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Review Article

Longitudinal Statistical Modeling of Orthodontic Treatment Efficiency and Patient-Reported Outcomes: A Conceptual Framework

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ABSTRACT

Orthodontic care is increasingly expected to deliver treatment that is not only technically effective but also efficient, acceptable, and responsive to patient experience. Conventional outcome assessment has often emphasized occlusal correction, treatment duration, appliance performance, or satisfaction as separate endpoints. This separation limits the ability to understand how clinical efficiency and patient-reported outcomes evolve together during treatment. A patient-centered conceptual model is therefore needed to connect what clinicians measure with what patients experience over time. The central problem addressed in this article is the absence of an integrated framework for studying orthodontic treatment efficiency and patient-reported outcome trajectories simultaneously. Treatment duration, number of appointments, appointment intervals, and rate of tooth movement are often interpreted as efficiency indicators, whereas pain, aesthetics, psychosocial impact, and satisfaction are assessed through patient-reported instruments. When these domains are analyzed separately, potential trade-offs may be overlooked. This creates uncertainty about whether faster treatment pathways preserve, improve, or compromise patient experience. The objective of this article is to propose a conceptual framework for the joint longitudinal statistical modeling of orthodontic treatment efficiency and patient-reported outcomes. The framework is designed for future empirical studies that collect repeated clinical and patient-reported measures across active treatment and retention. It emphasizes temporal ordering, repeated measurement, and individual heterogeneity rather than single end-point comparisons. The article positions longitudinal modeling as a methodological bridge between clinical performance and patient-centered evaluation. The framework was developed through a critical synthesis of 26 peer-reviewed articles published between 2017 and 2026 in orthodontics, health services research, patient-reported outcomes, and longitudinal statistical methodology. The synthesis focused on treatment efficiency metrics, patient-reported outcome domains, measurement timing, and modeling approaches suitable for repeated orthodontic data. The article does not present new empirical data. Instead, it defines the conceptual components, analytical logic, and implementation pathway required for future studies. The proposed framework specifies four linked elements: efficiency measurement, patient-reported outcome measurement, longitudinal model specification, and interpretation for patient-centered care. Four tables summarize orthodontic efficiency metrics, patient-reported outcome domains and instruments, longitudinal modeling strategies, and the integrated framework structure. The framework encourages researchers to evaluate whether efficiency gains are accompanied by acceptable pain trajectories, improved aesthetics, and sustained satisfaction. Its adoption may support orthodontic protocols that optimize treatment delivery without reducing the quality of the patient experience.

Keywords: Longitudinal modeling, Orthodontic treatment efficiency, Patient-reported outcomes, Conceptual framework, Mixed-effects, Growth curves

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Introduction

Orthodontic treatment is judged by two interdependent but often separately measured standards: the technical efficiency with which tooth movement and occlusal correction are achieved, and the subjective experience reported by patients during treatment. Evidence on accelerated orthodontic treatment has emphasized treatment speed, biological response, and the strength of available clinical evidence, yet such efficiency-oriented work often leaves patient experience as a secondary concern [1]. Studies comparing clear aligners and fixed appliances also show that effectiveness and efficiency can be framed through appliance performance, predictability, and treatment mechanics [2, 3]. A conceptual framework is needed because efficient care cannot be fully defined without considering the burden of care experienced by patients.

Recent orthodontic literature has expanded attention to treatment duration, appointment frequency, remote monitoring, and appliance-related differences in clinical workflow. Digital monitoring studies suggest that visit schedules and treatment supervision can be reorganized without necessarily relying on traditional appointment patterns alone [4, 5]. At the same time, randomized and observational evidence on Dental Monitoring indicates that efficiency should not be inferred only from reduced visits, because clinical quality, patient adherence, and monitoring intensity must also be interpreted [6, 7]. These developments show that orthodontic efficiency is a multidimensional construct rather than a simple synonym for shorter treatment.

Patient-reported outcomes have also become more visible in orthodontic research, particularly through studies of satisfaction, quality of life, pain, psychosocial impact, and perceived treatment process. Adult orthodontic satisfaction has been linked to expectations, communication, and treatment experience, indicating that patient-centered evaluation requires more than final occlusal assessment [8, 9]. Calls to increase the value of orthodontic research through dental patient-reported outcomes further support the need to embed patient perspectives into study design rather than treating them as optional secondary measures [10]. Longitudinal studies of oral health-related quality of life demonstrate that patient experience changes before, during, and after treatment, making repeated measurement central to interpretation [11, 12].

