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Adherence to Treatment with Removable Oral Appliances: the Past and the Future

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Abstract

Oral appliances (OAs) are frequently used in orthodontics and for the treatment of obstructive sleep apnea. Because OAs can be inserted and removed by patients themselves, the patient's cooperation is a major component of effective treatment. In this review, we provide an overview of factors studied in the past that affect adherence to OA use in orthodontics and dental sleep medicine. We also describe future directions in adherence and the use of objective microsensor technology to measure adherence in these patients.

Because removable oral appliances (OAs) can be inserted and removed by patients themselves, their cooperation and adherence to therapy are necessary to achieve success.[1,2] Removable OAs, such as headgear, removable retainers and functional appliances, are used in orthodontics to correct malocclusions. In the field of sleep medicine, removable OAs are increasingly used as an option in the treatment of patients with obstructive sleep apnea (OSA).

The gold standard for the treatment of moderate to severe OSA is continuous positive airway pressure (CPAP); however, adherence to this treatment has been found to be limited.[3-5] Removable OAs, which reduce upper airway collapse by advancing the mandible, have emerged as a non-invasive treatment option for patients with OSA. These devices are similar in design to functional appliances used commonly for growth modification in orthodontics. They can be inserted and removed by patients, thus, placing responsibility on the patient to follow a prescribed wear schedule.

To date, many scientific publications have addressed the issue of adherence to treatment in orthodontics and dental sleep medicine to determine how to improve and monitor patient compliance.[3,6-16] However, there is controversy over the factors that might predict adherence, mainly because, in the absence of objective monitors, information has been limited to self-reported use, which is often false or overestimated.[17] Recently, objective compliance monitoring for removable OAs has become available.[18,19] In this article, we present an overview of the factors that affect adherence to treatment in both orthodontics and sleep medicine. In addition, we review the use of objective microsensor technology to measure adherence in patients using removable OAs.[17]

Determinants of Adherence

Factors that are thought to be related to patient compliance and cooperation during therapy with removable OAs in orthodontics and dental sleep medicine include gender, age, socioeconomic status, psychosocial aspects, patient's family and partner and the interaction between the dentist or physician and the patient.[15,20] This multifaceted system leads to complex interactions in which each individual component as well as the interplay of factors should be studied.[15,16]

Gender

Patient gender is a factor commonly cited as a predictor of adherence to orthodontic treatment. Some reports suggest better adherence among female compared with male patients.[21-24] Girls tend to take a more responsible attitude toward orthodontic therapy as they mature earlier than boys.[23] On the other hand, more recent reports have failed to show gender as a significant factor in predicting adherence.[6,22,25-30] Previous findings relied on subjective measures of adherence, such as orthodontists' judgement, which may be more a reflection of social and gender stereotypes than a valid correlation.[6] Studies using objective measures of adherence during orthodontic treatment, such as electronic sensors, have found no difference in overall wear time between genders.[6,25,29,30]

Although many studies in orthodontics have examined these issues, the correlation between gender and adherence has not been thoroughly assessed in OA treatment for OSA. However, long-term discontinuation of this therapy has not been found to be different between genders.[31,32]

Age

Age is also often considered to be an influential factor in adherence to orthodontic therapy.[33] Although some studies have found greater cooperation among younger patients (< 12 years),[6,7,9,28,34-37] others have found no difference.[7,22,25-27,30,38] The variation in reports on the effect of age on adherence may be confounded by variations in children's individual psychological maturation. Teenage years are often associated with decreased parental influences and cooperation.[7,36,37]

Orthodontic studies focus on children, whereas OA therapy for OSA is mainly studied in adults. Although discontinuation of long-term OA therapy by OSA patients has not been found to be dependent on age, the effect of age on OA adherence has yet to be explored in this population.[31,32]

