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Speed limits to orthodontic treatment: a review

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Abstract

Orthodontic treatment aims to improve smile aesthetics and dental occlusion. However, the relatively long duration of treatment often prevents individuals from seeking the benefits of orthodontic treatment. Accurate prediction of the duration of orthodontic treatment is not always successful, as over 50% of the variation is unexplained by pre-treatment characteristics. In clinical practice, it is observed that tooth movement in response to identical force application varies considerably between individuals. Age, sex, characteristics of the malocclusion, treatment plan and type of appliance used are some of the factors that influence orthodontic treatment duration. Shortening the duration of orthodontic treatment would be beneficial for both orthodontist and patient, as it may reduce the likelihood of treatment related complications such as root resorption, gingival recession and white spot lesions. Additional benefits include reduced financial burden avoiding prolonged modifications to lifestyle such as eating habits. Recently, several approaches have been advocated to accelerate the rate of tooth movement and thereby shorten the duration of orthodontic treatment. This includes invasive surgical approaches and non-invasive strategies such as the use of vibration, low energy lasers, and pharmacological agents to speed up tooth movement.

Aim of this article is to review and critically appraise the scientific evidence behind factors influencing orthodontic treatment time. These include socio-demographic variables, malocclusion characteristics, and factors related to treatment, patient and orthodontist. We have also briefly highlighted the current status of new appliances, surgical and non-surgical adjunctive procedures attempting to increase the speed of tooth movement. The conclusion of this review clearly indicates that at the moment, acceleration of tooth movement remains an exciting field for further research, but with very limited clinical applications.

Introduction

Treatment time in orthodontics is a key factor that deters many subjects from seeking the benefits orthodontic treatment has to offer (Fatih *et al,* 2016). Often, the first question that a patient seeking orthodontic treatment asks pertains to the expected duration of treatment. Providing an accurate estimate of treatment duration ranks high in patients recommendation for orthodontists (O'Connor, 2000) and is an important factor for patient satisfaction (Pachêco-Pereira *et al,* 2015). Evidence suggests that average treatment time lasts over 20 months (range 14-33 months) (Fig 1) (Tsichlaki *et al,* 2016). Although treatment time can be reasonably estimated using clinical judgment, over 50% of its variation is unexplained by pre-treatment characteristics (Robb *et al,* 1998). Also, large inter-individual variations in the rate of tooth movement, regardless of force magnitude and modality, have been demonstrated in both animal (Pilon *et al,* 1996) and human studies (Giannopoulou *et al,* 2016).

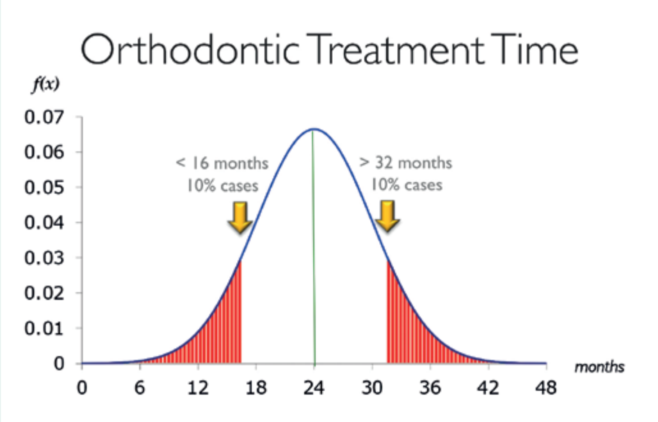

Figure 1. Gaussian curve[a] depicting orthodontic treatment time (in months). Treatment time follows a normal distribution (SD = 6 months).

[a] Data for the graph obtained from *Skidmore, KJ et al AJO DO (2006).*

Shortening treatment time is priority for both orthodontists and patients (Uribe *et al,* 2014), as it can potentially diminish cost (Jarvinen & Widstrom, 2002), reduce impact on lifestyle modifications, and also lessen the likelihood of orthodontic treatment complications such as root resorption (Brezniak & Wasserstein, 1993; Segal *et al,* 2004), gingival recession (McComb, 1994) and enamel decalcification (Khalaf, 2014). Duration of orthodontic treatment varies considerably depending on multiple factors (Mavreas & Athanasiou, 2008) with certain scenarios, such as multiple treatment stages, orthognathic surgery, sagittal occlusal correction, impacted canines and poor compliance, significantly adding to treatment time (Becker & Chaushu, 2003; O'Brien *et al,* 2009; Vig *et al,* 1998).

Predictive factors for treatment duration

Sociodemographic factors

These include age, sex, and psychosocial factors.