This article proposes a conceptual framework that integrates orthodontic treatment efficiency and patient-reported outcomes within a single longitudinal statistical structure. The framework builds on evidence from efficiency-oriented orthodontics, patient-reported outcome research, and accessible longitudinal modeling principles for repeated data [13, 14]. It first defines efficiency metrics, then reviews patient-reported outcome domains, and finally explains how longitudinal models can connect these domains over time. The purpose is to guide future empirical research toward testable, patient-centered analyses of how efficient orthodontic care is delivered and experienced.

Orthodontic treatment efficiency: concepts and metrics

Orthodontic treatment efficiency refers to the relationship between clinical progress and the time, visits, resources, and patient effort required to achieve that progress. In orthodontic trials and reviews, efficiency has commonly been operationalized through total treatment duration, appointment number, rate of alignment, or reduction in chairside burden [1, 15]. Clear aligner research has also emphasized the predictability and accuracy of planned tooth movements as clinically meaningful dimensions of efficiency [16, 17]. These indicators are useful, but they do not fully capture the temporal pathway by which treatment progresses.

Treatment duration is the most visible efficiency metric, yet it can be misleading when interpreted without context. A shorter treatment period may reflect favorable case selection, patient compliance, appliance type, or clinician protocol rather than intrinsically superior efficiency [2, 3]. Surgical adjuncts such as corticotomy have been evaluated as methods to accelerate treatment, but systematic review evidence shows that acceleration must be weighed against invasiveness, evidence quality, and clinical applicability [18]. Therefore, duration should be interpreted alongside biological, behavioral, and clinical process indicators.

The number of appointments and the interval between appointments are increasingly important because orthodontic care is affected by digital workflows and remote monitoring systems [19, 20]. Dental Monitoring studies suggest that some patients may require fewer in-person visits when monitoring is supported by digital assessment and structured communication [4, 5]. However, evidence comparing monitored and conventionally monitored care indicates that reduced appointment frequency should be evaluated together with clinical outcomes such as PAR scores and refinement needs [6, 7]. Visit-related metrics are therefore best understood as process variables that may influence both efficiency and patient experience.

Rate of tooth movement and progress toward planned correction offer a more dynamic view of efficiency than total duration alone. Clear aligner studies have examined the efficacy of prescribed tooth movements, highlighting that different movements may vary in predictability and require refinements or additional aligners [16, 17]. Reviews of clear aligner effectiveness similarly show that appliance efficiency depends on the type of movement, clinical complexity, and outcome definition used [2]. For longitudinal research, rate-based metrics should be measured repeatedly so that early acceleration, mid-treatment stagnation, and late refinement phases can be distinguished.

Standardized reporting is necessary because efficiency metrics vary across studies and are often reported as isolated endpoints rather than longitudinal processes. Research on adjunctive interventions and remote monitoring shows that efficiency claims may differ depending on whether the outcome is treatment duration, visit count, alignment accuracy, or patient burden [15, 21]. **Table 1** summarizes common metrics of orthodontic treatment efficiency and their operational definitions. Such standardization would allow future studies to compare treatment protocols while preserving the temporal structure of orthodontic care.

Table 1. Metrics of Orthodontic Treatment Efficiency: Definitions, Measurement Methods, and Data Sources

Efficiency metric	Operational definition	Measurement method	Primary data source	Conceptual relevance
Total treatment duration	Time from appliance placement or aligner start to debonding, final aligner, or active treatment completion	Calendar-based calculation in months or weeks	Clinical records and appointment logs	Captures overall treatment speed but may be confounded by case complexity and compliance
Number of appointments	Total count of in-person or virtual treatment contacts during active care	Count of scheduled and completed visits	Appointment system, electronic records, remote monitoring platform	Indicates service intensity and patient time burden
Appointment interval	Time between consecutive clinical or monitoring encounters	Days or weeks between visit dates	Appointment logs and remote monitoring timestamps	Reflects treatment supervision rhythm and potential access burden
Rate of tooth movement	Amount of planned or achieved tooth movement per unit time	Digital models, aligner staging records, cephalometric or intraoral scan comparisons	Digital treatment plans, scans, clinical measurements	Provides a dynamic estimate of biological and mechanical progress
Refinement or retreatment burden	Need for additional aligners, appliance adjustments, or extended finishing	Count and timing of refinements or additional phases	Clinical records and treatment planning software	Indicates whether apparent efficiency is offset by correction instability or incomplete movement
Chairside or monitoring burden	Clinical time required for adjustment, supervision, or remote review	Appointment duration, clinician time, monitoring review frequency	Practice management data and digital monitoring logs	Connects efficiency to resource utilization and workflow design
Efficiency-adjusted outcome quality	Clinical result achieved relative to time, visits, or treatment burden	Ratio or model-based index combining outcome score with process metrics	PAR, ABO, clinical records, appointment data	Supports integrated comparison of speed and quality

