Memory Recovery Aligners

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***Abstract*—** The advent of shape memory polymers in the field of dentistry, has simplified the work to a lot of extent. Its usage in various orthodontic applications like archwires and aligners have also proven to be of utmost importance. Known alloys, like zirconia, and smart-seal are examples of shape memory materials exhibiting a smart behaviour in dentistry. With the increasing trend in material science to develop and apply these intelligent materials, these materials would potentially allow groundbreaking dental therapies with a significantly enhanced clinical outcome of treatments. The history of aligners can be tracked back to Kesling who, described a tooth positioner for the final artistic positioning of the teeth as well as an effective retaining device in 1945, then Nahoum2, in 1964 developed vacuum-formed "dental contour" appliances which were thermoplastic and were best suitable for dental use. He developed the concept of using successive appliances, with small incremental changes, major corrections cab be made since they were formed on the basis of the construction of the popular Essix appliance and Invisalign. The purpose of this article is to review the history of shape memory aligners along with proven studies, and its surge to be applied in the field of orthodontics. This article also discusses potential benefits for patient as well as for dentist by replacing the conventional materials by smart materials in their inventory.

Index Terms*— *Aligners, shape memory, CAT, SMP.

I. INTRODUCTION

"Any modification heading towards a new invention is at all times, an evolution of something good in any field". Orthodontic treatment has always been upgrading its system in terms of its appliance technique and materials. From conventional braces of metal origin, orthodontic appliance has made its success to a convincing composite/ceramic braces, heading on to self-ligation prescription. And now, it is evolved to even more esthetic and comfortable clear aligners which is in great demand these days. Current trend in aligners materials restrict the amount of force delivery to a certain extent only and it needs frequent change in aligner sets within few days of its wear. The goal is to introduce novel materials that play an active role in the appliances in terms of materials from which they are fabricated. Such new materials termed as smart materials; also, stimuli-responsive materials are introduced to extend its uniqueness of shape recovery in treating mal-aligned occlusions quite well. These shape memory polymers also abbreviated as SMPs are able to react suitably with external stimuli, such as electrical, thermal, magnetic input, thereby producing a predictable repeatable output. These materials have been in highlight for decades back in fields of biomedical devices, aerospace, textiles, energy, bionics engineering, electronic engineering, etc. But it was in 1971, that they were first discovered in the field of orthodontics as orthodontic Niti arch wires with the same shape memory effect. Quite known from the fact, that conventional clear aligners available widely around the current demand, are made of thin, customized, transparent sheets of different polymers. These polymers such as polyethylene terephthalate glycol (PETG) and polyurethane (PU) and Thermoplastic polyurethane (TPU) are customized to create a sheet of 0.7-0.8mm thickness, specifically for correction of 1°-2°rotations and 0.2-0.3mm of translation movements, which needs to be worn religiously up-to 20hours per day. Since, aligners need to be changed roughly around every 14th day from the initial set delivered it needs an orthodontist to customize a considerable number of sets which needs to be fabricated during the entire course of its orthodontic treatment.

II. CONCEPT BEHIND SMPs

A shape memory polymers are from class of polymers which are actively moving polymers(AMP). They exibit the property of shape memory effect (SME), that is they can respond to several external stimuli such as temperature, magnetism, electricity, specific wavelength, moisture, pH and some specific chemicals. A stable polymer network (SMP)and a reversible switching transition(RST) of the polymer are the two pre-requites for the shape memory effect (SME)[3].

The shape memory effect clearly depends on the presence of a two-domain system that possesses different glass transition temperatures; in which one domains is **hard/elastic** at room temperature and the other domain is **soft/ductile**.[2]

