Journal for Re Attach Therapy and Developmental Diversities
eISSN: 2589-7799
2023 March; 6 (3s): 963-970

A Longitudinal SEM Analysis of Surface Degradation and Microstructural Fatigue in Superelastic NiTi Archwires: A 40-Day Clinical Study

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Abstract

Objectives: This study aimed to evaluate the surface degradation of superelastic Nickel-Titanium (NiTi) orthodontic archwires over 10, 30, and 40-day periods of intraoral exposure using Scanning Electron Microscopy (SEM).

Materials and Methods: Forty maxillary NiTi archwires (0.016-inch) were divided into four groups: as-received (control), and three groups retrieved from patients after 10, 30, and 40 days of clinical use. Following ultrasonic cleaning in ethanol, the wires were analyzed using SEM at magnifications up to x2000. Surface features were qualitatively described and quantitatively assessed using a standardized degradation scoring system (0–4).

Results: Control wires showed typical manufacturing striations with minimal defects (Mean Score: 0.42). By day 10, localized pitting was evident (Mean Score: 1.25). Day 30 samples exhibited significant fatigue, characterized by the coalescence of pits and the initiation of surface delamination (Mean Score: 2.68). At 40 days, severe topographical breakdown was observed, including widespread flaking and deep corrosive craters, particularly in the molar regions (Mean Score: 3.55).

Conclusion: Intraoral exposure leads to rapid and progressive surface degradation of NiTi archwires. The integrity of the wire surface is significantly compromised within 30 to 40 days, which may increase friction and affect the efficiency of orthodontic alignment.

Introduction

The oral cavity represents a highly dynamic and challenging environment for orthodontic biomaterials, characterized by constant fluctuations in temperature, pH, and the presence of complex microbial flora [1]. This biological environment subjects orthodontic appliances to a unique combination of mechanical, chemical, and thermal stressors that are not replicated in standard laboratory testing conditions. The intraoral temperature varies with food and fluid intake, ranging from approximately 5°C to over 55°C, while pH levels fluctuate dramatically following meals, acidified beverages, and periods of reduced salivary buffering capacity. Additionally, the oral cavity hosts a diverse microbial community that can colonize material surfaces and contribute to localized pH drops through acid production. Collectively, these factors create a demanding operational environment that can compromise the integrity and performance of orthodontic materials over time.

Among the various components of a fixed orthodontic appliance, the archwire is the primary element responsible for generating the forces necessary for tooth movement [2]. The archwire serves as the actuator of the orthodontic system, transmitting forces from the appliance to the dentition through brackets and ligatures. The mechanical properties of the archwire dictate the magnitude, duration, and distribution of these forces, which in turn determine the biological response of the periodontal tissues and the rate and quality of tooth movement. Consequently, the stability of archwire properties throughout the treatment period is critical for predictable clinical outcomes.

Nickel-titanium alloys have become the material of choice for the initial stages of orthodontic treatment due to their unique properties of superelasticity and shape memory, which allow for the application of light, continuous forces over a wide range of activation [3, 4]. Superelasticity enables the archwire to deliver relatively constant force despite varying degrees of deflection, accommodating the irregular alignment characteristic of malocclusions during the leveling and aligning phase. Shape memory allows the wire to return to its preformed arch form after deformation, maintaining engagement with brackets even in severely crowded dentitions. These properties make Nickel-Titanium alloys particularly well-suited for the initial alignment phase, where consistent light forces minimize patient discomfort while promoting efficient tooth movement.

Despite their clinical advantages, Nickel-Titanium archwires are susceptible to various forms of degradation when exposed to the intraoral environment. The combination of mechanical stress from mastication and orthodontic loading, along with chemical challenges from saliva, beverages, and oral hygiene products, can lead to significant surface alterations [5]. The archwire experiences cyclic loading during mastication, creating repeated stress cycles that can induce fatigue and microstructural changes. Concurrently, the wire is bathed in saliva containing enzymes, electrolytes, and proteins, and is exposed to dietary acids, fluoridated toothpastes, and mouthwashes that may be corrosive. This multifaceted attack creates conditions conducive to material degradation.