Patient-reported outcomes: domains and measurement

Patient-reported outcomes in orthodontics capture aspects of care that cannot be fully inferred from occlusal indices or appliance mechanics. Pain, discomfort, speech difficulty, chewing limitation, aesthetics, self-confidence, social interaction, and satisfaction are all central to how patients evaluate treatment. Studies of adult orthodontic patients show that satisfaction is influenced by the process of treatment as well as by final appearance and function [8, 9]. This supports the view that patient-reported outcomes should be treated as core endpoints in orthodontic research.

Pain and discomfort are among the earliest and most fluctuating patient-reported experiences during orthodontic treatment. Prospective clinical evidence comparing conventional, low-friction, lingual, and aligner appliances shows that pain and oral health-related quality of life can vary during the initial treatment phase [22]. Appliance-related quality-of-life studies similarly suggest that vestibular, lingual, and aligner approaches may affect adult patients differently during early adaptation [23]. These findings indicate that the timing of measurement is essential because patient burden is not constant across treatment.

Aesthetic and psychosocial outcomes are particularly important because many orthodontic patients seek treatment to improve appearance, confidence, and social well-being. Longitudinal studies have shown that oral health-related quality of life and self-esteem can change before, during, and after treatment in children and adolescents [12, 24]. A 3-year prospective cohort study using the Malocclusion Impact Questionnaire further demonstrates that orthodontic treatment effects can be evaluated through condition-specific patient-reported instruments over time [25]. These studies justify repeated assessments rather than single post-treatment satisfaction surveys.

Measurement instruments must be selected according to the conceptual domain being studied. The OHIP-14 captures broader oral health-related quality of life, whereas orthodontic-specific measures such as the Malocclusion Impact Questionnaire and Orthodontic Treatment Impact Questionnaire focus more directly on malocclusion and treatment-related impacts [25, 26]. Patient-reported experience measures also assess communication, information, and perceived service quality, which are relevant when efficiency strategies change the frequency or mode of contact [13, 27]. Instrument selection should therefore match the hypothesized pathway between efficiency and experience.

The proposed framework treats patient-reported outcomes as longitudinal trajectories rather than isolated judgments. Evidence on patient-reported experience and outcomes in orthodontics supports repeated collection of both outcome and experience measures so that changes during care can be interpreted alongside clinical progress [13]. **Table 2** categorizes the key domains of patient-reported outcomes in orthodontics and their associated instruments. This classification helps researchers align measurement tools with pain, function, aesthetics, psychosocial well-being, satisfaction, and care-process domains.

Table 2. Domains and Instruments for Patient-Reported Outcomes in Orthodontic Treatment

Patient-reported domain	What the domain captures	Common instruments or scales	Recommended timing	Role in the framework
Pain and discomfort	Intensity, duration, and perceived burden of pain after appliance activation or aligner change	Visual analog scales, numeric rating scales, pain diaries	Baseline, early activation, post-adjustment, periodic follow-up	Detects whether faster movement or wider appointment intervals increase short-term burden
Oral function	Chewing, speech, swallowing, and daily oral comfort	OHIP-14, condition-specific questionnaires, functional items	Baseline, early treatment, mid-treatment, debond, retention	Links appliance type and treatment phase to daily functional experience
Aesthetic perception	Perceived dental appearance and satisfaction with visible change	PIDAQ, Malocclusion Impact Questionnaire, aesthetic satisfaction items	Baseline, alignment phase, finishing, post-treatment	Evaluates whether visible improvement mediates satisfaction and adherence
Psychosocial impact	Self-esteem, social confidence, embarrassment, and emotional well-being	PIDAQ, self-esteem measures, orthodontic quality-of-life instruments	Baseline, mid-treatment, post-treatment, retention	Captures broader patient-centered value beyond clinical correction
Treatment satisfaction	Satisfaction with outcome, process, communication, convenience, and expectations	Satisfaction questionnaires, patient-reported experience measures	Mid-treatment, debond, retention	Assesses whether efficient protocols remain acceptable to patients
Care-process experience	Perceived access, communication, monitoring, information,	PROM/PREM surveys, structured experience questionnaires	Throughout treatment and after workflow changes	Connects appointment design and remote monitoring to patient-centered service quality