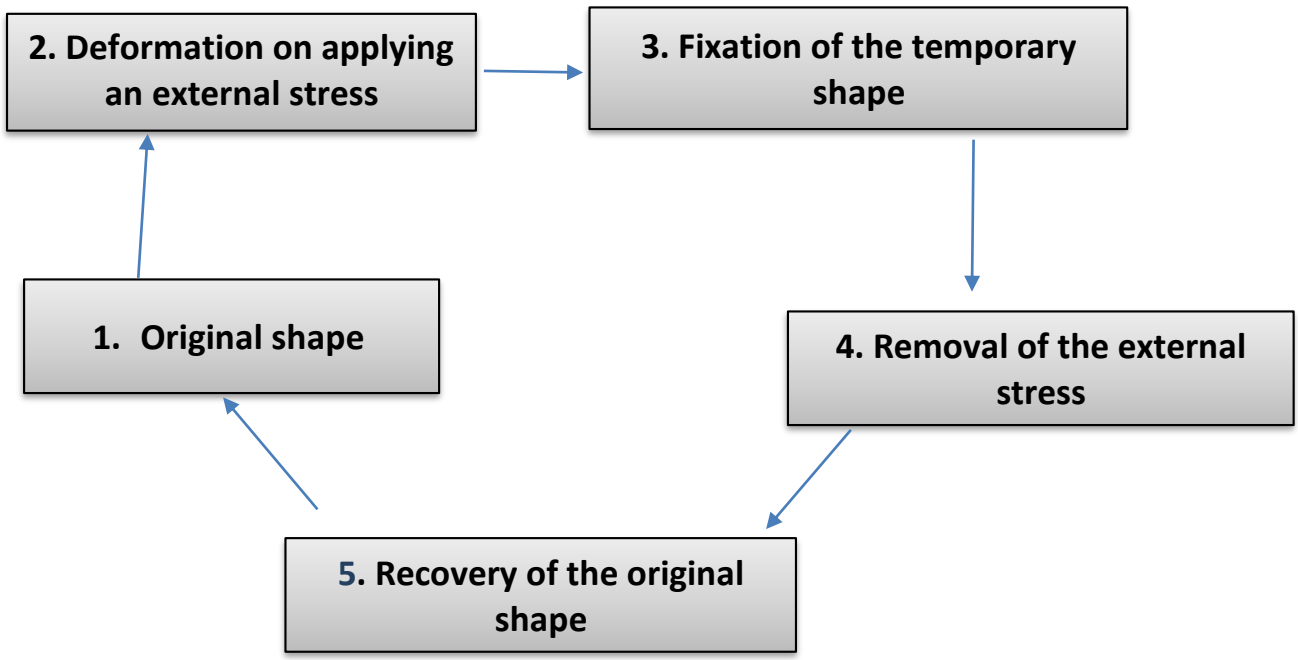
Reinforcing fillers such SIO_2, cellulose nanowhiskers, exfoliated nanoclay, microfibers, fabrics, and mats, etc.[3] are encouraged in these SMP to improve the mechanical performance and shape recovery stress through physical blending, in-situ polymerization and chemical cross-linking.[3]

PU(polyurethane) has phase-separated structures between the hard and soft segments due to its thermodynamic immiscibility.

hard segments = physical crosslinks with high melting temperature via hydrogen bonding and crystallization, and

soft segments = reversible phase transformation, necessary for achieving a shape memory.

Figure1. Shape-Memory Polymers in Dentistry [12]



The transition temperature of PU, which is near body temperature, can be controlled by the glass transition temperature(35°C) or the melting temperature of amorphous soft segments. Therefore, shape recovery in PU can be applied to orthodontic appliances as in aligners to correct misaligned teeth through thermal heating from body temperature.[1]

According to various patents in *USA publication and International application under PCT* [5,6], in which they claimed it as cap shaped tray which covers the entire surface of maxillary and mandibular teeth in which the original shape of polymer tray is same as of correctly aligned teeth after orthodontic treatment and temporarily formed shape of tray is identical to the original malocclusion of the patient. Then, this tray material is used in patient's mouth and the polymer restores back to its original form, at a specified glass transition temperature.[5,6]

Some of commercially made polymers in this category are listed as follows polyurethane (Diplex, SMP Technologies Inc., originally from Mitsubishi Heavy Industries), polystyrene based SMP (Veri flex, Verilyte, Veritex_, Cornerstone Research Group, Inc.), aliphatic polyurethane (TECO flex_, Lubrizol Advanced

Materials), epoxy based SMP (TEMBO_, Composite Technology Development, Inc.), and UV curable polyurethane (NOA-63, Norland Products Inc.).[3]

III. Advantage of Shape memory polymers (SMP)

Recently, by this new invention of **smart materials** in dentistry specially in the field of orthodontics by introduction of novel shape memory polymers.

- First and the best use is that it had helped minimizing the total sets of clear aligners throughout the treatment. Hence, there is a possibility of using only one shape memory aligner instead of three subsequent conventional aligners.
- There has been a decrease in number of aligners used per treatment, thereby reducing the total treatment cost and shortening of one's chair time.
- Reducing the number of orthodontic aligners in the therapeutic process, thereby lead to less material waste and hence less plastic consumption.
- SMPs share the unique properties of low density, high chemical stability, considerable elastic deformation and relatively transparent nature.[1]
- Moreover, these materials are inert in the oral environment as most materials need to behave mostly, like all other bio- materials out there. Hence, better compliance is delivered with ease.