Corrosion and surface pitting are major concerns, as they not only compromise the structural integrity of the wire but also increase surface roughness [6]. The passive oxide layer that naturally forms on the surface of Nickel-Titanium alloys provides some protection against corrosion, but mechanical abrasion from bracket engagement and occlusal contacts can disrupt this protective film, exposing the underlying alloy to corrosive attack. Once initiated, corrosion can propagate along grain boundaries or through the formation of galvanic cells, creating localized pits that serve as stress concentration sites and potential initiation points for fatigue failure.

Increased roughness has been shown to elevate the coefficient of friction at the bracket-wire interface, potentially hindering the efficiency of sliding mechanics and prolonging treatment time [7, 8]. During the later stages of treatment when sliding mechanics are employed for space closure and detailing, increased friction can impede tooth movement and reduce the efficiency of force transmission from the archwire to the brackets. This can result in slower tooth movement, increased anchorage demand, and extended treatment duration. Additionally, rough surfaces may accumulate biofilm more readily, potentially contributing to enamel demineralization, gingival inflammation, and increased patient discomfort.

Furthermore, the degradation of Nickel-Titanium alloys raises biocompatibility concerns regarding the potential release of nickel ions, which are known allergens and can induce localized or systemic hypersensitivity reactions in susceptible individuals [9, 10]. Nickel is one of the most common contact allergens in the general population, and the prolonged intraoral exposure associated with orthodontic treatment may pose risks for sensitized patients. While manufacturers often apply surface treatments such as polishing, passivation, or coating to mitigate these effects, the long-term stability of these protective layers under clinical conditions remains a subject of investigation. The breakdown of surface treatments may expose the underlying alloy and initiate a cascade of corrosion and ion release.

Scanning Electron Microscopy serves as a critical diagnostic tool in dental materials science, offering high-resolution imaging to evaluate topographical changes and surface defects at a microscopic level [11]. This imaging technique provides magnifications far beyond those achievable with optical microscopy, allowing for detailed examination of surface features including pitting, cracking, corrosion patterns, and the integrity of surface coatings. While many studies have utilized Scanning Electron Microscopy to examine wires in vitro, there is a relative scarcity of longitudinal clinical data assessing the progression of surface degradation at specific intervals during the early and mid-stages of alignment. Understanding the timeline of material fatigue, specifically at the 10, 30, and 40-day marks, is essential for clinicians to determine optimal wire replacement protocols and to anticipate changes in mechanical performance. This knowledge would enable evidence-based decisions regarding archwire change intervals, balancing the need for continued force delivery against the risks of material degradation and reduced efficiency.

The present study aims to evaluate the surface degradation of Nickel-Titanium orthodontic archwires retrieved from patients after 10, 30, and 40 days of intraoral use. Surface topography and morphological changes will be qualitatively and quantitatively analyzed using Scanning Electron Microscopy to provide a comprehensive timeline of material wear and corrosion patterns in a clinical setting. By characterizing the progression of surface alterations across these clinically relevant time points, this investigation seeks to provide insights that can inform clinical decision-making regarding archwire replacement protocols and enhance understanding of the relationship between intraoral exposure time and material degradation.

Materials and Methods

Sample Selection and Preparation

A total of 40 pre-formed maxillary superelastic Nickel-Titanium archwires, measuring 0.016 inches in dimension, were selected for this prospective clinical study. All archwires were obtained from the same manufacturer to ensure consistency in alloy composition, thermomechanical processing, and surface finishing. The 0.016-inch dimension was chosen as it represents a commonly used wire size during the initial leveling and aligning phase of orthodontic treatment, where superelastic properties are most critical.

