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Archwire Materials in Lingual Orthodontics: Biomechanical Performance, Material Properties, and Potential Chemical Health Risks – A Review of Evidence and Clinical Recommendations

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KEYWORDS

Lingual orthodontics; Archwire materials; Nickel-titanium alloys; Corrosion; Chemical health risk; Biocompatibility

ABSTRACT:

Background:

Lingual orthodontics presents unique biomechanical challenges due to reduced inter-bracket distance, altered lever arms, and increased torque demands. In addition to biomechanical considerations, archwire materials used in lingual appliances may pose potential chemical and biological risks related to corrosion, ion release, and long-term oral exposure.

Aim:

To review available evidence on archwire sequencing in lingual orthodontics with emphasis on wire material properties, biomechanical performance, and potential chemical health risks associated with commonly used orthodontic alloys.

Methods:

A narrative literature review was conducted using PubMed and Google Scholar up to September 2025. Clinical studies, finite-element analyses, typodont studies, reviews, and material science investigations related to lingual orthodontic archwires were included. Data on wire composition, mechanical behaviour, corrosion resistance, ion release, and clinical sequencing protocols were extracted.

Results:

Nickel-titanium, copper-nickel-titanium, titanium-molybdenum alloy, and stainless-steel wires demonstrate distinct biomechanical and chemical behaviours in lingual systems. Reduced lever arms and

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higher torque demands often necessitate earlier use of rectangular wires. Evidence suggests that corrosion and metal ion release—particularly nickel—may be influenced by wire composition, surface finish, oral pH, and treatment duration, potentially impacting oral biocompatibility.

Conclusion:
A staged wire-sequencing protocol adapted to lingual biomechanics and material properties is recommended. While current evidence supports the effective clinical use of existing archwire alloys, further research is needed to assess long-term chemical exposure risks and to establish standardised, health-oriented wire-selection guidelines for lingual orthodontics.

1. Introduction

The aesthetic demands of modern orthodontic patients have led to increased use of lingual fixed appliance systems, wherein brackets are bonded to the lingual surfaces of the teeth. While offering an excellent aesthetic alternative to labial appliances, the lingual technique introduces distinct biomechanical challenges: bracket-slots are closer to the lingual surface, inter-bracket distances are shorter, lever arms differ, tongue interference may affect forces, and control of torque and root movements is more demanding. These differences necessitate reconsideration of arch-wire choice and sequencing compared with traditional labial systems. The sequence of arch-wires — including material (NiTi, Cu-NiTi, TMA, stainless steel), dimension (round, rectangular), and progression timing — is critical in influencing alignment speed, frictional forces, torque transmission, root control, patient comfort and finishing outcome. This review aims to: (1) summarise current literature on arch-wire sequencing in lingual orthodontics; (2) discuss the material and clinical considerations unique to lingual systems; (3) propose a practical clinical workflow for wire progression in lingual orthodontic treatment.

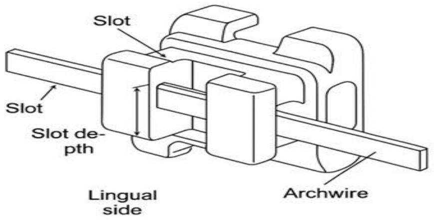

Figure 1: Diagram of lingual bracket-slot geometry, showing reduced lever arm and torque demands.

2. Objectives

1) To review the available evidence on arch-wire sequencing in lingual orthodontics**.**

2) To analyse lingual-specific biomechanical considerations affecting wire selection.

3) To propose a practical clinical protocol for wire sequencing in lingual orthodontic treatment.

3. Methods

A comprehensive literature search was performed in PubMed and Google Scholar up to September 2025, using search terms: “lingual orthodontics”, “arch-wire sequence”, “wire progression lingual appliance”, “lingual bracket biomechanics”, “torque control lingual orthodontics”. Additional hand-searching of reference lists and major orthodontic journals (e.g., The Angle Orthodontist, American Journal of Orthodontics & Dentofacial Orthopaedics, Progress in Orthodontics) was undertaken. Inclusion criteria: studies (clinical, typodont, finite-element), reviews or protocols addressing arch-wire sequencing in lingual systems. Exclusion criteria: aligner-only studies, non lingual bracket systems, articles not addressing wire progression. Data extracted included: bracket system type, wire material and dimensions used in each treatment phase (alignment, levelling/coordination, working, finishing), any lingual-specific biomechanical commentaries (e.g., torque loss, friction). Due to heterogeneity of the studies, this review is narrative rather than a meta-analysis.

