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REVOLUTIONALIZING IMPLANTS WITH SHAPE MEMORY SYSTEMS

Prosthodontics

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ABSTRACT

In recent years, there has been a quest to maintain the retrievability of cement-based systems while achieving the aesthetics and retention force of cement-based fixation. This study reviews the different shape memory systems currently present in the literature. A unique abutment system has been created to overcome the drawbacks of implant restorations that are cement- and screw-retained. Nickel titanium (NiTi) is an alloy which has the property of the shape memory alloy (SMA) that is used in various dental components. The abutments made with NiTi alloy provide retrievability by substituting a specifically created nickel-titanium sleeve that alternates between locking and unlocking of the prosthesis for the cement layer. Use of cements can be avoided to prevent preimplant issues related to cements. Also, the elimination of occlusal screw access holes can make way for predictable occlusal contacts and enhanced the structural stability of the prosthesis. This article reviews the clinical advantages and importance of the shape memory abutment system.

KEYWORDS

Smileloc; Shape memory Abutments; Nitinol, Smile key

INTRODUCTION

Implant technology, materials, and knowledge have evolved since Dr. Branemark discovered in 1952 that bone heals around titanium chambers.[1] NiTi alloys is one such material that has been coming up in implant dentistry because of the materials increased flexibility and shape memory properties. Nitinol, a titanium and nickel alloy with established human biocompatibility, is frequently utilized in interventional cardiology devices.[2] Utilizing nickel-titanium's super elastic characteristics, nitinol orthodontic arch wires and endodontic instruments are used in dentistry.[3] It has a locked and unlocked state because of a phase transformation in the nitinol from the martensite phase at body temperature to the austenite phase at elevated temperatures. In nitinol, the martensitic transformation, often referred to as the solid-state phase transformation, is a reversible phenomenon (FIG 1) .[3] The phase maintains martensite when an external deformation force is applied, although the alloy can undergo twinning, which keeps the alloy in its deformed state. One special quality of the nitinol alloy is twinning. Though there is an ion rearrangement without any slip, the alloy undergoes restricted deformation without any atomic bond breaking.[4]

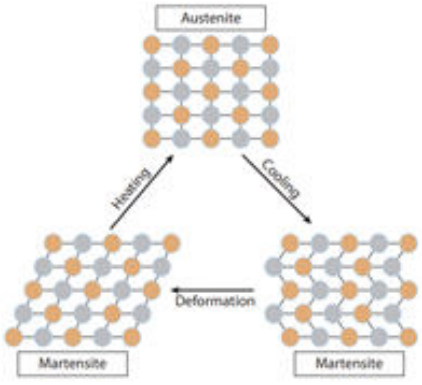

Fig 1- Transformation Phases Of Niti [3]

There are two ways to secure restorations to dental implants: screws and cements. Both systems have advantages and limitations (TABLE 1). Screw-retained implant restorations offer a retrievability that, in theory, allows for uncomplicated evaluation of underlying components. Since screw removal, reinsertion, and restoration of occlusal holes can be time-consuming, screw retrieval is typically limited to the repair of broken or damaged components.[5]

Table-1 Difference Between Screw Retained And Cement Retained Implant Restorations

	SCREW RETAINED	CEMENT RETAINED
Retrievability	Easy	Difficult
Off axis implant placement	Not possible	Possible
Ease of using	Difficult	Easy
Interocclusal space	Reduced space	Increased space required
Periimplantitis	Rarely noted	Common finding due to excess cement

Benefits

1. **Improved Fit and Comfort:** Shape memory abutments can adapt to changes in the oral environment, providing a better fit for the prosthesis and enhancing patient comfort.
2. **Reduced Mechanical Stress:** The super elasticity of SMAs reduces the stress on dental implants and surrounding bone, potentially increasing the longevity of the implant.
3. **Minimized Adjustments:** The shape memory effect reduces the need for frequent adjustments, saving time for both the dentist and the patient.
4. **Enhanced Precision:** The precise fit of shape memory abutments leads to better load distribution and a more stable prosthetic outcome.