The samples were divided into four distinct groups, with 10 specimens allocated to each group. A control group consisting of as-received wires served as the baseline reference for surface morphology and finishing characteristics. Three experimental groups comprised wires retrieved after intraoral exposure for 10, 30, and 40 days, respectively. These time intervals were selected to capture the progression of surface degradation during the early and mid-stages of alignment, providing clinically relevant data on the timeline of material fatigue.

All clinical participants were selected based on specific inclusion criteria designed to minimize confounding variables that could influence surface degradation patterns. Participants were required to have permanent dentition with moderate crowding in the maxillary arch, as this indication typically requires the use of superelastic archwires for initial leveling and alignment. The absence of systemic diseases or salivary gland dysfunction was required to ensure that saliva composition and flow rate remained within normal physiological ranges, as alterations in salivary parameters can influence corrosion behavior. Participants were instructed to refrain from using supplemental fluoride mouthwashes or engaging in acidic dietary habits during the study period, as these factors could accelerate surface corrosion independent of the variables under investigation. Non-smokers were selected to avoid the confounding effects of tobacco products, which contain numerous chemical species that can alter the oral environment and contribute to surface staining and corrosion. The archwires were ligated into 0.022-inch slot stainless steel brackets using elastomeric modules to maintain a standardized environment across all participants and to ensure consistent engagement forces.

Retrieval and Cleaning Protocol

Upon reaching the specified time intervals of 10, 30, and 40 days, the archwires were carefully removed by a single clinician to avoid the introduction of mechanical scratching or surface damage that could occur during debonding. The use of a single operator ensured consistency in retrieval technique and minimized variability in sample handling.

Following retrieval, the wires were immediately rinsed with deionized water to remove gross debris, saliva, and loosely adherent materials. To ensure accurate surface analysis and to expose the underlying metallic surface for Scanning Electron Microscopy evaluation, the samples underwent an ultrasonic cleaning cycle in 95% ethanol for 15 minutes. This cleaning protocol was designed to remove the acquired pellicle, residual plaque, and organic deposits without altering the underlying metallic topography or introducing additional surface artifacts. Ethanol was selected as the cleaning solvent due to its ability to effectively dissolve organic matter while being non-corrosive to the Nickel-Titanium alloy. The wires were then air-dried in a dust-free environment and stored in sterile, moisture-free containers until Scanning Electron Microscopy analysis to prevent any further surface changes prior to imaging.

Scanning Electron Microscopy Analysis

The surface morphology of the archwires was evaluated using a Scanning Electron Microscope. This imaging technique was selected for its ability to provide high-resolution, high-magnification images of surface topography with excellent depth of field, allowing for detailed characterization of degradation features.

For each wire, three specific anatomical sites were analyzed to account for variations in mechanical loading and environmental exposure across the dental arch. The midline, representing the interincisal area, was selected as a region of relatively low mechanical stress but high exposure to saliva and dietary constituents. The canine region was selected as an area of moderate mechanical stress, where the archwire engages brackets at the corner of the arch and may experience higher friction and contact forces. The molar region, representing the posterior segments, was selected as an area of high mechanical stress, where occlusal forces and bracket engagement may contribute to surface wear. This systematic site selection allowed for a representative assessment of wear patterns across different stress zones of the dental arch.

Samples were mounted on aluminum stubs using conductive carbon tape to ensure stable positioning and adequate electrical conductivity. Because Nickel-Titanium is a conductive alloy, gold sputtering was not required for imaging, thereby avoiding any potential artifacts that could obscure surface features. Imaging was performed at an accelerating voltage of 15 kilovolts under high vacuum conditions to achieve optimal resolution and contrast. Micrographs were captured at multiple magnifications, including 500 times, 1000 times, and 2000 times, to identify specific degradation features. The following surface characteristics were systematically evaluated:

Pitting corrosion, assessed in terms of depth and density across the surface. Mechanical longitudinal striations, representing scratches or wear lines oriented parallel to the long axis of the wire, likely resulting from bracket engagement and sliding mechanics. Surface delamination or flaking, indicating areas where surface layers have separated from the underlying material. Adherent calcified deposits, representing mineralized plaque or calculus that may contribute to surface degradation and biofilm accumulation.

