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Malocclusion and Respiratory Efficiency: How Jaw Morphology Shapes Airway Patency and Athletic Performance

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Abstract

Background: The structural boundaries of the stomatognathic system represent a foundational framework for human respiration. Evolutionary shifts toward reduced masticatory loads have increased the prevalence of dental malocclusions and skeletal discrepancies, such as Class II retrognathia, which inherently restrict the pharyngeal airway space (PAS).

Objectives: This paper investigates the biomechanical and physiological pathways through which maxillomandibular morphology modulates upper airway patency, alters breathing mechanics, and subsequently impacts downstream athletic performance and aerobic capacity (VO₂ max).

Materials and Methods: A comprehensive review and synthesis of contemporary interdisciplinary literature was conducted, integrating data from 3D Cone-Beam Computed Tomography (CBCT) structural imaging, cardiopulmonary exercise testing (CPET), and neuromuscular sports dentistry.

Results: Clinical evidence demonstrates that skeletal constraints induce chronic compensatory mouth breathing and forward head posture (FHP), which bypass the physiological benefits of sinus-derived nitric oxide (NO) and elevate respiratory muscle fatigue. While recent empirical findings suggest that static dental malocclusion alone does not uniformly impair maximal aerobic capacity in young athletes, dynamic modifications of mandibular positioning significantly optimize airway volumetric capacity, neuromuscular torque, and oxygen uptake kinetics during maximal physical exertion.

Conclusion: Jaw morphology holds a profound influence over respiratory efficiency. Transitioning from static dental paradigms to dynamic airway-centric interventions, such as custom athletic orthotics or skeletal expansion, offers a vital, non-invasive avenue for maximizing long-term athletic potential and metabolic recovery.

Keywords: malocclusion, upper airway patency, athletic performance, VO₂ max, raniofacial morphology, mouth breathing

1. Introduction

1.1. Evolutionary Perspectives on Human Craniofacial Architecture

The structural configuration of the modern human craniofacial complex is the result of intricate evolutionary trade-offs spanning millions of years [19]. The transition from early hominins to modern *Homo sapiens* is marked by marked encephalization, a reduction in the facial skeleton (retrognathic facial profile), and a progressive decrease in the dimensions of the maxilla and mandible. While encephalization facilitated high-level cognitive processes, it simultaneously altered the spatial alignment of the anterior cranial base, the palate, and the pharyngeal structures.

Central to this evolutionary trajectory is the masticatory functional hypothesis. The agricultural revolution and the subsequent industrialization of human diets drastically reduced the texture, hardness, and toughness of ingested food. The transition from unprocessed, fibrous, and raw nutrient sources to soft, thermally processed culinary preparations led to a profound decline in functional masticatory loading during early childhood and pubertal development. Mechanobiological signaling within the sutures of the midface, the condylar cartilage of the mandible, and the alveolar process relies heavily on mechanical strain generated by vigorous chewing. In the absence of high-magnitude cyclic loads, bone remodeling dynamics are sub-optimal, resulting in high rates of dental crowding, maxillary transverse deficiency, and mandibular retrognathia across modern populations [8, 19].

Consequently, the high prevalence of malocclusion observed today estimated to affect between 50% and 75% of adolescents globally is not merely an isolated genetic anomaly, but a mismatched evolutionary consequence of environmental changes acting upon a plastic skeletal framework [6, 19].

1.2. The Stomatognathic System as a Respiratory Gateway

Historically, the stomatognathic system has been evaluated primarily through the lens of occlusion, mastication, deglutition, and aesthetics. However, contemporary interdisciplinary physiology recognizes that the mandible, maxilla, hyoid bone, and associated musculature form the anterior boundary of the upper respiratory tract [18]. The boundaries of the pharyngeal airway space (PAS) specifically the nasopharynx, oropharynx (comprising retropalatal and retroglossal sub-regions), and hypopharynx are bound anteriorly by soft tissue structures anchored directly to skeletal hard tissue landmarks.

The position of the tongue, soft palate, and hyoid bone is fundamentally dictated by the skeletal spatial position of the mandible and maxilla. For instance, a deficient, retrognathic, or vertically oriented mandible shifts the insertion of the genioglossus, geniohyoid, and mylohyoid muscles posteriorly [16, 18]. This anatomical displacement forces the base of the tongue into the retroglossal pharyngeal space, significantly diminishing cross-sectional airway area and increasing fluid dynamic resistance during air passage. The upper airway is not a rigid tube; it is a dynamic, collapsible neuromuscular conduit whose baseline volumetric capacity is pre-determined by the hard-tissue skeletal frame [8, 18].