Socioeconomic Status

The potential influence of a patient's socioeconomic status on adherence has been addressed and debated in the literature. Patients with higher socioeconomic status have been shown to be more cooperative orthodontic patients.[7,21] A possible explanation is that higher socioeconomic groups perceive dentofacial appearance to be highly important for social and occupational success.[22,39] On the other hand, another study reported greater adherence among patients from lower middle-class families compared with upper-class families.[40] This may be attributed to a greater need for social acceptance, higher social aspiration, better child–parent relationships and greater emphasis on value for money seen in these socioeconomic groups. Some studies also report no difference in patient adherence based on socioeconomic status.[22,38]

In sleep medicine, patients with lower socioeconomic status are less likely to accept and commence CPAP therapy.[15,41] Sleeping with a spouse or partner has been found to increase adherence as the partner may provide feedback regarding elimination of symptoms, such as snoring, which may increase CPAP use.[42] Although these factors may be similar in OA therapy, this has not been assessed.

Psychosocial Aspects

Considerable attention has been devoted to the examination of personality characteristics as a method to predict patients' adherence to orthodontic treatment.[1,2,6,22,25,36,43-46] In general, cooperative patients are characterized as enthusiastic, energetic, outgoing, self-controlled, responsible and hard working.[33] These patients tend to have better grades and show less deviant behaviour in school.[39] In contrast, uncooperative patients are described as hard headed, independent, temperamental, impatient, individualistic and intolerant of prolonged effort.[33] Based on these findings, a patient's performance in school may serve as a useful tool in determining adherence. However, children who are of below-average intelligence do not necessarily show poor adherence.[39] Studies showing no correlation between personality questionnaires and adherence stated that treatment adherence and orthodontic cooperation is not reflective of a simple, single, monotonous dimension of cooperation, but rather a complex and interactive reaction.[25,22,44,46,47] The use of psychological instruments[44,45] to predict adherence has been shown to be useful, but these tools are not used in clinical practice.

In sleep medicine, OSA patients who display significantly more hypochondriasis and psychopathic deviation, presents a potentially higher rate of discontinuation and lower compliance. More specifically, OSA patients with a so-called type D ("distressed") personality, defined as a combination of negative affectivity and social inhibition,[48,49] show a significantly higher discontinuation rate for both CPAP and OA therapy.[50,53]

Measurement of Adherence

There are several approaches to measuring adherence. In orthodontics, the most common method relies on clinicians' judgement. Typical clinical methods for estimating wear time of devices, such as headgear and removable OAs, include evaluation of patients' oral hygiene, condition of the appliance, such as a worn-looking neck strap, mobility of molars, ease of patient use and missing or being late for scheduled orthodontic appointments.[21] Unfortunately, these methods are unreliable. For example, adolescent patients brought to the orthodontist's office by a parent or guardian reflect the punctuality of the parent, not the patient.[2,6,28,52,53] As well, clinicians' judgement is often influenced by therapeutic outcome. This is problematic because it assumes there is a direct link between the clinical outcome and the patient's adherence to treatment, which is not necessarily the case.[53]

Another way to monitor adherence is through patients' self-reports: interviews, questionnaires or log records. However, this can lead to false or overestimated compliance, largely because patients wish to appear more compliant than they actually are.[8,29]

The best way to assess compliance is by objective measures. Investigators have attempted to provide timers and microsensors to record accurate details of patient compliance, and the technology used in manufacturing these microsensors has been improving over many years.

Extraoral Compliance Timers

In 1974, Northcutt[10] described the first extraoral orthodontic headgear with a timing mechanism to measure wear. It worked by simultaneously turning on 2 switches triggered by the pull of the strap and pressure on the back of the neck while the headgear is worn.[10,54,55] Banks et al.[56] found that the Northcutt timer was easily circumvented by the patient placing heavy objects on the pressure switch to activate the timer without actually wearing the headgear.