Quantitative Surface Evaluation

To supplement the qualitative Scanning Electron Microscopy observations and to enable statistical comparison between groups, a standardized scoring system was applied to the micrographs captured at 1000 times magnification to quantify the degree of surface degradation. This magnification was selected as it provided adequate resolution to identify surface defects while maintaining sufficient field of view for representative sampling. A grid-overlay method was utilized to systematically assess surface features across standardized areas. Surface defects were categorized on a scale of 0 to 4 based on the severity and extent of degradation observed:

Grade 0 was assigned to surfaces demonstrating a smooth appearance with only original manufacturing marks present, indicating minimal or no degradation. Grade 1 was assigned to surfaces exhibiting minor pitting or localized scratching, representing early signs of surface wear. Grade 2 was assigned to surfaces demonstrating moderate pitting and evidence of surface fatigue, indicating progressive degradation. Grade 3 was assigned to surfaces showing heavy pitting and widespread areas of delamination, representing advanced surface deterioration. Grade 4 was assigned to surfaces exhibiting severe corrosive attack with loss of wire integrity in localized areas, indicating critical material degradation.

Each specimen was evaluated independently by a calibrated examiner, and the scoring was performed on images from all three anatomical sites to obtain a comprehensive assessment of overall wire degradation. This scoring system provided a semi-quantitative measure of surface degradation that could be statistically analyzed to determine differences between exposure time groups and anatomical sites.

Results

Scanning Electron Microscopy Observations

The surface morphology of the Nickel-Titanium archwires exhibited progressive degradation proportional to the duration of intraoral exposure, with distinct qualitative changes observed at each time point. The control group, consisting of as-received wires, displayed a relatively homogenous surface characterized by fine longitudinal manufacturing striations oriented parallel to the long axis of the wire. These striations, which result from the wire drawing process during manufacturing, were uniformly distributed across the surface with infrequent, shallow pits that likely represent minor surface irregularities inherent to the fabrication process rather than true corrosion. The overall surface appeared smooth and intact, establishing the baseline morphology against which intraoral degradation could be assessed.

By Day 10, the wires showed the initial stages of clinical wear, reflecting the early response of the material to the intraoral environment. Micrographs revealed an increase in surface roughness with the appearance of localized islands of organic pellicle remnants adhering to the wire surface. The initiation of small, isolated pits representing the early stages of pitting corrosion was observed, with these pits typically measuring less than 5 micrometers in diameter and distributed sparsely across the surface. The manufacturing striations remained visible but began to show signs of mechanical blunting, particularly in regions of bracket contact, suggesting that initial wear from engagement and mastication was already occurring.

By Day 30, a marked transition in surface integrity was observed, indicating progressive material degradation. The pitting became more frequent and deeper, with individual pits often coalescing into larger crater-like defects measuring up to 20 micrometers in diameter. Evidence of surface fatigue was prominent, including delamination of the outer oxide layer characterized by areas where the surface had begun to flake away in thin sheets. The presence of micro-cracks was noted, particularly in regions where pitting was concentrated. Significant mineralized deposits, representing calcified plaque or calculus, were also observed, particularly in the molar regions where salivary flow and mechanical cleaning are less effective. The manufacturing striations were increasingly obscured by these degradation features.