Understanding how age influences orthodontic treatment time is paramount as nowadays an increasing number of adults seek orthodontic treatment ("Increase in adults seeking orthodontic treatment," 2020; Nattrass & Sandy, 1995). Conflicting results have been reported in literature with regard to the association of chronologic age on treatment time. Some studies have reported that chronological age is not significantly associated with treatment time (Beckwith *et al,* 1999; Fink & Smith, 1992) whereas others have reported the opposite (Vig *et al,* 1998; Vig *et al,* 1990). A recent systematic review concluded that existing evidence does not indicate a difference in the overall duration of treatment with fixed appliances between adults and adolescents whilst adding a word of caution about the low confidence in the estimates due to the risk of bias in the included studies (Abbing *et al,* 2020). Interestingly, dental age, rather than chronologic age at treatment commencement has been suggested as a factor that might affect treatment time (Gianelly, 1995; von Bremen & Pancherz, 2002).

The possible effects of age on orthodontic treatment time may be explained by age-related changes in the biologic response to applied orthodontic force (Norton, 1988), but also by the level of patient cooperation across different age groups (Sinha & Nanda, 2000).

The influence of bone and periodontal ligament metabolism on orthodontic tooth movement is particularly important in adult patients. Bone turnover rates and periodontal status of middle aged and older adult patients are different from adolescents. Morphologically, alveolar bone gradually increases in density and the periodontal ligament becomes more fibrotic as age progresses (Graber *et al,* 2012; Tanne *et al,* 1998). In addition to the morphologic changes, on a cellular level, the levels of proliferation and differentiation of alveolar bone and periodontal ligament cells also diminish with advancing age (Ong *et al,* 1998). On a molecular level, adults have shown to have significantly higher levels of cytokine and osteoclastic activity but, counterintuitively, a significantly slower rate of tooth movement (Alikhani *et al,* 2018). Adolescent and adult subjects also show differences in the genetic expression of inflammatory mediators from the periodontal ligament cells in response to orthodontic force (George *et al,* 2020).

Age is also associated with patient cooperation with younger patients being deemed more cooperative than older ones (Allan & Hodgson, 1968; McDonald, 1973). On the other hand, literature also concludes that adults seeking treatment can be excellent patients with high co-operation (Nattrass & Sandy, 1995).

Gender can influence treatment time, with longer treatments commonly and consistently (Allan & Hodgson, 1968; Clemmer & Hayes, 1979; Kreit *et al,* 1968; McDonald, 1973; Starnbach & Kaplan, 1975; Swetlik, 1978) reported for the male gender. Male gender was found to add an additional 1-2 months to overall treatment duration (Skidmore *et al,* 2006). Missed orthodontic appointments were also found to be higher for males (Lindauer *et al,* 2009). Conversely, only one study reported no significant effect of gender as a predictor of treatment duration (O'Brien et al., 1995) and another even longer treatment duration in female subjects (Zahran *et al,* 2018). In female subjects, synchronising orthodontic force application during the menstrual period has been shown to lead to more rapid tooth movement than in the ovulation period (Deng & Guo, 2020). Interestingly, pregnancy in animal models has shown to be associated with faster tooth movement (Hellsing & Hammarstrom, 1991). However, it is remains unclear if the hormonal effects in female subjects have any effect on the orthodontic treatment duration.

Estimating the duration of orthodontic treatment begins at the pre-treatment stage and research has looked at predicting orthodontic treatment duration based on the socioeconomic factors (parental occupation, education and employment status). However, the relationship between socioeconomic factors and treatment time remains unclear with no consensus on whether a lower socioeconomic status is associated with a longer or shorter treatment time (Egolf *et al,* 1990; Graber *et al,* 2012; Starnbach & Kaplan, 1975; Turbill *et al,* 2001). Two recent research studies with a specific focus on socioeconomic factors and treatment duration found no statistically significant association (Fisher *et al,* 2010; Nakhleh *et al,* 2020).

Recent research that looked at psychosocial factors such as child resiliency, parental emotional support, and level of control/discipline established the distinct role of maternal emotional support compared to that of the father in predicting treatment duration. Adolescents with high levels of maternal emotional support were more likely to complete treatment faster (by up to 4 months) compared to those with low levels of maternal support (Nakhleh *et al,* 2020). It is important to be bear in mind that adolescents unlike adults are less independent in decision making.

Malocclusion characteristics

Severity of the presenting malocclusion adds to treatment duration (O'Brien *et al,* 1995; Skidmore *et al,* 2006). An increase in treatment duration with a starting index of orthodontic treatment need (IOTN) of grade 5 has reported in literature (Turbill *et al,* 2001; Zahran *et al,* 2018). Often, adults with severe malocclusions are candidates for orthognathic surgical correction since there is no remaining growth. Retrospective research has indicated a mean duration of approximately 2 years for treatment involving orthognathic surgical correction (Dowling *et al,* 1999). Prospective research on the other hand has suggested that overall treatment time may be longer than 2 years on average with orthognathic surgical correction (O'Brien *et al,* 2009).