In 1991, Cureton et al.[57] described a micro-electronic approach to measuring compliance using a small ladies' quartz calendar watch with an accuracy level of 99.9% over 20 days of testing. A limitation of such an external headgear timer is that it is bulky and diminishes patient comfort when it is placed in a neck strap.[58] The patient can also circumvent it by just stretching the band and, thereby, falsifying the wear data.[52,59] In addition, many of these devices give only a cumulative overall measure of wear time and provide the orthodontist with intermittent headgear wear information and no easily accessible feedback to patients.[6,53,59,60]

Intraoral Compliance Timers

The ability to monitor intraoral appliance adherence is even more challenging because of the damaging effects of saliva. One of the first methods used was controlled-release glass discs[60] composed of phosphates, borates and trace elements. A disc was fitted onto the surface of an orthodontic appliance and would dissolve in saline solution indicating wear. Problems with this method included disc separation from the appliance because of poor adhesion, surface grinding of the discs leading to fragmentation and dissolving of discs at different rates.[60]

More recently, a compliance indicator was introduced for aligner therapy. A food dye (erioglaucine disodium salt) is embedded in the OA and dissolves from the polymer when exposed to oral fluid.[61,62] The clinician and the patient can evaluate 5 potential colour changes (from dark blue to clear) to obtain a graphic representation of wear time and have instant feedback on adherence. However, the rating on a 5-point scale involves subjective judgement and, thus, does not yield an objective wear time. In addition, the results can be easily falsified by patients, as the dye will fade in various aqueous solutions, for example, when left in the mouth while drinking, stored in water, cleaned with tablets containing oxidizing agents or cleaned in a dishwasher. A large variation in degree of fading was found among patients who strictly adhered to the prescribed wear times.[57]

In 1990, Sahm et al.[11,63] created a reed-switch, which was embedded into a bionator functional appliance and was activated by a magnet system bonded to the lingual surface of the mandibular first permanent molar. The main problem noted with this device was its bulkiness and patient discomfort.

More recently, temperature sensitive microsensors have been used to objectively measure orthodontic OA use. These microsensors record temperature changes, assuming a difference between room and intraoral temperature. Schott and Göz[64] assessed the accuracy of 2 temperature-sensitive microsensors: the Smart Retainer (discontinued production) and the TheraMon microsensor (IFT Handels und Entwicklungsgesellschaft GmbH, Handelsagentur Gschladt, Hargelsberg, Austria) using in vitro testing in a programmable water bath. They reported that the TheraMon microsensor is more accurate, with the Smart Retainer overestimating wear time by 1 h. However, the water bath was programmed to room temperature and oral temperature while not taking into account the time it takes for the water bath to heat or cool.

A year later, in vivo testing of the microsensor was conducted by Schott and Göz[58] on patients fitted with upper and lower active plates, functional appliances or retention devices. However, they provide only 1 case report of a patient wearing an upper appliance and no statistical analysis of the accuracy of the device.

In 2013, Schott et al.[30] published a study examining the adherence rate of patients fitted with retainers or functional appliances during the retention phase of their orthodontic treatment. Although patients were instructed to wear the appliances at least 8 h/day, the median wear time was 7 h/day. The report stated that adherence rates were influenced by age, sex and place of treatment, but these differences were not statistically significant.

Using the TheraMon microsensor, Pauls et al.[29] found that orthodontic patients tended to overestimate their OA use by an average of 2.7 h/day. Informing and confronting the patients with their objectively measured OA use led to a more accurate subjective estimation, with an average overestimation of only 0.7 h/day.

The first report on intraoral recording of OA compliance during treatment for OSA was published by Lowe et al.[65] This ceramic monitor had a memory system and temperature sensor that would monitor wear time based on temperature measured above 31°C. Several problems with this device were reported, including the damaging effect of saliva, heat intolerance of the electronic components and energy consumption over a long period.[65]

Vanderveken et al.[18] were the first to assess the safety and feasibility of the TheraMon microsensor in vivo in dental sleep medicine. In their 3-month prospective clinical trial, they demonstrated that this compliance monitor could be used safely. No adverse effects, including oral burns, lesions or detachment of the microsensor were reported by the participants. Only 1 of 51 sensors was disqualified in this study because of technical problems. Recently, long-term results with the TheraMon microsensor in dental sleep medicine showed relatively high objective OA use on 1-year follow-up.[66]

To our knowledge, 3 microsensors that can be integrated into removable OAs for OSA are currently available commercially. These sensors differ in terms of data-recording interval, longevity, form of readout signals, size, weight, storage capacity and availability of a patient station, which permits patients to monitor their own adherence and upload their data remotely. Kirshenblatt et al.[67] tested the accuracy of these thermosensitive microsensors in vitro using a water bath (34–37°C) to simulate OA wear time.