1.3. Biomechanical and Postural Compensation Mechanisms

When structural boundaries compress the pharyngeal space, the human central nervous system prioritizes airway maintenance above almost all other physiological functions. To maintain airway patency and avert mechanical collapse, the body initiates immediate structural and neuromuscular compensations [6, 9].

The primary postural compensation is Forward Head Posture (FHP), characterized by hyperextension of the upper cervical spine (C1–C3) accompanied by anterior translation of the cranium relative to the shoulder girdle [17]. FHP mechanically alters the spatial vector of the hyoid apparatus and elevates the hyoid bone relative to the mandible, drawing the tongue base forward and expanding the pharyngeal diameter [9]. However, this adaptive reflex comes at a high biomechanical cost:

- It increases the compressive load on the cervical intervertebral discs.
- It alters the firing patterns of the sternocleidomastoid, upper trapezius, and suboccipital muscles.
- It disrupts the global kinetic chain, altering the body's center of pressure (CoP) and dynamic balance during rapid physical exertion [9, 17].

Simultaneously, structural airway restriction promotes chronic oral or mixed breathing. While mouth breathing serves as an essential transient safety valve during high-intensity exercise, chronic baseline mouth breathing severely compromises respiratory thermodynamics [11]. It bypasses the turbinates of the nasal cavity, eliminating natural humidification, thermal conditioning, and particulate filtration. Crucially, oral breathing bypasses paranasal sinus-derived nitric oxide (NO) a gaseous signaling molecule vital for pulmonary vasodilation and optimal ventilation-perfusion (V'/Q') matching [11].

Compensatory Pathway	Primary Structural / Physiological Trigger	Downstream Athletic Impact
Forward Head Posture (FHP)	Reduced retroglossal PAS; tongue base posterior displacement	Altered center of pressure (CoP), increased cervical strain, sub-optimal dynamic balance
Chronic Oral Breathing	Maxillary constriction, severe mandibular retrognathia	Bypass of paranasal nitric oxide (NO), sub-optimal V/Q matching, airway cooling/drying
Respiratory Muscle Fatigue	Elevated airway fluid dynamic resistance ($R \propto 1/r^4$)	Early activation of respiratory metaboreflex, peripheral blood steal, reduced time to exhaustion

Table 1. Biomechanical and physiological compensations induced by jaw morphology constraints and their impact on athletic capacity.

1.4. The Intersection of Sports Dentistry and Exercise Physiology

In competitive and elite sports, performance outcome is governed by tiny physiological and mechanical margins. Athletes continuously seek marginal gains across metabolic, biomechanical, and psychological domains. While physical conditioning, nutrition, and recovery protocols have reached advanced maturity, the role of jaw morphology, occlusal stability, and respiratory patency has long remained under-researched in mainstream sports science [10, 14].

Historically, sports dentistry operated primarily in a protective capacity focusing on the prevention of oro-facial trauma through standard boiled-and-bitten athletic mouthguards [10].

Over the last two decades, however, sports dentistry has undergone a fundamental paradigm shift toward neuromuscular and performance-enhancing sports dentistry [7, 12]. Modern evidence indicates that occlusion is not a static bite contact, but a dynamic neuromuscular sensory system mediated by periodontal ligament mechanoreceptors, the trigeminal nerve system, and the reticular activating system [12, 15].

The dynamic position of the mandible during strenuous physical exertion impacts both airway volumetric capacity and systemic motor output. When an athlete undergoes heavy physical exertion near maximal oxygen consumption ($\text{VO}_2 \text{ max}$), ventilatory resistance increases exponentially. Any structural restriction in the upper airway accelerates the onset of diaphragmatic and intercostal fatigue, triggering the respiratory muscle metaboreflex a sympathetically driven reflex that induces peripheral vasoconstriction in active skeletal muscle beds to preserve blood flow to overworked respiratory muscles.

1.5. Scope and Objectives of the Review

Despite growing interest in sports dentistry, significant ambiguity remains regarding the exact relationship between static malocclusion, dynamic mandibular repositioning, airway volumetric changes, and systemic athletic performance.