Class I malocclusions (Zahran *et al,* 2018), a large overjet as well as Class II division1 and Class II division 2 malocclusions have been linked to lengthening of orthodontic treatment time (Taylor *et al,* 1996; Vig *et al,* 1998) (Table 1).

Orthodontic treatment of impacted canines is challenging and duration of treatment is variable and extended (Abbing *et al,* 2020). Average treatment duration of almost 29 months has been reported to align an impacted canine prior to commencing finishing procedures (Iramaneerat, *et al,* 1998). Initial alignment of palatally impacted canines was found to take significantly longer than labially impacted canines (8.9 versus 4.2 months)(Cassina *et al,* 2018) Orthodontic correction of unilateral and bilateral palatal canine impactions

Table 1. Additional time for orthodontic treatment added by malocclusion characteristics, patient related and operator related factors

Authors / Journal	Factor	Anticipated impact in additional treatment time (months)
Malocclusion characteristics		
O'Brien et al. AJODO, 1995 Skidmore et al. AJODO, 2006	Severity of malocclusion	1.3 to 3.3
Vig et al. AJODO, 1990	Class II division 2	4.5
Robb et al. AJODO, 1998 Skidmore et al. AJODO, 2006	Large overjet	6 (46% explained variance)
Bazargani et al., Eur J Orthod, 2013	Impacted teeth	7.6 (zone 4-5)
O'Brien et al. AJODO, 1995	Pre-treatment PAR score Additional treatment Stage	Not stated Not stated
Skidmore et al. AJODO, 2006	3mm crowding Class II molars ANB > 6° Deep overbite (>5mm)	2.3 to 2.8 2.6 1.3 3.3
von Bremen et al. AJODO, 2002	Dental development (late mixed dentition verses permanent)	12
Beckwith et al. AJODO, 1999	Additional Treatment Stage	8 months (8% explained variance)
Fink & Smith, AJODO, 1992	Premolar extractions Use of Headgear	0.9 months per tooth Increased
O'Brien et al. AJODO, 1995	Extraction treatment	Not stated
Robb et al. AJODO, 1998	Treatment of buccal occlusion and OJ	46% of variance in stepwise regression
Skidmore et al. AJODO, 2006	Extraction treatment Delayed extractions	3.3 5.9
Turbill et al. Comm Dent Oral Epid, 2001	Appliance type–Fixed (dual or single arch) or removable only Additional treatment stage Extraction treatment (4x premolars) Treatment of buccal occlusion	9 6 9 6
Vig et al. AJODO, 1990	Additional treatment stage Both arch treatment	13 7
Patient cooperation		
Skidmore et al. AJODO, 2006	Poor elastic wear	2.6 to 4.5
Skidmore et al. AJODO, 2006 Beckwith et al. AJODO, 1999	Poor Oral hygiene	2.2 (6% explained variance)
Beckwith et al. AJODO, 1999	Missed appointments Negative oral hygiene chart entries	1 (18% explained variance) 0.6 (6% explained variance)
Fink & Smith, AJODO, 1992	Missed appointments	Increased
O'Brien et al. AJODO, 1995	Missed appointments Number of repairs required	Not stated Not stated
Robb et al. AJODO, 1998	Missed appointments	46% explained variance
Skidmore et al. AJODO, 2006	Poor OH Poor elastic wear Bracket breakages Missed appointments	2.2 2.6 to 4.5 1.5 (3+ breakages) 1.4 to 3
Operator related factors		
Beckwith et al. AJODO, 1999	Recemented brackets/bands	0.5 (13% explained variance)
Skidmore et al. AJODO, 2006	Rebonding > 3 teeth	2.5
Alsaeed SA, AJODO, 2020	More than one orthodontist	Not stated
Turbill et al. Comm Dent Oral Epid, 2001	Qualified Orthodontists	2

has been found to increase treatment duration by approximately 3 months and 10 months, respectively (Stewart *et al,* 2001).

Pre-treatment position of the impacted canine, surgical exposure technique (open or closed), root shape and proximity to cortical plates have been cited in literature as possible factors influencing the duration of forced eruption time.

Literature on the initial position of a palatally impacted maxillary canine and the influence on forced eruption time is conflicting, with some investigations reporting that pre-treatment position influenced forced-eruption times (Fleming *et al,* 2009; Motamedi *et al,* 2009; Power & Short, 1993; Stewart *et al,* 2001), while others report no differences (Grande *et al,* 2006; Zuccati *et al,* 2006).