The efficacy of conventional aligner materials is restricted by the rate-limiting staging of the amount of tooth movement planned. A team at the Fraunhofer Institute for Applied Polymer Research IAP in Potsdam, Germany, in cooperation with the University Hospital in Düsseldorf, Germany, has now developed a highly innovative material that enables completely new treatment concepts and reduces costs. The scientists focused on polymers with shape memory properties. Their potential to deliver extrinsic mechanical stimulus that evokes a response that is cellular in origin known as orthodontic tooth movement (OTM) was fully demonstrated.
Shape memory polymers display an alteration in their macroscopic shape upon the application of an appropriate stimulus. They retain this temporary shape stably and recover back to their original shape on the re-application of another stimulus.

IV. Scope of memory recovery aligners and its Orthodontic application

In a, in a study published by *Yong Chae Jung et al* in Journal of Mater Science: Mater Medicine (2010)[1], they concluded that in the orthodontic test performed, the shape recovery force of the wire was considered sufficient enough to correct malaligned teeth when the appliance was heated above its transition temperature(50°C).[1]
They measured the shape memory behaviour through a thermomechanical test which was performed using universal testing machine which was equipped with a controlled thermal chamber, and the relationship between stress and strain at various temperatures was analyzed to measure the recovery strain, and the shape recovery was calculated. Custom made PU wire which they used in their study showed high shape retention and shape recovery of 85% or more as well as good mechanical properties (elongation-at break of 1215% and a breaking stress of 26.8 MPa at 40 wt% hard segment content).This recovery force of wire was sufficient enough to cause shape memory effect and treat malalignment in orthodontics quite easily which also promotes the aesthetics among this well pronounced branch.
Takehiro MASUDA et al. in his publication in dental materials journal (2011), introduced invention of new orthodontic material by adding 1-butanol to PEMA-TA/HX resin. He obtained results with increased in elastic strain in a concentration-dependent manner. Also, he concluded that this material has the ability to restore force as a function of its shape-memory effect in cases of plastic deformation at the insertion
of appliances. This new orthodontic elastic material has the potential to be clinically effective in orthodontic treatment.[7]
Similarly, a recent typodont study done by *Tarek M. Elshazly et al* [4] published in dentistry journal (MDPI) in the year 2021, they have evaluated shape recovery of orthodontic aligners fabricated from shape memory polymer (SMP) with in vitro examination of a customized resin typodont model with a movable left central incisor by incorporating wax over that area of model to potentially overcome the rate-limiting staging restriction. They used creation of a custom-made aligned typodont model with a movable upper central incisor and the generation of resin models utilizing orthodontic software and a 3D printer in their study. Clear X

sheets of 0.76 mm thickness, shape memory material, supplied by Kline-Europe GmbH, Düsseldorf, Germany was utilized for the same. They corrected a specified mal alignment of around 1.9mm in a single SMP sheet rather than conventional 3 sets of aligner sheets.
They used thermoforming booster machine for subsequent aligner activation. This study showed that the total correction efficiency of the aligner fabricated from the polymer material was approximately 93% (1.76 mm), with a corrective movement of 0.94 ± 0.04 mm after the reforming step, 0.66 ± 0.07 mm after the first activation step, and 0.15 ± 0.10 mm after the second activation step.[4]
South Korean manufacturer Graphy showcased the world's first direct 3D-printed aligner, produced from the company's own 3D printing resin. Owing to the direct production process, no printing models or vacuum forms are needed. It reduces carbon emissions and produces less refuse because no cutting is needed, which benefits the environment. Some other resins like 3Dresyns also show the same elastic properties and exhibit simplicity in printing with affordable pricing. Clear-A 3D printing resin by the brand name Senertek is also widely available for fabricating memory shape strong and durable flexible clear aligners.

CONCLUSION

Since, the newly introduced "smart" material also known as stimulus-responsive material proved to produce considerable amount of tooth movement and treating mal-aligned teeth by creating certain amount of force under a specific temperature stimulation, this SMP had changed the game for polymers used in aligners. The clever choice of material thickness as well as the gradual heating of the aligner additionally controls the force applied to the teeth. For orthodontic applications, these special features harbor a number of unique advantages in aligner therapy - from smaller shape adjustments through controlled heating to a reduction in the number of treatment steps.
Because of these merits, SMPs may have great potential to invaginate virtually in aligner treatment course. They reduce the overall plastic burden on the environment by minimising the deleterious effects of microplastics in world's oceans.

This narrative review has attempted to comprehensively encompass in total that these memory recovery polymers bear great potentials to be used widely in orthodontics and contribute to a promising future in the area of clear aligner therapy.

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