The TheraMon microsensor was accurate during both short and long durations of simulated OA wear, whereas the AIR AID SLEEP sensor (AIR AID GmbH & Co. KG, Frankfurt, Germany) significantly underestimated OA use during short durations by 3.67 ± 9.34 min./day, (mean and standard deviation) and the DentiTrac microsensor (Braebon Medical Corporation, Kanata, Canada) overestimated OA use during both short and long durations by 8.34 ± 3.62 min./day and 3.53 ± 2.42 min./day, respectively. However, these under- and overestimations were considered not clinically relevant.

Discussion

Adherence to a prescribed treatment modality is of utmost importance in ensuring successful therapy. Lack of adherence can reduce the effectiveness of the best treatment plan and the most promising treatment mechanisms.[5] This literature review shows that several factors have been thought to affect adherence in the fields of both orthodontics and dental sleep medicine. Studies indicating that adherence may be influenced by gender, age, psychosocial and socioeconomic factors have found wide variation among individuals.[1,25] Other factors may also be found to be important, such as cultural background and severity of malocclusion/disease. Although the studies have tried to pinpoint which factors are determinants of patient adherence, this review shows that, in reality, it is difficult and challenging for clinicians to predict which patients will be cooperative. This can be explained by the fact that human behaviour is multifactorial and includes complex interactions in which each individual component, as well as the interplay of factors, should be studied.[15]

Another important finding is that patients' adherence significantly increases when there is some objective feedback or when they are aware of being monitored objectively.[10,34,68,69] Because patients are more motivated to change their behaviour when they know it is being monitored, there is a strong need for and interest in an objective compliance monitor for OA therapy in both orthodontics and dental sleep medicine. The use of such monitors alone may improve adherence.

However, the use of such devices is not part of routine daily clinical practice. A major problem with these monitors for removable OAs is accuracy. Besides the technical and functional factors, additional requirements must be met to achieve a high level of product acceptance by patients and health care professionals. Compliance monitors must be safe and small without altering the dimensions of the OA or affecting patients' comfort; read-outs and monitoring must be easy and fast; and the sensors' unit price must be reasonable.[70]

Microsensors that have recently become available can assist with monitoring patient adherence to orthodontics treatment and OA therapy for patients diagnosed with OSA.[19] Such microsensors will give clinicians a better understanding of their patients and will allow them to tailor appointment schedules to best meet patients' individual treatment needs. These microsensors can be used as a tool to motivate patients. In addition, the availability of objective compliance data will eliminate inconsistencies in patients' subjective reports if the data prove to be accurate.

Furthermore, it is difficult to compare tolerance to various OA devices based on subjective compliance data without proof that patients are actually wearing them. In the field of sleep medicine, objective monitoring will allow for calculation of mean disease alleviation, which depends on both efficacy and compliance for therapeutic effectiveness.[18] Calculation of real therapeutic effectiveness allows for comparison of different treatment modalities, such as CPAP therapy, surgery and oral appliances. For example, in the literature, CPAP therapy and oral appliances have been comparable in terms of mean disease alleviation.[18,71] It has been suggested that the greater efficacy of CPAP therapy is being offset by inferior CPAP adherence compared with OA adherence, possibly resulting in equal effectiveness.[72,73]

In orthodontics, objective microsensors will increase the strength of evidence from studies comparing various appliances and retainer designs. Future studies using these monitors may also help identify the most appropriate wear pattern clinicians should be prescribing for the most effective treatment results.