At Day 40, the archwires exhibited severe topographical alterations reflecting advanced material degradation. The original manufacturing marks were almost entirely obscured by a combination of corrosive attack and mechanical abrasion. Large areas of surface flaking, representing extensive delamination of the surface layers, were identified across multiple regions of the wires. Dense clusters of deep pits, some exceeding 30 micrometers in depth, were observed, often arranged in patterns following the orientation of the manufacturing striations. The surface appeared highly irregular and porous, with interconnected pits and delaminated areas creating a complex three-dimensional topography. This highly irregular surface suggests a significant increase in potential friction at the bracket-wire interface and a higher surface area for microbial colonization, both of which have clinical implications for treatment efficiency and oral hygiene.

Quantitative Analysis of Surface Degradation

The qualitative observations from Scanning Electron Microscopy were supported by the quantitative scoring of the micrographs using the standardized 0 to 4 grading system. The mean degradation scores increased progressively across the study groups, reflecting the cumulative effect of intraoral exposure time on surface integrity.

The control group, consisting of as-received wires, demonstrated a mean degradation score of 0.42 ± 0.12, with a median score of 0. This low score confirms that the baseline surface morphology was characterized primarily by manufacturing striations with minimal surface defects. The narrow standard deviation indicates consistent surface quality across the control specimens. Following 10 days of intraoral exposure, the mean degradation score increased to 1.25 ± 0.45, with a median score of 1. The increased variability reflected the early stages of degradation, with some wires showing more pronounced pitting than others. The predominant feature observed in this group was localized pitting, consistent with the qualitative observations.

At 30 days of intraoral exposure, the mean degradation score increased substantially to 2.68 ± 0.62, with a median score of 3. This significant increase reflects the marked transition in surface integrity observed during this period. The predominant features were fatigue and delamination, indicating that the material had undergone substantial structural changes beyond simple surface pitting.

At 40 days of intraoral exposure, the mean degradation score reached 3.55 ± 0.51, with a median score of 4. This high score reflects the severe topographical alterations observed, with severe pitting and corrosion being the predominant features. The consistent scores across specimens indicate that by 40 days, the degradation was uniformly advanced across the samples.

Table 1: Mean Surface Degradation Scores across Study Groups (n = 10 per group)

Group	Mean Score (±SD)	Median Score	Predominant Feature
As-Received (Control)	0.42 (±0.12)	0	Manufacturing striations
10 Days Intraoral	1.25 (±0.45)	1	Localized pitting
30 Days Intraoral	2.68 (±0.62)	3	Fatigue & Delamination
40 Days Intraoral	3.55 (±0.51)	4	Severe pitting/Corrosion

Regional Variation in Degradation

Analysis across different segments of the archwire revealed notable regional variations in the pattern and extent of surface degradation, reflecting the differential mechanical and environmental stresses experienced by different regions of the dental arch. These regional differences were most pronounced at the 40-day time point, where cumulative exposure had allowed for the greatest differentiation.

The midline region, corresponding to the interincisal area, demonstrated the lowest levels of degradation across all parameters. Pitting density at this region was measured at 14.2 pits per square millimeter, with delamination affecting approximately 15% of the surface area. Mineralized deposits were classified as low in this region, likely due to the self-cleansing action of the tongue and the relatively lower exposure to retained food debris.

The canine region, representing the corner of the arch where the archwire changes direction, showed intermediate levels of degradation. Pitting density increased to 22.5 pits per square millimeter, while delamination affected approximately 28% of the surface area. Mineralized deposits were classified as moderate in this region. The increased degradation in this area likely reflects the combination of mechanical stress from archwire engagement at the bracket and the anatomical location where food impaction and plaque accumulation are more common.

The molar region, representing the posterior segments of the arch, demonstrated the highest levels of degradation across all parameters measured. Pitting density reached 38.9 pits per square millimeter, more than 2.5 times that observed in the midline region. Delamination affected approximately 42% of the surface area, reflecting extensive loss of surface integrity. Mineralized deposits were classified as high in this region, consistent with the known predilection for plaque and calculus accumulation in posterior segments where salivary flow and mechanical cleaning are less effective.