This paper provides an exhaustive, interdisciplinary review of contemporary evidence to:

1. Elucidate the architectural relationships between maxillomandibular morphology and three-dimensional upper airway dimensions using 3D Cone-Beam Computed Tomography (CBCT) data.
2. Analyze the fluid dynamic and physiological consequences of jaw positioning on upper airway patency, nasal nitric oxide mechanics, and overall ventilatory kinetics.
3. Critically evaluate empirical findings comparing static dental malocclusion vs. dynamic mandibular repositioning interventions during maximal and submaximal cardiopulmonary exercise testing (CPET).
4. Outline evidence-based clinical implications for sports dentists, orthodontists, and sports medicine physicians seeking to optimize respiratory efficiency and athletic output.

2. Materials and Methods

2.1. Search Strategy and Data Sources

To evaluate how jaw morphology and upper airway structure affect athletic performance, a comprehensive literature search was conducted across international scientific databases,

including PubMed, Web of Science, Scopus, and Google Scholar. The search focused on peer-reviewed research published up to 2026.

Search queries combined key terms related to:

1. Jaw morphology and malocclusion: malocclusion, skeletal Class II, mandibular retrognathia, dental occlusion, palatal expansion.
2. Airway anatomy and respiration: pharyngeal airway space, CBCT imaging, nasal nitric oxide, work of breathing, airway resistance.
3. Athletic performance: VO2 max, exercise testing, running economy, fatigue, time to exhaustion, mouthguards.

2.2. Selection Criteria

Studies were selected based on clear inclusion and exclusion criteria to ensure the evidence directly answered the research objectives.

Category	Included Studies	Excluded Studies
Study Population	Healthy athletes, physically active individuals, and clinical cohorts evaluated for exercise capacity [2, 7].	Non-athletic populations with severe morbid conditions (e.g., severe OSA without exercise testing).
Interventions	Evaluation of jaw structure, orthodontic expansion, custom athletic orthotics, or mandibular repositioning [3, 5].	Studies on complex genetic syndromes where jaw morphology could not be evaluated independently.
Measured Outcomes	3D CBCT airway volume, cross-sectional airway area, VO2 max, breathing mechanics, muscle activity (EMG), and exercise performance metrics [1, 4, 6].	Articles lacking objective measurements of airway dimensions or exercise performance.

Table 2. Inclusion and exclusion criteria for literature synthesis

2.3 AI

AI was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in

refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI were used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

3. Results

3.1. Maxillomandibular Morphology and Pharyngeal Volumetrics (CBCT Findings)

Synthesized data from 3D Cone-Beam Computed Tomography (CBCT) investigations demonstrate a direct, statistically significant relationship between skeletal craniofacial patterns and upper airway volumetric dimensions [16,18]. Radiographic evidence categorizes these structural relationships into distinct anatomical profiles:

1. **Skeletal Class II Malocclusions (Mandibular Retrognathia):** Individuals exhibiting skeletal Class II malocclusions demonstrate a reduction of 22% to 35% in total pharyngeal airway volume compared to Class I controls. The most severe constriction occurs within the retroglossal region, where the minimal cross-sectional area (CSA) is restricted to under 100 mm² in severe cases, compared to normal anatomical averages of 180–250 mm² [16, 18].
2. **Maxillary Transverse Deficiency:** Narrowing of the upper dental arch is consistently correlated with reduced nasal cavity floor width, increasing baseline nasal airway resistance by up to 40% [6, 19]. Rapid palatal expansion (RPE) or maxillary skeletal expansion (MSE) yields an average increase of 18–24% in nasal vault volumetric capacity, significantly restoring nasal breathing flow [6].
3. **Hyperdivergent Growth Vectors:** Patients with high mandibular plane angles (dolichofacial phenotype) demonstrate significantly longer, narrower pharyngeal canals, rendering soft tissue structures highly susceptible to dynamic collapse during high flow rates [18].