Background

Nickel-titanium is the only shape memory abutments (SMA) with valuable biomedical applications among the different SMAs and belong to the group of metallic alloys known as smart functional materials. Properties of nitinol that suit its application in dentistry are good biocompatibility, corrosion resistance, super elasticity, and fatigue resistance. This biomaterial is widely used in all fields of dentistry: prosthetics, orthodontics, and endodontics.[6] The nickel-free zone within the upper surface and the presence of homogenous titanium oxide are the main factors defining good biocompatibility of this alloy.[7]

Due to thermoelastic martensitic transformation, this alloy can adapt to the conditions of the environment. Crystal state defines the physical properties of the material. The austenitic form is rigid, contrary to the ductile martensitic, which is recognized as a distinctive feature, i.e., the alloy's capability to be adjusted to the desired application. Phase transformations are characterized by diffusion-less, coordinated movement of the atoms.[8]

Titanium-rich alloys are known for their excellent shape recovery (i.e., thermal phase transformation phenomenon). In contrast, nickel-rich Ni-Ti alloys gained attention for their super elastic behavior (i.e., stress-triggered phase transformation), which is why most Ni-Ti

biomedical applications rely on this feature. Moreover, higher nickel content has been reported to improve mechanical properties, and yield strength is the most important for biomedical purposes. The addition of heavy metals, like nickel, can reduce grain size during solidification. Besides improving mechanical properties, grain refining enhances surface characteristics and consequently improves tear resistance.[9]

Numerical analysis showed that using a super elastic NiTi shaft instead of titanium alloy could result in the ability of the attachment system to withstand large deformations and forces upon masticatory loading while avoiding over-stressing. Moreover, necking the flexible SMA shaft in the middle could prompt better accommodation of large deformations triggered through masticatory loading. An increased contact area between the shaft and the mal.[10]

Nitinol alloy has very strong biomechanical properties with a capacity of up to 100,000 psi (195–690 MPa for austenite), whereas the average human bite force is 150 to 200 psi, therefore, nitinol being a multiple of the maximum force the jaw musculature provides during clenching and mastication.[21]

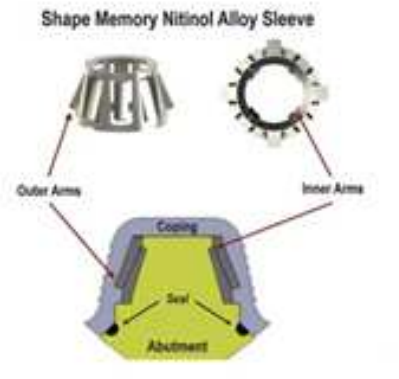

Fig 2: Mechanical Interlocking System Used To Retain Dental Prosthesis [18]

Methodology

For this narrative review, an unrestricted literature search was performed by four evaluators using specified key - words in the Google Scholar. Eligibility criteria for included studies required the full text to be available, and to be in the English language, with a publication date up to July 2024. Keywords relating to the restoration of root filled teeth were searched using Medical Subject Heading (MeSH) terms. An additional manual search of references in the included papers was also carried out to identify potentially relevant research.

DISCUSSION

Shape-memory implant abutment system

- The shape-memory implant abutment system was developed as a novel alternative of retaining implant restorations that combines the advantages of and eliminates the limitations of cement- and screw-retained implant restorations. This system involves a nickel-titanium (nitinol) sleeve that has the ability to transform and switch configurations, which allows the prosthesis to lock and unlock onto the abutment (FIG2) .[11] Retrieval is typically performed only when screw loosening, fracture, peri implantitis, or peri-implant mucositis necessitates pros thesis removal. The presence of screw access channels disrupts the structural continuity of porcelain and can act as a preferred site for microcrack nucleation, which ultimately compromises the structural integrity.[12] A clinical study investigating the relationship between excess cement and peri-implant disease found that 81% of the study participants with residual cement demonstrated signs of peri-implant disease.[13] In another study conducted, the results showed minimal differences observed between baseline and endpoint assessment of the plaque and gingival indices, probing depth, and proximal and occlusal contacts, with overall peri-implant health unchanged from the baseline evaluations for all participants.[11]

Shape memory abutments provide good long-term stability. The presence of access channels can compromise the long-term stability of occlusal contacts. Specifically, the composite resin used to cover these channels is prone to wear and therefore does not offer stable control over occlusal contact. [14,15] This type of failure surrounding long screw access holes is particularly problematic in complete-arch implant supported prostheses.[16,17] Shape memory abutments provided no change in the occlusal contact, and radiographic results showed no movement of the restoration after evaluation period of 6 months.[11]

Shape memory nitinol alloy sleeve has outer arms that engage coping undercuts and inner arms that engage the undercuts on abutment (FIG 3). These engaging arms reversibly switch between a locked and unlocked state because of a phase transformation in the nitinol from the martensite phase at body temperature to the austenite phase at elevated temperatures. Heating shape memory alloy sleeves to 60^0 C causes instantaneous shape change that causes arms to disengage the undercuts.[18]