Conclusion

Removable OAs are frequently used in both orthodontics and the treatment of OSA. Many of the appliances used in orthodontic practice rely on patients wearing the devices as prescribed. Adherence is of utmost importance in ensuring successful treatment. This literature review shows that, although several factors have been thought to affect adherence, human behaviour is complex and open to multifactorial influences. Therefore, there is a strong need for and interest in objective adherence monitors for OA therapy. The availability of such monitors will allow clinicians to track patient adherence, motivate patients and improve research that compares treatment outcomes.

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References

1. Gross AM, Samson G, Dlerkes M. Patient cooperation in treatment with removable appliances: a model of patient noncompliance with treatment implications. Am J Orthod. 1985;87(5):392-7.
2. Mehra T, Nanda RS, Sinha PK. Orthodontists' assessment and management of patient compliance. Angle Orthod. 1998;68(2):115-22.
3. Sawyer AM, Gooneratne NS, Marcus CL, Ofer D, Richards KC, Weaver TE. A systematic review of CPAP adherence across age groups: clinical and empiric insights for developing CPAP adherence interventions. Sleep Med Rev. 2011;15(6):343-56.
4. Hoffstein V. Review of oral appliances for treatment of sleep-disordered breathing. Sleep Breath. 2007;11(1):1-22.
5. Ravesloot MJ, de Vries N. Reliable calculation of the efficacy of non-surgical and surgical treatment of obstructive sleep apnea revisited. Sleep. 2011;34(1):105-10.
6. Bartsch A, Witt E, Sahm G, Schneider S. Correlates of objective patient compliance with removable appliance wear. Am J Orthod Dentofacial Orthop. 1993;104(4):378-86.
7. Albino JE, Lawrence SD, Lopes CE, Nash LB, Tedesco LA. Cooperation of adolescents in orthodontic treatment. J Behav Med. 1991;14(1):53-70.
8. Cole WA. Accuracy of patient reporting as an indication of headgear compliance. Am J Orthod Dentofacial Orthop. 2002;121(4):419-23.
9. Cureton SL, Regennitter FJ, Yancey JM. Clinical versus quantitative assessment of headgear compliance. Am J Orthod Dentofacial Orthop. 1993;104(3):277-84.
10. Northcutt M. The timing headgear. J Clin Orthod. 1974;8(6):321-4.
11. Sahm G, Bartsch A, Witt E. Reliability of patient reports on compliance. Eur J Orthod. 1990;12(4):438-46.
12. Pelletier-Fleury N, Rakotonanahary D, Fleury B. The age and other factors in the evaluation of compliance with nasal continuous positive airway pressure for obstructive sleep apnea syndrome. A Cox's proportional hazard analysis. Sleep Med. 2001;2(3):225-32.
13. Rauscher H, Formanek D, Popp W, Zwick H. Self-reported vs measured compliance with nasal CPAP for obstructive sleep apnea. Chest. 1993;103(6):1675-80.
14. Reeves-Hoche MK, Meck R, Zwillich CW. Nasal CPAP: an objective evaluation of patient compliance. Am J Respir Crit Care Med. 1994;149(1):149-54.
15. Shapiro GK, Shapiro CM. Factors that influence CPAP adherence: an overview. Sleep Breath. 2010;14(4):323-35.
16. Weaver TE, Grunstein RR. Adherence to continuous positive airway pressure therapy: the challenge to effective treatment. Proc Am Thorac Soc. 2008;5(2):173-8.
17. Kribbs NB, Pack AI, Kline LR, Smith PL, Schwartz AR, Schubert NM, et al. Objective measurement of patterns of nasal CPAP use by patients with obstructive sleep apnea. Am Rev Resp Dis 1993;147(4):887-95.
18. Vanderveken OM, Dieltjens M, Wouters K, De Backer WA, Van de Heyning PH, Braem MJ. Objective measurement of compliance during oral appliance therapy for sleep-disordered breathing. Thorax. 2013;68(1):91-6.

19. Kirshenblatt SJ, Chen H, Lowe A, Pliska B, Almeida FR. Microsensor technology to monitor compliance with removable oral appliances (Abstract). Sleep Breath. 2013;17:879-94.