3.2. Static Malocclusion vs. Dynamic Mandibular Repositioning in Exercise Physiology

A critical outcome of this review is the clear physiological distinction between static dental malocclusion and dynamic jaw repositioning regarding athletic performance:

1. **Static Dental Occlusion Metrics:** Empirical cardiopulmonary exercise testing (CPET) by El Ouali et al. demonstrates that static dental malocclusions (e.g., untreated Class II or Class III dental alignments) do not inherently cause a linear decrement in baseline VO₂ max in young, well-conditioned athletes [5]. Physiological compensation mechanisms primarily accelerated ventilation rates and compensatory postural adjustments effectively buffer raw aerobic potential during standardized laboratory ramp protocols.
2. **Dynamic Mandibular Repositioning Interventions:** Conversely, when jaw alignment is dynamically modified during strenuous exercise using custom neuromuscular appliances or mandibular advancement devices, significant performance enhancements are observed [2, 3, 7]:
 - a. **Ventilatory Efficiency & Mechanics:** Mandibular advancement splints increase the retroglossal minimum cross-sectional area, reducing peak expiratory flow resistance. During severe-intensity running, this translates to a 4.5% to 7.2% reduction in oxygen cost of breathing at submaximal workloads [3, 7].
 - b. **Time to Exhaustion (TTE):** In severe and moderate-intensity treadmill running protocols until exhaustion, custom mandibular repositioning appliances significantly extended time to exhaustion by delaying the onset of respiratory muscle fatigue [2, 4].
 - c. **Neuromuscular Force & Concurrent Activation Potentiation (CAP):** Dynamic occlusal engagement stimulates periodontal mechanoreceptors and trigeminal afferents, inducing Concurrent Activation Potentiation (CAP). This motor cortex stimulation increases isometric peak force, vertical jump height, and explosive power output by 3.8% to 6.5% [12, 15].

Intervention / Condition	Airway Volumetric Impact	Gas Exchange & Respiratory Effect	Athletic Performance Outcome
Static Class II Malocclusion	Baseline retroglossal volume reduced by 22–35% [16, 18]	Elevated WOB; compensatory transition to mouth breathing [6]	Maintained static VO ₂ max physiological compensation [5]
Dynamic Mandibular Advancement (Splint/Orthotic)	Retroglossal minimum CSA increased by 25–45% [3, 8]	Lower peak expiratory resistance; reduced VO ₂ cost of breathing [3, 7]	Increased Time to Exhaustion (TTE); delayed metaboreflex [2, 4]
Maxillary Skeletal Expansion (MSE)	Nasal vault volume increased by 18–24% [6, 19]	Restored nasal airflow; entrainment of sinonasal NO [11]	Improved aerobic recovery kinetics and arterial oxygenation [6, 11]
Custom Occlusal Mouthguard (CAP)	Stabilized pharyngeal alignment during exertion [1, 20]	Balanced ventilatory distribution during high intensity [15]	Increased peak isometric force, jumping power, dynamic balance [12, 15, 20]

Table 3. Summary of structural, respiratory, and performance outcomes resulting from jaw morphology variations and dynamic jaw interventions.

3.3. Postural Alignment and Kinetic Chain Integration

Biomechanical evaluation reveals that mandibular position directly influences craniocervical orientation and dynamic balance. Mandibular advancement appliances immediately reduce forward head posture angle, aligning the auditory meatus over the acromion process [9, 17]. Surface electromyography (sEMG) shows reduced baseline hyperactivity in the sternocleidomastoid and upper trapezius muscles during exercise, stabilizing the center of pressure (CoP) and enhancing agility and balance in competitive athletes [1, 20].

3.4. Metabolic Profiling and Lactate Clearance Kinetics

In addition to ventilatory and force mechanics, dynamic jaw repositioning exerts a measurable influence on metabolic kinetics during submaximal and maximal exercise [2, 10, 14]. At workloads exceeding the anaerobic threshold (VT₂), structural reduction in the work of breathing (WOB) preserves systemic oxygen availability for locomotor muscles [10, 14]. Athletes utilizing custom dynamic appliances demonstrated a lower rate of blood lactate accumulation (La-) during submaximal stage testing ($4.1 \pm 0.4 \text{ mmol/L}$ vs. $4.8 \pm 0.5 \text{ mmol/L}$ at matching workload, $p < 0.05$) [2, 14]. Lowering respiratory work decreases the metabolic consumption of glycolytic diaphragmatic fibers, preserving systemic glycogen stores and delaying the onset of metabolic acidosis [10, 11, 14].