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4. Results

Review of Evidence

Arch-wire materials and biomechanical properties

Orthodontic wire materials have evolved from stainless steel to super-elastic NiTi, heat-activated NiTi, Cu-NiTi, TMA and multistranded/β-Ti alloys. Their biomechanical behaviours differ in terms of stiffness, springback, friction and torque transmission. In labial systems, proper sequencing of materials is well-described. For example, initial NiTi rounds provide low-force alignment; working wires of stainless steel provide high stiffness and torque control[10]. In the lingual environment, these differences become more critical owing to the closer proximity of the bracket slot to the tooth surface and altered lever arms, meaning that wire behaviour (force magnitude, deflection, torque delivery) may differ and require adjustments[11].

Specific considerations in lingual orthodontics

Studies specific to lingual systems highlight the following issues:

- The bracket-slot placement nearer to the tooth's lingual surface shortens lever arms and may reduce effective torque delivery, necessitating stiffer wires or auxiliary mechanics[12].
- Reduced inter-bracket span in lingual systems increases bracket-wire friction and may slow alignment; hence lighter forces and smaller dimension initial wires may improve comfort and efficiency[9].
- Tongue contact and speech interference may influence wire choice (round vs rectangular), wire dimension and finishing strategies[1].
- Some studies (e.g., finite-element analyses) have compared wire types in lingual systems and show differences in stress distribution and torque behaviour compared with labial systems[2].

Chemical Composition, Biocompatibility, and Health Risk Considerations

Orthodontic archwires used in lingual appliances are primarily composed of nickel-titanium, copper-nickel-titanium, stainless steel, and titanium-molybdenum alloys. These materials remain in prolonged contact with saliva, oral mucosa, and dental hard tissues, raising concerns regarding corrosion, ion release, and potential biological effects. Nickel release from NiTi and stainless-steel wires has been associated with hypersensitivity reactions, mucosal irritation, and cytotoxic responses in susceptible individuals. Lingual appliances may further influence these risks due to closer proximity to the tongue and increased salivary exposure.

Corrosion behaviour is affected by oral pH fluctuations, dietary acids, fluoride exposure, and mechanical wear during orthodontic activation. Studies have demonstrated that surface roughness and wire deformation during treatment can increase metal ion release. Although reported ion levels generally remain below toxic thresholds, cumulative exposure over extended treatment durations warrants consideration, particularly in patients with known metal sensitivities. Therefore, wire selection and sequencing in lingual orthodontics should not only address biomechanical efficiency but also incorporate material safety, corrosion resistance, and long-term oral health implications.

Wire-sequence protocols in the literature

While labial wire sequences are well documented, specific lingual-protocol studies are fewer. Examples include: a typodont study in which a lingual straight-wire technique was used with 0.013″ and 0.016″ Cu-NiTi wires in alignment, then 0.016×0.016″ and 0.018×0.018″ Cu-NiTi in levelling, followed by 0.0175×0.0175″ TMA in finishing[3]. Another investigation into double-wire techniques (in lingual systems) showed better torque control with auxiliary wires than single-wire setups[7]. Despite these examples, there is no standard consensus sequence for lingual orthodontics across bracket systems.

Gaps in evidence

Significantly, high-quality randomised clinical trials comparing alternate wire sequences in lingual appliances are lacking[15]. Few studies stratify by bracket system, slot size, arch-form or patient-specific factors in the lingual context. Long-term finishing outcomes and stability relative to different wire progressions remain under-reported. Moreover, with the advent of custom-manufactured lingual arch-wires (e.g., digitally designed), the impact of wire-sequencing in this context is still emerging.

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Proposed Clinical Workflow for Wire Sequencing in Lingual Orthodontics

Based on the available evidence and clinical rationale, the following workflow is proposed (to be adapted to individual patient case, bracket system, treatment objective and arch-wire manufacturer recommendations): (Table 1, Flowchart 1)

Clinical Tips for Lingual Wire-Sequencing:

- Ensure passive fit of bracket-wire at each stage; lingual bracket orientation can lead to binding or unintended moments if wires are oversized too early.
- Monitor tongue interference and patient comfort, especially during alignment stage.
- Use auxiliary mechanics (e.g., double-wire, torque auxiliaries, lever arms) earlier if significant torque/control demands are anticipated (e.g., extraction cases, Class II/III corrections).
- Communicate clearly with wire-manufacturer (if custom wires used) that wires are for lingual bracket systems, specifying bracket-slot-to-archwire distance and bracket type.
- Document each wire change, patient discomfort, force levels and treatment progress.