Overall treatment duration of impacted canines with different types of surgical exposure have also reported conflicting findings, with one study reporting a time saving of 4 months with open exposure (Wisth *et al,* 1976), whilst another described open exposure as taking 4 months longer (Pearson *et al,* 1997) and a further study reporting no difference in treatment duration (Iramaneerat *et al,* 1998). A recent systematic review and meta-analyses reported a mean difference of 2.1 months between open and closed exposure techniques and concluded that open surgical exposure seems to be superior in treatment duration over the closed technique (Cassina *et al,* 2018). Additional surgical intervention at the time of canine exposure using the ostectomy-decortication technique has reported to speed up forced eruption time of palatally impacted canines by a factor of 3.2 times than surgical exposure alone (Ferguson *et al,* 2019). The influence of age on time required for resolving canine impaction is also conflicting. Both increased length of treatment in younger subjects (Stewart *et al,* 2001), and more number of treatment visits and significantly longer treatment duration in adults, for resolving canine impactions (Becker & Chaushu, 2003) have been reported in literature.

A recent retrospective study using 3D cone-beam computed tomography found that treatment duration of impacted maxillary canines with bent roots was longer (by 3.1 months) than canines with normal roots (Amuk *et al,* 2021).The same study found that when impacted canines roots were in proximity to cortical bone, treatment was significantly increased as the initial phase of treatment involved a prolonged period of traction to move the roots away from the cortical plates.

Treatment factors

Treatment-related factors include, the selection of appliance, the number of treatment stages, and biomechanics, amongst others.

An accurate treatment plan is key to minimising undesirable side effects and undue prolonging of orthodontic treatment. With a cognitive application of biomechanics concepts, it is possible to achieve the planned position of the teeth within the dental arches and relative to the underlying skeletal bases, both efficiently and effectively (Nanda, 2015). Biomechanics planning must include careful consideration of the teeth that do not require movement (reactive units) and maximisation of the movement of the active units. During orthodontic appointments the focus should not merely be on reactivation of the forces delivered by the appliance but also on ensuring a proper force system to obtain desired tooth movement. A good management of biomechanics helps to prevent indiscriminate or unnecessary tooth movements, so called “round tripping” and to optimise treatment time. Intuitively, biomechanics has a major impact on orthodontic treatment time, but surprisingly this has been only scarcely investigated in the scientific literature.

The assumption that friction can negatively influence the rate of tooth movements has been often used by manufacturers to promote so-called low-friction “bracket systems”, as an option to reduce treatment time. In particular, self-ligating (SL) brackets have been promoted as having lower friction than traditional brackets. The initial clinical studies on SL brackets supported the finding of shorter treatment times (Eberting *et al,* 2001; Harradine, 2001). However, these studies were retrospective in design and at high risk of bias. More recently, prospective studies comparing SL brackets and conventional brackets failed to identify any statistically or clinically significant difference in treatment time or efficacy (Miles, 2005; Miles *et al,* 2006). Subsequent systematic reviews that combined the evidence from well-designed randomised clinical trials (RCTs) also concluded that there was no difference in treatment time between conventional brackets and SL brackets (Chen *et al,* 2010; Fleming & Johal, 2010). A recent meta-analysis that combined the data from several studies concluded that no clinical recommendation can be made regarding the different ligation modes (Papageorgiou *et al,* 2014). Despite claims about the advantages of SL brackets, duration of treatment with self-ligating brackets is similar to that of conventional brackets and shortened chairside time appears to be the only significant time based advantage of SL systems over conventional systems (Chen *et al,* 2010). It is important to acknowledge that friction itself plays a relatively minor role in the resistance to sliding of teeth, whereas binding and notching may play a more important role (Burrow, 2009). The latter two do not differ between conventional and SL brackets (Thorstenson & Kusy, 2002).

With an increasing number of adults seeking orthodontic treatment, the popularity of esthetic orthodontic appliances including clear aligners and lingual appliances continues to grow. (Auluck, 2013; Rosvall *et al,* 2009) However, differences in treatment details, operator choice and ease with technique make it difficult to compare treatment time between lingual and labial brackets. There is a no randomised clinical trial investigating treatment duration with lingual brackets (Long *et al,* 2013). Nonetheless, low level evidence suggests that the average treatment duration with lingual brackets is similar to that with labial brackets (Mistakidis *et al,* 2016). Custom designed lingual brackets and archwires continue to be advocated with the premise of creating more efficient tooth movement (Khosravi, 2018), with some being slightly "faster" than others. These findings however come from retrospective observations at very high risk of bias (Knosel *et al,* 2014).