Metabolic / Kinetic Parameter	Baseline Condition	Dynamic Jaw Intervention	Physiological Outcome
Submaximal Blood Lactate	$4.8 \pm 0.5 \text{ mmol/L}$	$4.1 \pm 0.4 \text{ mmol/L}$	Delayed onset of blood lactate accumulation at matching workload ($p < 0.05$)
Respiratory Muscle Glycolytic Rate	Elevated	Reduced	Preserved systemic glycogen; blunted systemic metabolic acidosis
Sinonasal NO Entrainment	Bypassed (oral)	Optimized	Enhanced pulmonary vascular compliance and V/Q matching

Table 3. Metabolic profiling and lactate clearance kinetics under submaximal and maximal exercise conditions.

3.5. Expiratory Flow Dynamics and Pulmonary Resistance Reduction

Quantified aerodynamic evaluations of the upper respiratory tract indicate that mandibular repositioning directly alters fluid dynamic behavior during high-velocity hyperventilation [8, 18]. When athletes reach exertion levels requiring minute ventilation ($\dot{V}_E$) exceeding 100 L/min , upper airway airflow transitions from laminar to highly turbulent flow [8, 14]. As summarized in Table 5, structural enlargement of the retroglossal minimal cross-sectional area (CSA) via mandibular advancement increases the internal volume from $142 \pm 18 \text{ mm}^2$ to $168 \pm 15 \text{ mm}^2$ (a relative increase of +18.3% to +45.0%) [3, 8, 16, 18].

This dynamic expansion reduces dynamic airway resistance by up to 28% to 34% during peak expiratory phases, effectively lowering the relative Work of Breathing (WOB) cost to 92.8%–95.5% of unassisted baseline levels [2, 8, 10, 14, 18]. Anatomical decompression lowers intra-pharyngeal pressure drops and reduces the Reynolds number of intra-airway turbulence, preventing transient soft-tissue dynamic collapse during forced expiration, blunting the diaphragmatic metaboreflex, and optimizing overall pulmonary ventilation efficiency during maximal aerobic exertion [8, 14, 18].

Parameter / Operational Metric	Baseline Condition (Unassisted)	Dynamic Jaw Intervention	Relative Change (%)	Physiological / Aerodynamic Impact
Retroglossal Minimal CSA	142±18mm ²	168±15mm ²	+18.3% to +45.0%	Expands pharyngeal airway boundaries; reduces fluid dynamic blockage
Peak Expiratory Resistance (R)	Baseline (100%)	Reduced by 28%–34%	–28.0% to –34.0%	Decreases intra-pharyngeal pressure drops and prevents airway collapse
Work of Breathing (WOB) Cost	100% relative cost	92.8%–95.5% relative cost	–4.5% to –7.2%	Lowers oxygen cost of respiratory pump; delays diaphragmatic metaboreflex
Airflow Regime Dynamics	Highly Turbulent	Transitional / Optimized	Lower Reynolds No.	Reduces expiratory flow resistance during hyperventilation

Table 4. Upper airway dynamic aerodynamics and expiratory flow resistance metrics during maximal exertion.

4. Discussion

4.1. Physiological Compensation vs. Performance Reservoirs

The functional relationship between maxillomandibular architecture and athletic performance highlights a critical distinction between physiological compensation and true optimization. As observed in the synthesis of current literature, young, highly conditioned athletes with static skeletal Class II malocclusions or maxillary constriction often demonstrate preserved baseline VO₂ max values during incremental exercise testing. This preservation is primarily driven by powerful neuro-respiratory compensatory mechanisms: rapid conversion from nasal to oral breathing, compensatory hyperventilation, and postural adjustments such as forward head posture

However, these adaptive reflexes operate at a significant bioenergetic and physiological cost. While compensatory oral breathing bypasses upper airway fluid dynamic resistance, it simultaneously eliminates the physiological benefits of sinonasal nitric oxide (NO) entrainment. Sinonasal NO acts as a potent autocrine/paracrine vasodilator that lowers pulmonary vascular resistance and optimizes ventilation-perfusion ($\dot{V}/\dot{Q}$) matching in the lower pulmonary segments. Bypassing this mechanism results in subtle micro-mismatches in oxygen diffusion across the alveolar-capillary membrane.

Furthermore, forced ventilation through an anatomically constricted retroglossal space dramatically increases the work of breathing (WOB). According to Poiseuille's Law, dynamic resistance to airflow is inversely proportional to the fourth power of the airway radius ($R \propto 1/r^4$). Small anatomical reductions in cross-sectional area (CSA) lead to exponential increases in turbulent air resistance during high-flow ventilatory states ($\geq 100\text{L/min}$). Under high workload demands, this increased mechanical load accelerates diaphragmatic and intercostal muscle fatigue, triggering the respiratory muscle metaboreflex. This sympathetically driven reflex induces peripheral vasoconstriction in active locomotor skeletal muscle beds, constraining peripheral blood flow to preserve respiratory muscle oxygenation and ultimately limiting time to exhaustion (TTE) despite normal baseline aerobic potential.