	and involvement in decisions				

Longitudinal statistical models for orthodontic data

Longitudinal orthodontic data are characterized by repeated observations collected from the same patient across biologically and clinically distinct treatment phases. This structure is visible in studies that follow oral health-related quality of life before, during, and after orthodontic treatment, where individual trajectories may differ from average group change [11, 12]. The repeated nature of these data violates the independence assumption of simple cross-sectional comparisons. Linear mixed-effects modeling is therefore useful because it allows researchers to estimate average change while accounting for patient-specific deviations [14].

Mixed-effects models can represent both fixed effects, such as appliance type or monitoring protocol, and random effects, such as individual differences in baseline pain or rate of improvement. In orthodontic applications, this structure is well suited to patient-reported pain and quality-of-life outcomes that change after appliance activation, aligner initiation, or treatment adjustment [22, 23]. The model can also include clinical efficiency indicators as predictors of patient-reported outcome trajectories. For example, appointment interval or movement rate may be modeled as covariates associated with changes in pain or satisfaction.

Growth curve models extend this logic by emphasizing the shape of change over time rather than only the difference between two measurement points. Longitudinal orthodontic studies of quality of life and self-esteem demonstrate that patient-centered outcomes may improve, decline, or fluctuate depending on treatment phase [11, 12, 24]. A growth curve approach allows investigators to estimate intercepts, slopes, and nonlinear changes across baseline, active treatment, debonding, and retention. This is particularly relevant when aesthetic satisfaction improves early while discomfort may remain elevated during active adjustment.

Latent class trajectory analysis can be used when researchers expect that patients follow distinct patterns rather than a single average trajectory. In orthodontic care, one group may show rapid improvement in appearance and satisfaction, whereas another may report persistent pain or slower psychosocial benefit despite clinical progress [25]. Such modeling can identify subgroups that require different communication, monitoring, or appointment strategies. When linked to efficiency metrics, latent trajectories can show whether faster care benefits all patients equally or only selected groups.

Longitudinal orthodontic datasets often include irregular visit intervals, missed appointments, incomplete patient-reported questionnaires, and treatment extensions. Remote monitoring and clear aligner studies make this issue especially important because digital review schedules may not match conventional in-person appointment timing [4-7]. **Table 3** describes the longitudinal statistical models applicable to orthodontic efficiency and patient-reported data. These models provide a methodological foundation for handling repeated observations, unequal follow-up intervals, and patient-specific variability [14].

Table 3. Longitudinal Statistical Models for Orthodontic Research: Assumptions, Applications, and Data Requirements

Model type	**Core assumption**	**Orthodontic application**	**Efficiency variables that can be included**	**Patient-reported outcomes that can be modeled**	**Data requirements**
Linear mixed-effects model	Repeated observations are nested within patients, and individuals may differ in baseline level and rate of change	Modeling repeated pain, satisfaction, or quality-of-life scores over treatment	Treatment duration to date, appointment interval, visit count, appliance phase, monitoring protocol	Pain scores, OHIP-14, satisfaction, PIDAQ, treatment experience	At least three repeated observations per patient, visit dates, outcome measures, patient identifiers
Generalized mixed-effects model	Outcome distribution may be non-normal, binary, ordinal, or count-based	Modeling high pain versus low pain, missed visits, or satisfaction categories	Number of visits, refinement occurrence, monitoring frequency, appliance type	Ordinal satisfaction, binary adverse experience, categorical quality-of-life change	Repeated categorical or count outcomes with appropriate link functions