The duration of treatment with clear aligner therapy was found to be shorter than conventional edgewise treatment by a mean duration of 5.5 months, possibly due to the software assisted positioning of teeth so that the finishing or detailing phases are not required (Buschang *et al,* 2013) (Ke *et al,* 2019). In terms of treatment duration, a recent systematic review concluded that clear aligner therapy is more efficient than conventional fixed appliances (Zheng *et al,* 2017). However, all the patients included in the meta-analysis were non-extraction cases and when extraction cases were considered, treatment duration with clear aligners was 44% longer (Li *et al,* 2015). Furthermore, aligners appear to be less effective to control root movements and result in a worse treatment outcome than fixed appliance (Papageorgiou *et al,* 2020).

Custom brackets permit the use of preformed archwires with little or no manual wire bending, whereas wire-bending robots produce custom archwires for a particular patient. Both approaches are targeted at reducing the time spent in the finishing and detailing stage.

Brackets–In the early days of customised orthodontic appliances, expert opinion and case reports suggested the possiblity to achieve shorter active orthodontic treatment duration (Weber *et al,* 2013). A retrospective study found that a customised CAD/CAM orthodontic appliance that aims to eliminate wire bending, significantly reduced treatment time in comparison to directly or indirectly bonded conventional brackets (Brown *et al,* 2015). Interestingly, the study attributed more of the decrease to indirect bonding than bracket customisation. Recent studies with more robust designs have concluded that customisation of orthodontic appliances was not significantly associated with reduced treatment duration (Penning *et al,* 2017) (Papakostopoulou & Hurst, 2018).

Wires–In order to reduce the clinical time spent in bending wires, the use of computer controlled machines to shape archwires as desired have been attempted. The same orthodontist using robot formed wires took shorter overall treatment time (mean duration of 9 months) to finish patients than with manual wire bending (Alford *et al,* 2011). However malocclusion severity was lower in the customised wire group and allocation of patients was not randomised.

The number of stages of orthodontic treatment can markedly influence treatment time, but are scarcely relevant to adult orthodontics. Growth modification treatment has been, for instance, is often advocated as adjunctive treatment for the management of skeletal Class II in teenagers with the justification of psychosocial and skeletal change benefits (Fleming, 2017). However, it is well established that starting treatment for Class II in the pre-adolescent stage, increases overall treatment duration as the dentition is still developing and the mandibular growth spurt is yet to begin. The contemporary view is that early treatment for Class II malocclusion cases is no more effective, but less efficient, than later treatment (Proffit, 2006) (Tulloch *et al,* 2004). Similarly, extraoral force (headgear and facemask), expansion appliances, and other treatments with multiple stages have also been linked to longer treatment duration (Beckwith *et al,* 1999; Mandall *et al,* 2016; Turbill *et al,* 2001; Vig *et al,* 1998; Zahran *et al,* 2018).

Extraction of teeth for orthodontic treatment has been positively associated with increased treatment time (Fink & Smith, 1992) and number of appointments (Zahran *et al,* 2018) (Turbill *et al,* 2001). Duration of treatment increases proportionally to the number of teeth extracted, with an additional month of treatment added per extracted premolar (Fink & Smith, 1992). Interestingly, when looking separately at individual orthodontic clinics with varying philosophies regarding extraction and non-extraction treatment, consistently longer treatment lengths for the extraction group over the non-extraction group were reported. However, when the data from the clinics were combined there was no statistical difference in treatment duration, suggesting that the extractions do not necessarily prolong treatment time (Vig *et al,* 1990). The method followed for extraction space closure may also have an influence on treatment time with limited evidence suggesting that two-step closure takes longer than closure *en masse* space closure(Rizk, *et al,* 2018).

Patient cooperation

Patient compliance is a vital ingredient of a successful orthodontic treatment result (Bos, *et al,* 2005). Patient compliance during orthodontic treatment can broadly be viewed in two main areas. One is adherence of patients to treatment recommedations of the orthodontist and includes wearing elastics/removable appliances and avoding food/activities that may damage the orthodontic applicance. Failure of adherence to treatment recommendations can have consequenses on treatment time and progress (Beckwith *et al,* 1999; Skidmore *et al,* 2006). The second area of patient compliance is following oral health recommendations and includes maintaining good oral hygiene and being punctual for appointments.

Compliance with removable intraoral and extroral appliances that require a considerable level of co-operation is often less than required (Brandao *et al,* 2006; Parekh *et al,* 2019) and has been conclusively seen even when objective methods were used to quantify wear time (Bos *et al,* 2007; Huanca *et al,* 2019; Stocker *et al,* 2016). Interestingly, quantifying the wear time of removable appliances during active orthodontic treatment using wearable microelectronics has also been suggested as a possible tool for shorter orthodontic therapy (Schäfer *et al,* 2015).