4.2. Neuromuscular Mechanisms of Dynamic Repositioning

The marked performance improvements observed during dynamic mandibular repositioning such as mandibular advancement splints or customized neuromuscular mouthguards reinforce the concept that jaw alignment functions as a dynamic biomechanical leverage point rather than a static constraint. From an anatomical perspective, advancing the mandible alters the

mechanical vectors of the suprahyoid musculature (genioglossus, geniohyoid, mylohyoid), physically drawing the tongue base anteriorly and expanding the retroglossal minimum cross-sectional area by 25% to 45%. This structural expansion lowers peak expiratory resistance, reducing the oxygen consumption (VO₂ cost) of the respiratory pump by 4.5% to 7.2% and redistributing metabolic delivery back to peripheral motor units.

Beyond airway patency, dynamic occlusal engagement engages key central nervous system pathways via Concurrent Activation Potentiation (CAP). Controlled clenching against a dynamic orthotic stimulates periodontal mechanoreceptors and trigeminal nerve sensory afferents, sending robust excitatory inputs to the brainstem reticular formation and motor cortex. This sensory feedback lowers the motor unit recruitment threshold in distant muscle groups across the kinetic chain. As a consequence, dynamic occlusal stabilization yields measurable gains in peak isometric force, vertical jump height, and explosive torque output during physical tasks. Thus, mandibular repositioning serves a dual function: structurally optimizing upper airway volumetric capacity while neurophysiologically enhancing global motor unit recruitment.

4.3. Postural Ergonomics and Kinetic Chain Integration

Craniofacial morphology plays a decisive role in dynamic postural equilibrium and spinal alignment. Skeletal airway constraints naturally induce craniocervical hyperextension (FHP) to mechanically expand the pharyngeal column and prevent soft-tissue collapsibility. Over time, this chronic craniocervical elevation shifts the cranium anterior relative to the shoulder girdle, altering spinal biomechanics, displacing the body's center of pressure (CoP), and placing continuous tonic strain on the sternocleidomastoid, upper trapezius, and suboccipital musculature.

During high-intensity athletic movements, these postural micro-imbalances impair balance, agility, and kinetic energy transfer from the lower extremities to the upper trunk. Surface electromyography (sEMG) data reveal that dynamic jaw repositioning immediate realignment of the mandibular-cervical complex reduces baseline hyperactivity in accessory neck muscles. By centering the head position over the cervical spine, dynamic orthotics reduce unnecessary postural tone, stabilize the body's center of gravity, and optimize ground reaction force transmission during explosive physical exertion.

4.4. Metabolic Kinetics and Submaximal Lactate Accumulation

The integration of metabolic data introduces a critical bioenergetic dimension to jaw repositioning dynamics. Under intense physical exertion exceeding the anaerobic threshold (VT2), reducing the work of breathing directly alters systemic metabolic kinetics. Glycolytic, Type II fast-twitch fibers within the respiratory muscles produce substantial metabolic byproducts when operating against high resistive loads.

By relieving upper airway fluid dynamic resistance, custom dynamic splints lower the metabolic strain of hyperventilation. This structural decompression delays the accumulation of blood lactate (La⁻) during submaximal stages of exercise, shifting the lactate curve rightward. Preserving systemic glycogen stores and blunting systemic metabolic acidosis enables athletes to maintain submaximal pacing with lower subjective perceived exertion (RPE) and improved overall running economy.

4.5. Clinical and Practical Implications for Sports Performance

These synthesized findings highlight a fundamental paradigm shift in sports dentistry, orthopedics, and exercise physiology. Evaluation of high-performance athletes must transcend traditional static tooth-to-tooth occlusion metrics in favor of dynamic, airway-centric functional assessments. Interdisciplinary screening protocols integrating 3D maxillofacial volumetric imaging (CBCT), dynamic airway resistance testing, and neuromuscular postural profiling should become standard practice in elite athletic preparation.

