract

Nowadays, invisible orthodontics with clear aligners represents the type of treatment of first choice for patients who need to correct malocclusions and dental crowding. The strong point of this invisible treatment is represented precisely by the high aesthetics thanks to the optical properties of the thermoplastic materials used to manufacture the aligners. The purpose of this short review is to update clinicians to help them choose the most appropriate type of material for their treatment needs, based on new scientific research in the literature. It is necessary that other investigations are carried out to search for the most performing thermoplastic material for the orthodontic movement determined by the clear aligners.

Keywords

Clear aligner; thermoplastic materials; PET-G; PU; PP

Invisible orthodontics

In recent decades, attention to the aesthetics of orthodontic treatments has gradually grown, becoming one of the predominant aspects. The new 3D digital methods and the development of dedicated software have allowed the realignment

of the teeth by eliminating the discomforts of the traditional fixed orthodontic appliance. The increase in the demand for aesthetic orthodontic appliances has led to a turning point in the orthodontic field marked by the appearance of invisible appliances, such as aesthetic brackets, lingual appliances and, above all, clear aligners (1). The manufacturing of the aligners is determined by the CAM-CAD technology (Computer-aided design/Computer-aided manufacturing), through which the geometry of the dental arches is digitized first from 3D scans of plaster models of the patient or directly from scans via scanner intraoral. Subsequently, the corrective stages of the malocclusion and the physical models of the arches are reproduced for each of the phases programmed using a CAD software. Based on these physical models, the entire series of aligners required is printed (2).

The invisible orthodontic treatment involves the sequential use of a series of aligners which, applied on the dental arches, allow for a controlled distribution of forces with consequent gradual realignment of the teeth, according to the planned treatment plan. The forces exerted by the aligners essentially depend on the difference between the position and orientation of the teeth in the oral cavity and in the aligner itself (3). However, the properties of the manufacturing material must also be considered, which can affect the quality of the force applied, from a mechanical point of view, and the aesthetics of the aligner. The properties required for making the aligners are as follows: great elasticity and resilience, low stiffness, good formability, biocompatibility, resistance to ageing, transparency (4). To date, the materials widely used for this purpose are thermoplastic polymers, which have various advantages including ease of use, excellent aesthetic characteristics and superior formability.

Thermoplastic polymers

This type of material shows strong decreases in viscosity following heating, becoming easily malleable and workable. Once the action of heat ceases, thermoplastics regain their rigid state and retain the shape obtained. The influence of heat on thermoplastics is very marked and can determine an overall decrease in its mechanical characteristics (5).

Currently, the thermoplastic materials most used for the manufacture of invisible orthodontic appliances are represented by polyethylene terephthalate glycol (PET-G), polyurethane (PU) and polypropylene (PP).

Polyethylene terephthalate glycol (PET-G)

PET-G is a non-crystalline resin that is aesthetically transparent and glossy. It has high

impact resistance, remarkable ductility, excellent chemical inertness. Compared to PET, modification with glycol lowers the melting temperature of the polymer and makes crystallization following heating more difficult, with a consequent reduction in workability, opacification and unpleasant aesthetic defects (6). For this reason, PET-G is particularly suitable for the thermoforming process to manufacture orthodontic aligners (7).

It is essential to know that mainly the physical properties of the thermoplastic material influence the biomechanical characteristics of the clear aligners (8). Resistance is an essential requirement that must be considered since the aligners are positioned within the oral environment. The type of force produced by the chosen polymer can also influence the orthodontic treatment, therefore it is essential to choose the most appropriate aligner system (9).

The study by Lombardo et al. (10) highlighted that there is a significant difference in stiffness between double- and single-layer polymers and this needs to be considered as some aligner systems may not be able to exert sufficient force to align teeth following the planned treatment plan. The measurements made in UV-VIS spectroscopy in the study by Daniele et al. (11) showed improved transparency of PET-G thermoplastic discs, even upon observation after immersion in different coloring agents. Additionally, PET-G discs have demonstrated a low ability to absorb water as temperature increases over time, which is critical as significant water absorption can lead to signs of swelling and polymer deterioration.

Polyurethane (PU)

Polyurethane is one of the most versatile engineering thermoplastics with elastomeric properties. It is a polymer obtained from the polycondensation of an isocyanate with a diol: the chemical nature of this chain influences the mechanical behavior and the chemical resistance of the material (12). It has important characteristics such as excellent physical properties, chemical resistance, abrasion resistance; impermeability, adhesion characteristics, ease of processing, and biocompatibility (13). However, polyurethane is not an inert material and is sensitive to heat, humidity and prolonged contact with salivary enzymes (14).

This material has been extensively studied and several references are found in the literature. The study by Gerard Bradley et al. (9) found no change in the chemical properties but in the mechanical properties of the polyurethane-based aligners after intraoral aging. This was demonstrated by the fact that the force applied by the aligner to realign the teeth was less and

the deformation of the material increased as it aged. However, Fang et al. (15) evaluated negligible creep strain after 2 weeks in the intraoral environment, implying that the material was ductile enough to provide the necessary force for the aligner to drive orthodontic movements. A more recent study (16) demonstrated the highest crystallinity and mechanical strength of polyurethane compared to PET-G based material. However, the analysis of water absorption, used to predict the mechanical failure of the material during clinical use, showed that PU had the worst performance. This was also confirmed by SEM evaluations which highlighted signs of swelling on the surface of the PU samples (11).

Polypropylene (PP)

Polypropylene is a thermoplastic polymer with a partially crystalline structure, very light and similar to high density polyethylene (17). Among the properties there are good chemical, humidity and heat resistance, good surface hardness, dimensional stability, excellent resistance to flexural fatigue, good resistance to loads, traction, impact and abrasion and insulating properties.