Growth curve model	Change follows an estimable trajectory that may be linear, nonlinear, or phase-specific	Estimating baseline status and slope of improvement during alignment, finishing, and retention	Time since treatment start, rate of tooth movement, alignment phase duration	Aesthetic satisfaction, psychosocial impact, oral function	Multiple time points with consistent timing or modeled time scale
Latent class trajectory model	Patients may belong to unobserved subgroups with distinct longitudinal patterns	Identifying groups with rapid adaptation, persistent discomfort, or delayed satisfaction	Early alignment speed, visit burden, refinement need, total treatment duration	Pain trajectories, satisfaction trajectories, psychosocial response	Large enough sample to estimate trajectory classes and validate class membership
Time-varying covariate model	Predictors and outcomes both change across time and can be linked dynamically	Testing whether changing appointment intervals or progress rates predict subsequent patient experience	Current movement rate, current appointment interval, cumulative visits, phase-specific efficiency	Pain, function, perceived convenience, satisfaction	Repeated clinical and patient-reported measures aligned by date
Joint modeling approach	Two or more longitudinal processes may be statistically related over time	Simultaneously modeling clinical efficiency progression and patient-reported outcome change	Efficiency trajectory as a linked process rather than a single covariate	Pain, aesthetics, satisfaction, quality of life	Dense longitudinal data with synchronized clinical and patient-reported assessments

Integration of efficiency and patient experience

The conceptual integration of efficiency and patient experience begins with recognizing that neither domain is complete on its own. Evidence on accelerated orthodontics shows that faster treatment remains clinically meaningful only when the evidence base, biological plausibility, and patient burden are considered together [1]. Similarly, satisfaction studies show that patients evaluate not only final alignment but also communication, convenience, discomfort, and expectations during care [8, 9]. Patient-reported outcome scholarship therefore supports treating experience as a central dimension of orthodontic value rather than a secondary endpoint [10].

Efficiency metrics can be incorporated into longitudinal models as time-invariant or time-varying predictors of patient-reported outcomes. Appliance type, baseline malocclusion complexity, or remote monitoring allocation may function as time-invariant variables, whereas appointment interval, cumulative visits, refinement status, and movement progress may change during treatment [4, 5]. Pain and quality-of-life studies indicate that patient experience is most sensitive during early appliance adaptation, making temporal alignment between efficiency indicators and patient-reported assessments essential [22, 23]. This approach allows researchers to ask not only whether treatment was faster, but also when efficiency gains were comfortable or burdensome.

Existing research has attempted partial integration by examining remote monitoring, treatment quality, patient perspectives, and satisfaction within the same clinical setting. Dental Monitoring studies have evaluated appointment reduction and clinical outcomes, while patient-reported experience studies have emphasized how patients perceive orthodontic care processes [6, 7, 13]. Recent work linking patient satisfaction with objective grading systems also illustrates the need to interpret technical outcomes and patient judgments together [28]. However, these studies generally stop short of a fully longitudinal joint model that estimates reciprocal changes over time.

Patient feedback can also inform efficiency targets by identifying the level of treatment acceleration or appointment reduction that remains acceptable. Survey-based research on PROMs and PREMs indicates that orthodontic outcome assessment can include both health impact and experience of care [27]. Longitudinal studies of malocclusion impact and oral health-related quality of life show that benefits may emerge gradually rather than immediately [12, 25]. An integrated framework should therefore treat efficiency as patient-centered only when it improves care delivery without worsening pain, function, psychosocial well-being, or satisfaction.

Proposed conceptual framework

The proposed framework begins with synchronized data collection across clinical and patient-reported domains. At baseline, researchers should record malocclusion characteristics, appliance type, treatment plan, expected duration, and patient-reported pain, aesthetics, psychosocial impact, and satisfaction. During treatment, efficiency indicators such as visit count, appointment interval, movement progress, refinement need, and treatment phase should be recorded alongside repeated patient-reported outcomes [2, 16, 17]. Follow-up after active treatment is important because quality-of-life studies show that patient benefit may continue into retention or post-treatment evaluation [11, 12].

The second component is model specification, where efficiency metrics are translated into variables suitable for longitudinal analysis. Total treatment duration can be modeled as a final endpoint, whereas appointment interval, cumulative visit count, and progress rate can be modeled as time-varying covariates [14]. Studies of adjunctive acceleration and monitoring systems show that efficiency interventions may operate differently across biological, clinical, and workflow pathways [15, 21]. The framework therefore recommends models that can distinguish baseline complexity, treatment phase, clinician protocol, and patient response [29].