Patients who exhibit forms of noncompliance, such as lack of headgear or elastics wear and increased appliance breakage are also more likely to exhibit other forms of non compliance such as missed appointments, and poor oral hygiene. Patients who miss orthodontic appointments during active treatment are likely to remain in treatment longer. The number of missed appointments was found to explain 18%-46% of the variation in treatment duration (Becker & Chaushu, 2003; Fink &

Smith, 1992; Robb *et al,* 1998). Missed appointments exhibited a statistically significant correlation with treatment time (Beckwith *et al,* 1999; Zahran *et al,* 2018). Each failed appointment was associated with 1-3 months of additional estimated time in treatment (Beckwith *et al,* 1999). Poor oral hygiene might prolong treatment duration, comprimise enamel and periodontial health, and even jeopardize treatment outcome (Beckwith *et al,* 1999; Skidmore *et al,* 2006).

Studies have demonstrated that active reminders sent by smartphone Apps could slighly (around 7 weeks) but significantly improve appointment attendance, compliance and also reduce tretment duration (Choi *et al,* 2021; Li *et al,* 2016; Zotti *et al,* 2016).

Although, improving patient cooperation can shorten treatment time, making accurate predictions regarding patients cooperation is nearly impossible thereby diminishing the possibility of precisely predicting the duration of orthodontic treatment. Clear communication with adult patients regarding realistic long-term expectations and risk of relapse is also crucial. Effective communication is a key component of orthodontic treatment success (Yao *et al,* 2016). Adult patients must be clearly informed that orthodontic treatment time cannot be accurately predicted, so that unrealistic expectations for the end of active treatment are mitigated and properly managed. It is advisible to leave a relatively broad margin of uncertainty around prediction of treatment time (e.g. ± 6 months).

Operator related factors

Skill level, number of operators and the clinic involved in treatment also seem to play a role in variability of orthodontic treatment duration (Beckwith *et al,* 1999; Fink & Smith, 1992; Vig *et al,* 1990). The key role of the operator in influencing orthodontic treatment duration was stressed in a RCT that failed to show significant advantages of appliance customisation (Penning *et al,* 2017). A retrospective study in a teaching environment (McGuinness & McDonald, 1998) found that change of operator could significantly increase treatment duration by an average of 8.4 months. Longer treatment times were also reported when treatment was performed by two collaborating orthodontists rather than a single orthodontist (Alsaeed *et al,* 2020). Time spent in finishing by individual practitioners has been cited as a reason for the source of variation in treatment time (Fink & Smith,1992) and could also possibly explain why cases treated by orthodontically qualified practitioners averaged nearly 2 months longer than those of general practitioners (Turbill *et al,* 2001). Good finishing, while not critical for oral health and function, is still beneficial. Cases finished to a very high standard still remain better than those finished to a low-level over long term and also have a lesser likelihood of relapsing to their pre-treatment condition.

Adjuncts to accelerate tooth movements

during the past two decades there have been attempts to accelerate tooth movements based on the application of various stimuli to enhance bone turnover associated with orthodontic tooth movements. These attempts include using surgical adjuncts, vibratory stimulation, low-level laser therapy, and pharmacological approaches.

Surgical

Surgical intervention may either supplement routine orthodontic treatment as an adjunctive procedure in an attempt to accelerate tooth movement or be a part of the orthodontic treatment plan in the form of extractions or orthognathic surgery.

The quantity and quality of orthodontic tooth movement is determined by bone turnover rate (Verna *et al,* 2000), with a higher turnover significantly increasing the rate of tooth movement (Engstrom *et al,* 1988; Midgett *et al,* 1981). Frost described the biological mechanisms underlying increased tissue turnover incidental to the magnitude and site of injury in spatial-temporal terms, a phenomenon he termed the regional acceleratory phenomenon (RAP) (Frost, 1989a, 1989b). Orthodontic forces alone are sufficient to elicit a RAP adjacent to the periodontal ligament (Verna *et al,* 1999). However, the level of RAP expression with orthodontic force alone may be considered as mild to moderate. With additional, intentional surgical insult, at selective sites, an enhanced level of RAP is induced resulting in osteopenia in specific regions, consequently enabling faster tooth movement. With this biologic rationale in mind, a range of relatively invasive surgical techniques have been used to expedite orthodontic treatment time. These surgical interventions are undertaken along with fixed mechanotherapy, with the procedure being carried out prior to, or at the start of treatment.

The complexity of surgical manipulation has ranged from therapeutic fractures of the anterior alveolus (Kole, 1959), selective alveolar decortication (Baloul *et al,* 2011), corticotomy (Munoz *et al,* 2020; Wilcko *et al,* 2001), trans mucosal corticision(Charavet *et al,* 2016; Kim *et al,* 2009; Park, 2016), undermining of interseptal bone (Liou & Huang, 1998) to micro-osteoperforations (MOP) (Alikhani *et al,* 2015); with varying degress of success demonstrated by the different techniques in animal models (Librizzi *et al,* 2017).