Table 2: Regional Distribution of Surface Roughness Features at 40 Days

Region	Pitting Density (per mm^2)	Delamination (%)	Mineralized Deposits
Midline	14.2	15%	Low
Canine	22.5	28%	Moderate
Molar	38.9	42%	High

The regional variation in degradation scores highlights the importance of site-specific analysis when evaluating orthodontic archwire performance. The posterior segments, which are subjected to higher mechanical loads from mastication and greater biofilm accumulation, appear to be the primary sites of material degradation, potentially serving as initiation points for surface changes that may propagate along the wire over time. These findings suggest that the degradation process is not uniform along the length of the archwire but rather is concentrated in areas of greatest mechanical and environmental challenge.

Discussion

The intraoral degradation of Nickel-Titanium archwires is a multifaceted process involving both electrochemical corrosion and mechanical wear, each contributing to the progressive deterioration of surface integrity observed in this study [12]. Our Scanning Electron Microscopy analysis demonstrated a clear, time-dependent increase in surface roughness and structural compromise, with significant changes occurring as early as 10 days and reaching severe levels by 40 days of clinical use. These findings provide a detailed timeline of surface degradation that has important implications for clinical decision-making regarding archwire replacement intervals and patient management.

The as-received control wires exhibited relatively smooth surfaces with longitudinal manufacturing striations, which are typical of the cold-drawing process used during fabrication [13]. These striations represent the mechanical marks left by the wire drawing process and serve as baseline features against which intraoral degradation can be assessed. The overall surface homogeneity of the control specimens confirms that the manufacturing process produces wires with consistent initial surface characteristics suitable for clinical use.

However, even after only 10 days in the oral cavity, these surfaces began to show signs of pitting corrosion. This early onset of pitting is clinically significant, as it suggests that the degradation process begins almost immediately upon placement. The initiation of pitting is likely mediated by the presence of chloride ions in saliva, which are known to penetrate the protective titanium oxide passive layer that normally renders Nickel-Titanium biocompatible [14, 15]. The titanium oxide layer, typically only a few nanometers thick, provides a barrier against corrosion by preventing direct contact between the underlying alloy and the corrosive oral environment. However, chloride ions can locally disrupt this passive film, creating sites where galvanic corrosion can initiate. The mechanical stresses associated with bracket engagement and early mastication may further compromise this protective layer, accelerating the initiation of pitting.

By the 30-day mark, the degradation transitioned from localized pitting to more extensive surface fatigue and delamination. The observed flaking of the wire surface, characterized by the separation of thin layers of material from the underlying substrate, suggests that the repetitive stress cycles of mastication and orthodontic loading, combined with the corrosive environment, lead to a synergistic effect known as corrosion-fatigue [16]. This phenomenon occurs when cyclic mechanical loading and environmental corrosion act together to accelerate material degradation beyond what would be predicted from either factor alone. The stress concentrations created at pit sites serve as initiation points for fatigue crack propagation, while the corrosive environment prevents repassivation of freshly exposed surfaces, creating a cycle of progressive degradation. This is particularly concerning for clinical efficiency, as surface roughness increases the coefficient of friction between the wire and the bracket slot, potentially impeding the sliding mechanics essential for efficient tooth movement [17]. Increased friction can necessitate higher force levels to achieve the same rate of tooth movement, potentially increasing the risk of anchorage loss, patient discomfort, and root resorption [18].

The 40-day samples displayed the most severe alterations, with deep, coalescing pits and significant mineralized deposits covering large areas of the wire surface. The high density of pitting in the molar regions, as shown in Table 2, suggests that the posterior segments are subjected to greater mechanical challenges from masticatory forces and longer periods of plaque stagnation due to reduced salivary flow and self-cleansing in these areas [19]. The accumulation of mineralized deposits on the wire surface further complicates the degradation process, as these deposits may create local environments with altered pH and increased bacterial activity. These deep pits may serve as reservoirs for bacteria and acidic by-products, further accelerating the corrosion process in a self-perpetuating cycle where surface irregularities promote biofilm accumulation, which in turn enhances local corrosion [20].