The third component is interpretation of trajectories and trade-offs. An intervention may reduce visits but increase refinement burden, or it may shorten alignment time while causing temporary discomfort. Evidence comparing appliance systems and accelerated approaches suggests that clinical efficiency cannot be interpreted independently of predictability, invasiveness, and quality of final outcome [3, 18]. Patient satisfaction studies further show that a technically successful result may not produce optimal patient experience if expectations, communication, or treatment burden are poorly managed [8, 9].

The visual logic of the framework can be described as a left-to-right process moving from multidomain baseline assessment to repeated treatment-phase measurement, longitudinal modeling, interpretation, and patient-centered decision support. Clinical efficiency data and patient-reported outcomes enter the model as parallel streams, but they are analyzed as interacting trajectories rather than isolated endpoints. Patient-reported experience measures provide an additional feedback layer because communication, access, and monitoring quality may modify the relationship between efficiency and satisfaction [13, 27]. In this structure, the framework becomes both an analytical guide and a design template for future orthodontic studies.

Figure 1 illustrates the proposed longitudinal conceptual framework linking orthodontic treatment efficiency, patient-reported outcome trajectories, statistical modeling, and patient-centered decision support.

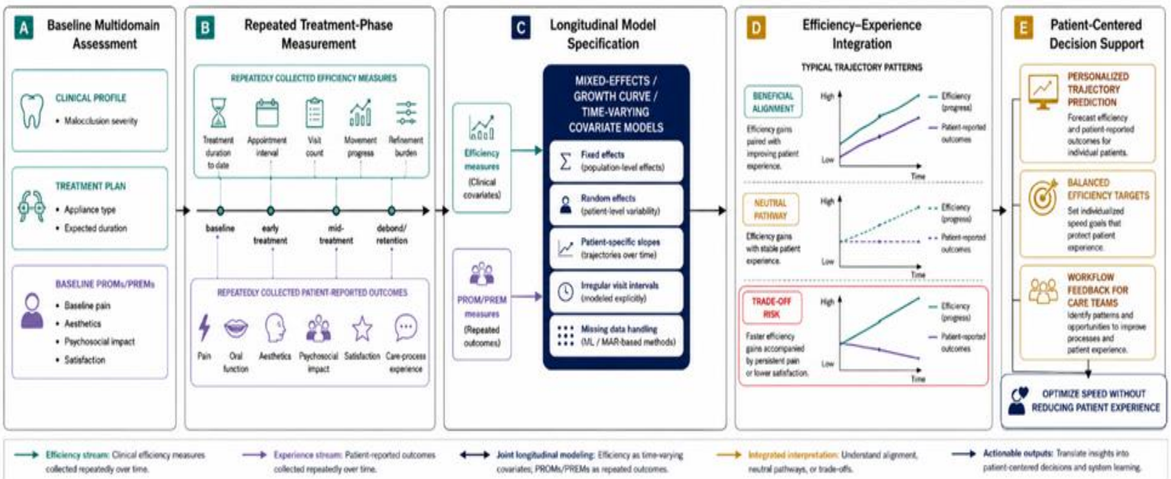

Figure 1. Integrated Longitudinal Conceptual Framework for Modeling Orthodontic Treatment Efficiency and Patient-Reported Outcomes

The final component is translation into research and care decisions. The framework can support estimation of whether faster alignment predicts earlier aesthetic satisfaction, whether wider appointment intervals affect reassurance or anxiety, and whether fewer visits reduce burden without weakening perceived care quality [4, 6]. **Table 4** presents the proposed conceptual framework linking efficiency metrics, patient-reported outcome trajectories, and analytical components. This table organizes the framework into measurable domains, model roles, and interpretive outputs for future patient-centered orthodontic research.