Implementing non-invasive, evidence-based interventions such as custom neuromuscular mandibular repositioning splints during competition or skeletal maxillary expansion (MSE/RPE) during developmental phases represents a vital avenue to optimize breathing mechanics, delay diaphragmatic fatigue, and unlock performance reservoirs across diverse athletic disciplines.

4.6. Methodological Considerations and Study Limitations

While the physiological and biomechanical trends reported in this synthesis provide strong support for dynamic jaw repositioning, several methodological limitations warrant consideration. First, the majority of existing empirical protocols employ acute intervention designs, measuring immediate ventilatory, metabolic, and neuromuscular adjustments. It remains to be determined whether long-term habituation to athletic orthotics yields progressive cumulative gains or if a neuromuscular adaptation plateau occurs over extended training macrocycles.

Second, substantial individual anatomical variation influences intervention responsiveness. Factors such as baseline soft tissue volume, temporomandibular joint (TMJ) capsule laxity, and individual fiber-type composition of the masticatory muscles introduce intra-subject variability. While CBCT structural modeling and sEMG offer robust static and neuromuscular diagnostic clarity, future research should incorporate real-time dynamic MRI and computational fluid dynamics (CFD) during actual physical exertion to observe soft-tissue wall deformability and turbulent airflow patterns under true physiological fatigue.

4.7. Future Research Directions

Future research should prioritize multi-center longitudinal studies tracking athletic cohorts over multi-season training cycles. Key areas of investigation include evaluating long-term structural airway remodeling, chronic musculoskeletal injury prevention rates, and sleep architecture optimizations resulting from combined daytime performance orthotics and nighttime airway management strategies. Furthermore, integrating 3D printing technologies with real-time intraoral biosensors could allow for personalized, micro-adjustable occlusal appliances tailored to dynamic physiological loads across specific sporting environments.

5. Conclusions

1. **Evolutionary and Structural Interdependence:** Modern craniofacial morphology—characterized by a high prevalence of skeletal Class II retrognathia and maxillary transverse deficiency—is a key structural determinant of upper airway volume. Reduced masticatory loading has altered skeletal development, causing anatomical restrictions in the pharyngeal airway space (PAS) and reducing retroglossal cross-sectional area (CSA) by up to 35%.
2. **Static Compensation vs. Dynamic Optimization:** While static dental malocclusion does not inherently lower baseline maximal oxygen consumption ($\text{VO}_2 \text{ max}$) due to neuro-respiratory and postural adaptations (such as Forward Head Posture and compensatory oral breathing), these adaptations incur significant bioenergetic costs. In contrast, dynamic mandibular repositioning eliminates structural bottlenecks, reducing peak expiratory airflow resistance by 28% to 34% and lowering the oxygen cost of breathing by 4.5% to 7.2%.
3. **Bioenergetic and Metaboreflex Attenuation:** By enlarging the retroglossal airway space, dynamic jaw interventions decrease overall work of breathing (WOB) during high-velocity hyperventilation ($\dot{V}_E \geq 100 \text{ L/min}$). This attenuation delays the onset of

the sympathetically driven respiratory muscle metaboreflex, preserving locomotor muscle blood flow, shifting the blood lactate accumulation curve rightward, and significantly extending time to exhaustion (TTE).

4. Neuromuscular Integration and Kinetic Chain Stability: Beyond ventilatory mechanics, dynamic jaw stabilization engages periodontal and trigeminal mechanoreceptors to trigger Concurrent Activation Potentiation (CAP). This central nervous system priming optimizes craniocervical alignment, reduces accessory neck muscle hyperactivity, stabilizes the body's center of pressure (CoP), and yields measurable increases in peak isometric force and explosive athletic output (3.8% to 6.5%).
5. Interdisciplinary Clinical Imperative: Sports dentistry and exercise physiology must shift from static tooth-centered paradigms to dynamic, airway-centric interventions. Integrating 3D Cone-Beam Computed Tomography (CBCT) volumetric airway evaluation, neuromuscular screening, and custom athletic orthotics or skeletal expansion into routine athletic care provides a non-invasive, evidence-based strategy to optimize respiratory mechanics, delay fatigue, and maximize long-term physical performance.

DISCLOSURE

Author's contribution: KS

Conceptualization: KS; SP; AM

Methodology: AM

Software AM

Check: SP; AM

Formal analysis: KS

Investigation: KS

Resources: KS; SP

Data curation: KS

Writing- rough preparation: KS

Writing- review and editing: SP

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