Interestingly, in human subjects, three separate systematic reviews attempting to answer if a specific type of surgical intervention (MOP) increases the rate of tooth movement reached different conclusions, despite synthesizing evidence from almost the same literature (Fu *et al,* 2019; Shahabee *et al,* 2020; Sivarajan *et al,* 2020). Currently, low-level evidence concludes that surgically facilitated orthodontics can accelerate tooth movement (Fleming *et al,* 2015), but the acceleration is minor and transient (Mheissen *et al,* 2021).The clinical significance of this acceleration is still dubious, and possible side effects are still unclear. The procedures are rather invasive, and more research is needed before these can be recommended in the clinical practice.

Alternatively, when surgery is a part of the treatment plan, the timing and/or sequencing of the surgical intervention can be manipulated to shorten treatment time. For instance, the timing of tooth extractions may be optimised to shorten treatment time. Anecdotal evidence shows that space closure tends to be faster when space closure is commenced immediately after tooth extraction, possibly owing to the reduced bony resistance offered by the newly healing extraction site to tooth movement. A similar phenomenon is observed when teeth are moved through new bone regenerated after interdental distraction osteogenesis (Liou *et al,* 2000).

Traditional orthognathic surgery significantly increases treatment duration (O'Brien *et al,* 2009). However, altered sequencing of procedures, as in the surgery first orthognathic approach (SFOA)(Chng, 2019), has reported to reduce treatment time in both retrospective (Uribe *et al,* 2015) and prospective research (Jeong *et al,* 2016). Unlike the traditional approach, no orthodontic tooth movement is carried out for decompensation in the initial stage of the SFOA. Tooth movement is carried out subsequent to the surgical osteotomies performed for correction of jaw deformities. Studying serum bone formation and resorption markers and correlating with mobility of maxillary and mandibular incisors in the SFOA showed that jaw osteotomies trigger a 3-4-month period of increased osteoclastic activity and metabolic changes in the dentoalveolus post-osteotomies and a corresponding increase in tooth mobility (Chng, 2019). The temporal pattern of gingival crevicular fluid (GCF) bone marker levels suggests that the accelerated tooth movement after osteotomies in the SFOA is possible due to elevated levels of bone remodelling factors with overlapping functions during fracture healing and tooth movement (Zingler *et al,* 2017). In summary, in the SFOA , the biological surge in bone modelling and remodelling activity and associated tooth mobility that happens immediately post-osteotomy is utilised to assist faster tooth movement to facilitate a shorter orthodontic treatment duration (Liou *et al,* 2011) .

Vibration

Vibration is a mechanical stimulus characterised by oscillatory motion. The key aspects in delineating vibration are frequency (indicates the number of complete up and down movement cycles per second; measured in Hz), amplitude (the extent of the oscillatory motion; measured in mm) and direction of the vibration movement. High-frequency, low-magnitude vibration has been applied to teeth with the aim of increasing the rate of orthodontic tooth movement. Research on vibration and orthodontic tooth movement on animal models, in particular, rats has shown an increased rate of tooth movement by accelerating periodontal and bony tissue modelling/remodelling (Darendeliler *et al,* 2007; Nishimura *et al,* 2008). A short term (two months) study in human subjects demonstrated that vibratory stimuli from an electric toothbrush enhanced secretion of IL-1β in GCF and accelerated tooth movement (Leethanakul, *et al,* 2016). Similarly, vibration (50 Hz) from a battery powered flosser applied to maxillary canines during retraction was found to accelerate space closure (Liao *et al,* 2017).

Devices (AcceleDent, Tooth masseur, VPro5) claiming to increase the rate of orthodontic tooth movement, when used as an adjunct to fixed appliance or aligner treatment, are commercially available. One of the first clinical studies that used a commercially available vibration appliance (Tooth Masseuse), at a frequency of 11 Hz on teeth for 20 minutes daily, failed to find any clinical advantage for the early resolution of crowding (Miles *et al,* 2012). However, results from another vibration appliance (OrthoAccel Device), which provided vibrational frequency of 30 Hz for 20 minutes daily showed increased rate of space closure when applied as an adjunct to orthodontic treatment (Pavlin *et al,* 2015). A systematic review that followed concluded that there is insufficient evidence regarding the positive effect of vibration to accelerate tooth movement (El-Angbawi *et al,* 2015). Subsequently several RCTs indicated an absence of evidence that a vibrational stimulus can increase the speed of tooth movement (Miles, 2018; Miles & Fisher, 2016; Miles *et al,* 2018). Similar conclusions have been drawn by two recent systematic reviews (Aljabaa *et al,* 2018; Lyu *et al,* 2019). Likewise, when clear aligner therapy was supplemented with vibration (AcceleDent), there was no evidence that suggested vibration increased the rate of tooth movement (Katchooi *et al,* 2018).