Table 4. Conceptual Framework for Integrated Longitudinal Analysis of Orthodontic Efficiency and Patient-Reported Outcomes

Framework component	Required measures	Longitudinal role	Analytical strategy	Expected interpretive output
Baseline patient and clinical profile	Age, sex, malocclusion severity, appliance type, treatment plan, baseline PROMs	Defines starting condition and potential confounding	Fixed covariates and baseline adjustment	Identification of patient and case factors shaping efficiency and experience
Efficiency process stream	Treatment duration to date, visit count, appointment interval, movement progress, refinement need	Captures treatment delivery over time	Time-varying covariates, growth curves, mixed-effects models	Estimation of how treatment speed and service intensity change across phases
Patient-reported outcome stream	Pain, oral function, aesthetics, psychosocial impact, satisfaction, treatment experience	Captures patient experience over time	Repeated PROM/PREM models and trajectory analysis	Estimation of average and patient-specific experience trajectories
Integration layer	Interaction between efficiency metrics and patient-reported trajectories	Links clinical process with subjective response	Joint models, interaction terms, mediation logic, latent trajectory classes	Identification of beneficial, neutral, or harmful efficiency–experience patterns
Interpretation layer	Model estimates, predicted trajectories, subgroup profiles, uncertainty intervals	Converts statistical output into clinical meaning	Prediction, subgroup analysis, sensitivity analysis	Patient-centered evidence on when efficiency supports or compromises experience
Implementation layer	Data collection schedule, reporting standards, clinical feedback mechanisms	Embeds framework into research and practice	Prospective cohort design, multicenter registries, digital monitoring integration	Standardized evidence for patient-centered orthodontic treatment planning

Research propositions and future directions

The framework generates testable propositions for future empirical research. First, faster initial alignment rate may be associated with steeper improvement in aesthetic satisfaction but a slower decline in pain scores during early treatment. This proposition is supported conceptually by studies showing both appliance-related early discomfort and longitudinal improvement in oral health-related quality of life [11, 22, 23]. Future studies should test this proposition using repeated pain and aesthetic measures aligned with objective progress indicators.

A second proposition is that reduced appointment frequency improves perceived convenience only when patients receive adequate monitoring, communication, and reassurance. Dental Monitoring studies suggest that remote supervision can change the structure of care, but its value depends on how clinical outcomes and patient perspectives are measured together [4-6] [30-32]. Patient-reported experience research further indicates that the process of care is itself an outcome domain [13, 27]. Therefore, fewer visits should not automatically be interpreted as patient-centered efficiency.

A third proposition is that treatment efficiency has nonlinear effects on satisfaction. Moderate efficiency gains may increase satisfaction by reducing burden, whereas overly compressed or poorly communicated treatment may increase discomfort, anxiety, or perceived loss of support. Adult satisfaction studies and evidence linking patient satisfaction with objective grading systems indicate that final technical quality and subjective experience may not always move in parallel [8, 9, 28]. Future models should therefore include interaction terms and nonlinear functions rather than assuming that faster treatment is always better.

Figure 2 presents testable longitudinal propositions showing how orthodontic efficiency indicators may interact with pain, aesthetic satisfaction, and overall treatment satisfaction over time.