A 6-month pilot clinical study was conducted, where eight participants were recruited for restoration with the nitinol shape-memory-retained abutment system for a single osseo-integrated implant in a posterior quadrant. The parameters measured were oral hygiene, probing depths, plaque index, gingival index, proximal contacts, and occlusal contacts. Comparing the baseline values to the follow-up appointment (minimum of 6 months), minimal differences were noted. Six out of 8 participants had probing depths of less than 3 mm, plaque and gingival indices scores of "0", no visible plaque retention, and absence of peri implant inflammation throughout the follow-up period. One participant had improved plaque and gingival indices and another participant had indices of "1" that remained unchanged throughout the follow-up period. Participants in the study had no issues or discomfort with the final prosthesis. The study concluded that the shape memory implant abutment system does not negatively affect peri-implant health, as seen with traditional cement retention. An evaluation of the wear and retention performance of these shape-memory abutment systems after 6 months of clinical use was completed through scanning electron microscopy and tensile testing, respectively. Results showed no evidence of damage to the shape-memory alloy sleeves and no significant differences in retention values before and after clinical use. The mean retention force of control nitinol sleeves was higher (480±37 N) than that of a commercial resin cement (336.3±188 N). The mean retention force of nitinol sleeves remained unchanged after 5,000 compression load cycles compared to traditional cement which decreased in retention force.[19] Furthermore, the application of this shape-memory system is not limited to conventional single unit restorations and can be efficiently used for treatment with full-arch prostheses.[20]

Computer guidance planning for single-tooth guided surgery for implant placement is simplified by the use of the nitinol alloy abutment mainly because there is no need to be concerned about screw access hole orientation. Therefore, implants can be placed at slight buccal angles and with ideal orientation within the alveolar envelope.[23] There is no need to place the implant deep or shallow but usually at bone level, midcrestal, the abutment orientation aimed toward the incisal edge. But even a slight deviation to the buccal will not interfere with retention and draw of a Shape memory Abutment and nitinol sleeve. Shape memory for retention is much easier and more forgiving and the implant body position and abutment angle, more ideal.[22]

Fig:3 Shape Memory Alloy Retention System [18]

Micro-Locking Implant Prosthetic System

The recently introduced micro-locking implant prosthetic system is composed of an assembly attachment and a single-piece implant.[23]

The attachment consists of four subcomponents: body, ball, spring, and cap. The body consists of grooved hexagonal receptacles that are identical to the hexagonal structure of the implant post. This prevents the prosthesis rotation (FIG4) .[23] The ball, a main component of

zirconium oxide (ZrO2) and hafnium oxide (HfO2), has two functions:
(1) To directly participate in the retentive force by residing in the retention groove, and
(2) By preventing the spring from rotating.

The spring is situated on the exterior of the zirconia ball, it is mainly composed of a nickel-titanium (Ni-Ti) shape memory alloy, identified as nitinol. Nitinol are super elastic alloys, indicating they revert to their original shape when stressed, similar to rubber. When the stress is removed in this stage, an opposite behavior to the yielding phenomena occurs. The spring is made of super elastic nitinol, provides for effortless positioning of the ball under the retention groove in the implant post by slightly expanding when the attachment is engaged. Additionally, after the attachment is connected to the implant, the spring applies a constant force on the ball.[24] The cap is the part where the prosthesis is attached and has a groove and a slot to prevent the rotation of the prosthesis.

In a study it was concluded that the geometry of the retention grooves had a substantial impact on the retention of the micro-locking implant prosthetic system. After the first year, the retention loss rate decreased and then stabilized.

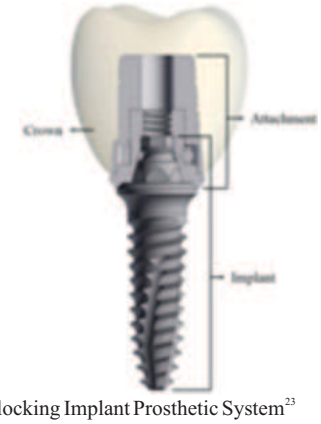

Fig:4 Micro-locking Implant Prosthetic System[23]

CONCLUSION:

NiTi alloys in the form of shape memory abutments are widely used in implant dentistry for its features like biocompatibility, corrosion resistance, super elasticity, and fatigue resistance. They also have favorable characteristics which include high compressive strength, similar to human bone, as well as an elasticity modulus nearly equivalent to bone tissue. The shape-memory implant abutment system is a third method of retention for implant restorations that can be easily incorporated into clinical practice, has excellent clinical performance, does not sacrifice esthetics for retrievability, and eliminates the need for cement. Without the presence of cement, the risk of peri-implantitis can potentially be significantly reduced, and the nitinol shape-memory sleeve seems to be a promising alternative solution to accomplish just that. Shape memory abutments have the potential to revolutionize dental care, providing more precise and durable solutions for patients requiring dental prosthetics.

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