Furthermore, the significant surface breakdown observed at 40 days raises important questions regarding the release of metal ions into the oral environment. The disintegration of the passive titanium oxide layer and subsequent delamination of the alloy surface are the primary mechanisms by which nickel ions are released from orthodontic archwires [21]. Nickel is a known allergen, and its release has been associated with both localized and systemic hypersensitivity reactions in susceptible individuals. While the levels of nickel released during orthodontic treatment are often below established toxic thresholds, they may still be sufficient to trigger localized gingival inflammation, burning sensations, or allergic responses in sensitized patients [22, 23]. Patients with a known nickel allergy may be particularly vulnerable to the effects of wire degradation, and the progressive surface breakdown observed over time may increase the cumulative exposure to nickel ions.The findings of this study suggest that while Nickel-Titanium archwires are designed for long-term use, their surface integrity begins to fail significantly within the first month of clinical service. This has important implications for clinical practice. Clinicians should be aware that the mechanical properties, frictional characteristics, and biocompatibility profile of the wire at day 40 are vastly different from those at day 1. The progressive increase in surface roughness may alter the force delivery characteristics of the wire, potentially affecting the rate and quality of tooth movement. The increased friction associated with surface degradation may reduce the efficiency of sliding mechanics, requiring longer treatment times or the application of higher forces that could compromise patient comfort and periodontal health.

This data supports the consideration of more frequent wire monitoring in patients undergoing initial leveling and alignment, particularly in those with highly acidic oral environments, poor oral hygiene, or known nickel sensitivity. For patients at higher risk of corrosion-related complications, the use of coated archwires or alternative materials may be considered to mitigate the effects of surface degradation. Coated archwires, which incorporate a protective polymeric layer over the Nickel-Titanium substrate, may offer improved resistance to corrosion and reduced nickel release, though the durability of such coatings under clinical conditions requires further investigation.

The limitations of this study should be acknowledged. The relatively small sample size of 10 wires per group, while sufficient to detect qualitative trends, may limit the statistical power for detecting subtle differences between time points. The use of a single wire dimension and manufacturer may limit the generalizability of findings to other wire sizes, alloys, or manufacturing processes. The cleaning protocol, while designed to remove organic deposits without altering metallic topography, may have incompletely removed some surface deposits or may have introduced minor artifacts. The scoring system, while standardized, involves an element of subjective interpretation that could introduce examiner bias. Future studies should investigate the correlation between surface degradation and mechanical property changes, evaluate the effectiveness of coated archwires in mitigating degradation, and assess the clinical impact of wire replacement intervals on treatment outcomes and patient comfort. Additionally, longitudinal studies correlating surface degradation with nickel ion release and clinical signs of allergic response would provide valuable insights into the biocompatibility implications of prolonged wire use.

Conclusion

Based on the scanning electron microscopy analysis of retrieved superelastic NiTi archwires, it can be concluded that significant material degradation occurs within the intraoral environment over a 40-day period. The surface topography of the wires undergoes a progressive transformation from a relatively smooth, manufactured state to a highly irregular surface characterized by dense pitting, mechanical fatigue, and material delamination.

Initial signs of corrosion and localized pitting are evident as early as 10 days of clinical use. By 30 days, these features coalesce into larger craters, accompanied by the flaking of the protective oxide layer. At the 40-day interval, severe surface breakdown is observed, particularly in the molar regions where masticatory forces and plaque accumulation are most prevalent.

These findings indicate that the clinical performance of NiTi archwires, particularly regarding sliding mechanics and friction, is likely compromised well before the typical 6-to-8-week appointment interval. Clinicians should consider these time-dependent changes in wire integrity when planning treatment mechanics and managing patients with known metal sensitivities or high-corrosion oral environments.

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