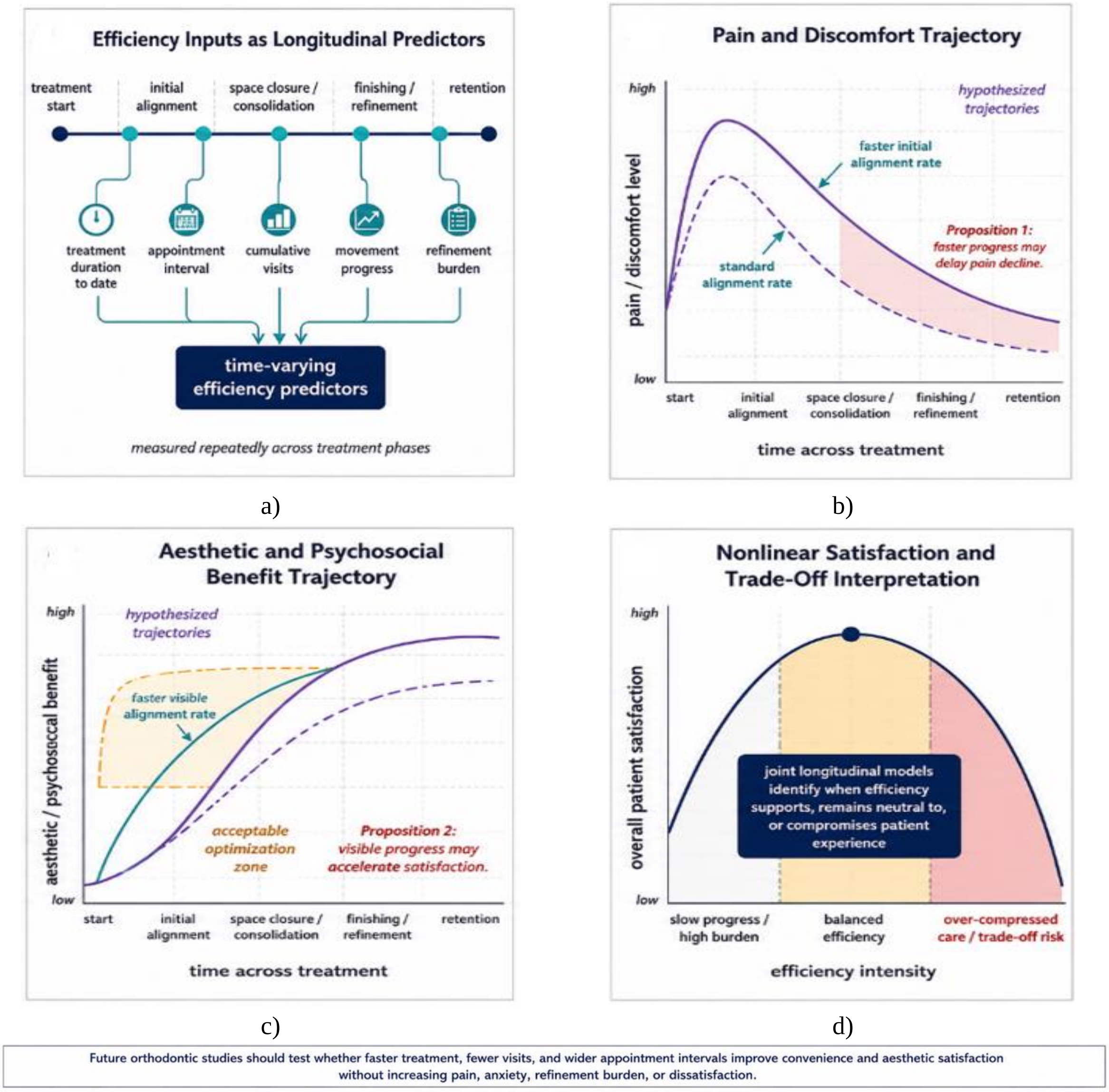

Figure 2. Testable Longitudinal Propositions for Efficiency–Experience Trade-Offs in Orthodontic Treatment

Future research should develop standardized efficiency metrics and embed them within multicenter longitudinal datasets. Systematic reviews of clear aligner effectiveness, adjunctive acceleration, and monitoring highlight that heterogeneous outcome definitions limit comparability across studies [2, 15, 21]. Prospective cohorts should collect synchronized clinical, workflow, and patient-reported data across baseline, early treatment, mid-treatment, debonding, and retention. Such datasets would allow researchers to estimate not only average effects but also personalized predictions for patients with different clinical profiles and experience trajectories [14, 25].

Conclusion

This conceptual framework bridges two research streams that have often developed separately in orthodontics: clinical efficiency and patient-reported outcomes. By placing treatment duration, visits, appointment intervals, and movement progress in the same longitudinal structure as pain, aesthetics, psychosocial impact, and satisfaction, the framework supports a more complete definition of orthodontic value. It encourages future studies to evaluate not only whether treatment is faster, but whether it remains acceptable, comfortable, and meaningful for patients.

A patient-centered approach to orthodontic care requires attention to the dynamic interplay between what clinicians measure and what patients experience. Efficient treatment should not be judged only by shorter duration or fewer appointments if these gains are accompanied by greater discomfort, anxiety, or dissatisfaction. Conversely, patient-reported improvements can help identify when efficient protocols are truly beneficial because they reduce burden while preserving or improving quality of life. The framework therefore treats clinical and experiential outcomes as mutually informative rather than competing priorities.

Future orthodontic research should adopt integrated longitudinal designs that collect repeated clinical and patient-reported data across the full course of care. Such designs can generate evidence for individualized treatment planning, more transparent communication, and balanced evaluation of emerging technologies such as remote monitoring and aligner-based workflows. The proposed framework offers a structured guide for designing those studies and interpreting their results. Its broader contribution is to move orthodontic outcome assessment toward a model in which efficiency and patient experience are optimized together.

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