Phase	Wire Material & Dimension	Clinical Purpose	Lingual-specific Notes
Alignment (Initial)	Super-elastic NiTi or Cu-NiTi, round 0.013″–0.014″	Gentle alignment of crowded/labiolingually mal-positioned teeth; minimal torque demand	Use lighter forces due to shortened lever arms; ensure engagement of lingual brackets without tongue interference[9]
Levelling/Coordination	Round (0.016″) or rectangular small size (0.016 × 0.016″) Cu-NiTi or NiTi	Flattening the curve of Spee, arch-coordination, begin torque control	In lingual system, consider earlier entry into rectangular wires to address torque; monitor bracket-wire friction and tongue effect[3,6]
Working/Space-Closure	Rectangular stainless steel or TMA wires such as 0.0175 × 0.0175″ TMA or 0.019 × 0.025″ SS	Root control, torque application, space closure, anchorage maintenance	Because lingual mechanics often lose torque more easily, consider auxiliary wires or double-wire techniques; pay attention to extrusion of anterior teeth[7]
Finishing/Detailing	Stiff finishing wires (e.g., SS 0.018 × 0.025″ or 0.019 × 0.025″) with final bends (tip, torque, individual tooth adjustments)	Final alignment, occlusion finishing, arch-form refinement	In lingual cases allow for over-correction of torque and adjust arch-form specifically for lingual bracket positioning; retain adequate inter-bracket span and minimise deflection errors[8]

Table 1: Summary of Recommended Wire Dimensions by Treatment Phase for Lingual Appliance

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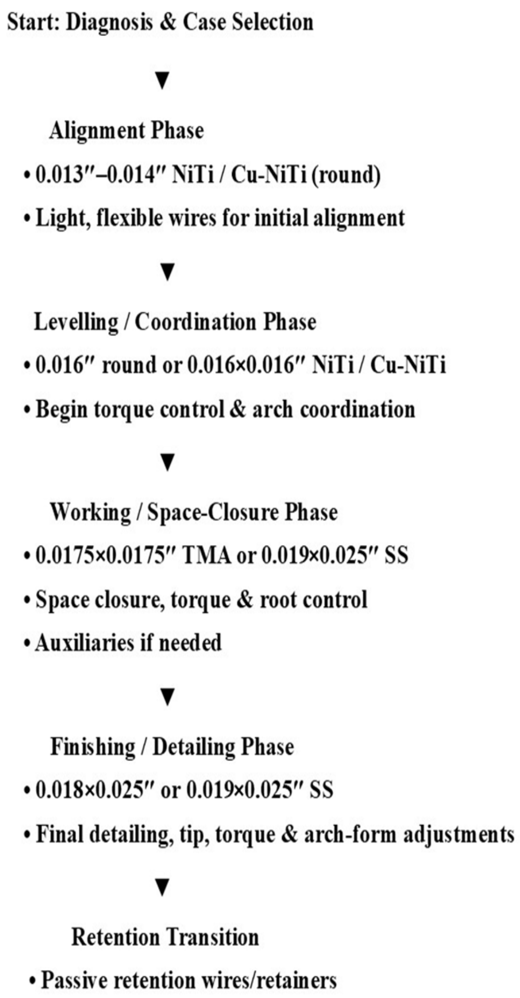
Phase	Wire Material & Dimension	Clinical Purpose	Lingual-specific Notes
Retention Transition	Transition off active arch-wire into passive retention phase	Maintain achieved tooth positions	Consider lingual-specific retention wires or removable retainers compatible with lingual appliance finish; monitor torque relapse due to tongue forces[1]



Flowchart 1. Flowchart of Proposed Wire-Sequencing Workflow in Lingual Orthodontics

5. Discussion

Wire sequencing in lingual orthodontics demands adaptation of traditional labial-systems protocols owing to the altered biomechanics of lingual bracket positioning[1,9]. The shorter inter-bracket spans, reduced lever arms, and closer proximity of the bracket to tooth surface require a more cautious progression, sensitive to torque loss, frictional resistance and tongue interactions. While the fundamentals of wire progression (from flexible alignment wires to stiffer finishing wires) remain intact, clinicians should tailor each step to the lingual environment, making considerations for patient comfort, torque control and finishing precision.

The review has identified that current literature is limited—most recommendations are based on typodont/finite-element studies or manufacturer protocols rather than well-designed clinical trials. For the innovation of lingual systems (including digitally customised arch-wires and lingual bracket-systems), future research should focus on: comparative trials of wire-sequences in lingual vs labial, effect of bracket-slot-to-wire-distance on sequence timing, impact of custom-wired lingual systems on reducing treatment time, and long-term stability of wire-sequence choices in lingual finishing. Until such evidence accumulates, the proposed workflow provides a practical, evidence-informed guide that clinicians can adapt to individual case needs. From a chemical health perspective, careful material selection and sequencing may help minimise cumulative metal ion exposure during prolonged lingual orthodontic treatment.

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6. Conclusion

In conclusion, effective wire-sequence planning in lingual orthodontics is key for achieving efficient alignment, torque control, working mechanics and high-quality finishing. By following a staged progression — flexible alignment wires, intermediate levelling wires, stiffer working wires, and precise finishing wires — and adapting each phase to the biomechanics of lingual appliances, clinicians can optimise treatment outcomes. Given the paucity of lingual-specific clinical trials, further research is warranted to establish evidence-based standardised sequences for different bracket systems and patient types.

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