Kwon et al. (18) compared different polyethylene and polypropylene samples showing a significant difference in strength and energy, which decreased after thermal cycling. The study of the influence of water penetration and the deformation of the elastic modulus of PP revealed that this material had a low absorption capacity and this was probably due to the presence of a crystalline phase found in the X-ray diffraction analysis (19). Furthermore, the latter analysis allowed to ascertain that PP is also less subject to deformation due to its molecular chains with helical structure, suggesting that it could have a constant elastic modulus. However, the wear analysis has highlighted major criticalities of PP-based aligners which can easily break and thus negatively influence orthodontic treatment (19).

Conclusions

This brief review summarizes the most recent research which reports the various analyzes carried out to highlight the advantages and problems of the most used thermoplastic materials currently in the manufacture of orthodontic aligners. In detail, it is essential to know the composition of these polymers, studying their chemical-physical characterization and their mechanical and aesthetic properties. Despite the large number of thermoplastic polymers available on the market, none of these have all the ideal characteristics and it would be appropriate to develop a new material that could include all the characteristics necessary to optimize orthodontic treatment.

References

1. Kaur S, Singh R, Soni S, Garg V, Kaur M. Esthetic orthodontic appliances-A review. Ann Geriatr Educ Med Sci 2008; 5:11–14.

2. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod 2015; 85:881–889.

3. Zheng M, Liu R, Ni Z, Yu Z. Efficiency, effectiveness and treatment stability of clear aligners: A systematic review and meta-analysis. Orthod Craniofac Res 2017; 20:127–133.

4. Weir T. Clear aligners in orthodontic treatment. Aust Dent J 2017; 62 (Suppl.1):58–62.

5. Gold BP, Siva S, Duraisamy S, Idaayath A, Kannan R. Properties of Orthodontic Clear Aligner Materials-A Review. J Evol Med Dent Sci 2021; 10(37):3294-3301.

6. Barone S, Paoli A, Neri P, Razionale AV, Giannese M. Mechanical and Geometrical Properties Assessment of Thermoplastic Materials for Biomedical Application. In: Eynard B, Nigrelli V, Oliveri S, Peris-Fajarnes G, Rizzuti S. (eds) Advances on mechanics, design engineering and manufacturing. Lecture notes in mechanical engineering. Springer Cham 2017; 437-46.

7. Zhang N, Bai Y, Ding X, Zhang Y. Preparation and characterization of thermoplastic materials for invisible orthodontics. Dent Mater J 2011; 30(6):954-9.

8. Ihssen BA, Willmann JH, Nimer A, Drescher D. Effect of in vitro aging by water immersion and thermocycling on the mechanical properties of PETG aligner material. J Orofac Orthop 2019; 80(6):292-303.

9. Gerard Bradley T, Teske L, Eliades G, Zinelis S, Eliades T. Do the mechanical and chemical properties of InvisalignTM appliances change after use? A retrieval analysis. Eur J Orthod 2016; 38(1):27-31.

10. Lombardo L, Martines E, Mazzanti V, Arreghini A, Mollica F, Siciliani G. Stress relaxation properties of four orthodontic

aligner materials: A 24-hour in vitro study. Angle Orthod 2017; 87(1):11-18.

11. Daniele V, Macera L, Taglieri G, Di Giambattista A, Spagnoli G, Massaria A, Messori M, Quagliarini E, Chiappini G, Campanella V, Mummolo S, Marchetti E, Marzo G, Quinzi V. Thermoplastic Disks Used for Commercial Orthodontic Aligners: Complete Physicochemical and Mechanical Characterization. Materials 2020; 13(10):2386.

12. Brinkmann S, Oberbach K, Baur E, Schmachtenberg E, Osswald TA (2006). Materials. In: Verlag, C.H. (Ed.) International Plastics Handbook. Munich, HANSER, pp. 507-699.

13. Gupta DK, Tuli A, Jain A. 3D printed material application in orthodontics. Materials Today: Proceedings 28 (2020): 1635-1642.

14. Condo' R, Pazzini L, Cerroni L, Pasquantonio G, Lagana' G, Pecora A, Mussi V, Rinaldi A, Mecheri B, Licoccia S, Maiolo L. Mechanical properties of "two generations" of teeth aligners: Change analysis during oral permanence. Dent Mater J 2018; 37(5):835-842.

15. Fang D, Li F, Zhang Y, Bai Y, Wu BM. Changes in mechanical properties, surface morphology, structure, and composition of Invisalign material in the oral environment. Am J Orthod Dentofacial Orthop 2020; 157(6):745-753.

16. Daniele V, Macera L, Taglieri G, Spera L, Marzo G, Quinzi V. Color Stability, Chemico-Physical and Optical Features of the Most Common PETG and PU Based Orthodontic Aligners for Clear Aligner Therapy. Polymers 2021; 14(1):14.

17. Reddy MM, Vivekanandhan S, Misra M, Bhatia SK, Mohanty AK. Biobased plastics and bionanocomposites: Current status and future opportunities. Prog Polym Sci 2013; 38(10-11), 1653-1689.

18. Kwon JS, Lee YK, Lim BS, Lim YK. Force delivery properties of thermoplastic orthodontic materials. Am J Orthod Dentofacial Orthop 2008; 133(2):228-234.

19. Inoue S, Yamaguchi S, Uyama H, Yamashiro T, Imazato S. Influence of constant strain on the elasticity of thermoplastic orthodontic materials. Dent Mater J 2020; 39(3):415-421.