Light based

Animal (Sun *et al,* 2001; Yamaguchi *et al,* 2010) and human studies (Cruz *et al,* 2004; Genc *et al,* 2013; Sousa *et al,* 2011) have demonstrated that low-energy laser radiation can speed up orthodontic tooth movement. On the other hand, there are studies that show no effect of low-energy laser irradiation tooth movement rate (Gama *et al,* 2010; Marquezan *et al,* 2010) with one study even finding the opposite effect (Seifi *et al,* 2007). Lack of uniformity and the different wavelengths of the lasers, irradiation doses, locations, and frequencies used in these studies may account for the discrepancies. The biologic effects of low-energy laser irradiation that have been reported include stimulation of alveolar bone remodelling activities as indicated by the increased numbers and functions of osteoclasts and osteoblasts (Kawasaki & Shimizu, 2000; Sun *et al,* 2001), as well as upregulation of several molecular markers (Yamaguchi *et al,* 2010) and the RANK/RANKL/OPG system (Fujita *et al,* 2008). The non-invasiveness and relative ease of operation make low-level laser irradiation an appealing device for accelerating orthodontic tooth movement. However due to the very weak evidence in support to its effectiveness, and conflicting research findings, it presently cannot be recommended in daily clinical practice (Gkantidis *et al,* 2014).

Pharmacologic agents

Orthodontic tooth movement is a sterile inflammatory process (Kapoor *et al,* 2014). Although there have been several studies that have demonstrated the effect of molecules on speeding up the rate of tooth movement in animal models (Kouskoura *et al,* 2017), limited research has been done on humans. It is difficult to extrapolate the results of animal studies to humans due to differences in periodontal ligament and alveolar bone morphology and physiology.

Prostaglandins are released during the inflammatory process as they stimulate both osteoclasts and osteoblast and consequently have repercussions on tooth movement. Two investigations in humans with a split-mouth design showed significant increases in the rate of palatal premolar movement after multiple local injections of Prostaglandin E_1 (PGE_1) at a dosage of 10 μg (Spielmann *et al,* 1989; Yamasaki *et al,* 1984). Dosing of 1g PGE_1 has also demonstrated an acceleration of the rate of orthodontic tooth movement in human subjects by 1-2 mm per month (Patil *et al,* 2005). These findings are consistent with increased bone resorption in humans (Takahashi *et al,* 2000). However a recent systematic review suggested that the actual effect of PGE_1 had previously been overestimated (Kaklamanos *et al,* 2019).

Platelet rich plasma (PRP) is an autologous concentration of platelets in a minute volume of plasma (Rodrigues *et al,* 2012) that contains numerous proteins, including growth factors and chemokines, which are crucial for primary haemostasis and wound healing (Eppley *et al,* 2004). PRP has recently been used in an attempt to accelerate the rate of orthodontic tooth movement. Two recent animal studies showed a positive correlation between local injection of PRP and acceleration of orthodontic tooth movement (Güleç *et al,* 2017; Rashid *et al,* 2017). Statistically significant increases in the rate of canine retraction during the early stages of tooth movement concomitant with PRP injections have also been demonstrated in human experiments (El-Timamy *et al,* 2020). However this study concluded that PRP did not exhibit long-term acceleration of tooth movement. No beneficial effects of PRP injections on tooth movement have also been reported (Akbulut *et al,* 2019).

The main problem that remains with the use of pharmacologic agents in attempting to accelerate tooth movement is the potential for concomitant side effects especially in association with systemic administration. However, newer models of drug delivery allowing for sustained, controlled drug release look promising for possible future site specific applications to speed up orthodontic tooth movement (Sydorak *et al,* 2019).

Conclusion

undoubtedly, patients and orthodontists will benefit from a shorter treatment duration. Clearly, a good understanding and application of biomechanical principles helps prevent round tripping and unnecessary increase of treatment time. Research continues to be focussed at achieving the goal of a shorter treatment duration. Presently, evidence suggests that most of the interventions that induce faster tooth movements are able to do so only for a short and transient period, with no influence on the overall treatment time. Advances in technology and a better understanding of the biology of tooth movement continue to support the endeavour to attain treatment goals in a shorter duration. It will be interesting to see if newer biomaterials enhancing the biologic responses to applied orthodontic forces will help achieve the goal of shorter treatment time in the future. For the moment, acceleration of tooth movement remains an exciting field for further research, but with very limited clinical applications.

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