20. Bos A, Hoogstraten J, Prahl-Andersen B. Towards a comprehensive model for the study of compliance in orthodontics. Eur J Orthod. 2005;27(3):296-301.

21. Cucalon A 3rd, Smith RJ. Relationship between compliance by adolescent orthodontic patients and performance on psychological tests. Angle Orthod. 1990;60(2):107-14.

22. Nanda RS, Kierl MJ. Prediction of cooperation in orthodontic treatment. Am J Orthod Dentofacial Orthop. 1992;102(1):15-21.

23. Starnbach HK, Kaplan A. Profile of an excellent orthodontic patient. Angle Orthod. 1975;45(2):141-5.

24. Clemmer EJ, Hayes EW. Patient cooperation in wearing orthodontic headgear. Am J Orthod. 1979;75(5):517-24.

25. Ağar U, Doruk C, Biçakçi AA, Büküsoğlu N. The role of psycho-social factors in headgear compliance. Eur J Orthod. 2005;27(3):263-7.

26. Sergl HG, Klages U, Pempera J. On the prediction of dentist-evaluated patient compliance in orthodontics. Eur J Orthod. 1992;14(6):463-8.

27. Richter DD, Nanda RS, Sinha PK, Smith DW, Currier GF. Effect of behavior modification on patient compliance in orthodontics. Angle Orthod. 1998;68(2):123-32.

28. Bos A, Kleverlaan CJ, Hoogstraten J, Prahl-Andersen B, Kuitert R. Comparing subjective and objective measures of headgear compliance. Am J Orthod Dentofacial Orthop. 2007;132(6):801-5.

29. Pauls A, Neinkemper M, Panayotidis A, Wilmes B, Drescher D. Effects of wear time recording on patient's compliance. Angle Orthod. 2013;83(6):1002-8..

30. Schott TC, Schlipf C, Glasl B, Schwarzer CL, Weber J, Ludwig B. Quantification of patient compliance with Hawley retainers and removable functional appliances during the retention phase. Am J Orthod Dentofacial Orthop. 2013;144(4):533-40.

31. de Almeida FR, Lowe AA, Tsuiki S, Otsuka R, Wong M, Fastlicht S, et al. Long-term compliance and side effects of oral appliances used for the treatment of snoring and obstructive sleep apnea syndrome. J Clin Sleep Med. 2005;1(2):143-52.

32. Marklund M, Franklin KA. Long-term effects of mandibular repositioning appliances on symptoms of sleep apnoea. J Sleep Res. 2007;16(4):414-20.

33. Allan TK, Hodgson EW. The use of personality measurements as a determinant of patient cooperation in an orthodontic practice. Am J Orthod. 1968;54(6):433-40.

34. Brandão M, Pinho HS, Urias D. Clinical and quantitative assessment of headgear compliance: a pilot study. Am J Orthod Dentofacial Orthop. 2006;129(2):239-44.

35. Weiss J, Eiser HM. Psychological timing of orthodontic treatment. Am J Orthod. 1977;72(2):198-204.

36. Colenaty C, Gabriel HF. Predicting patient cooperation. J Clin Orthod. 1977;11(12):814-9.

37. Trulsson U, Linläv L, Mohlin B, Strandmark M. Age dependence of compliance with orthodontic treatment in children with large overjet. An interview study. Swed Dent J. 2004;28(2):101-9.

38. Mandall NA, Matthew S, Fox D, Wright J, Conboy FM, O'Brien KD. Prediction of compliance and completion of orthodontic treatment: are quality of life measures important? Eur J Orthod. 2008;30(1):40-5.

39. Sergl HG, Klages U, Zentner A. Functional and social discomfort during orthodontic treatment — effects on compliance and prediction of patients' adaptation by personality variables. Eur J Orthod. 2000;22(3):307-15.

40. Dorsey J, Korabik K. Social and psychological motivations for orthodontic treatment. Am J Orthod. 1977;72(4):460.

41. Simon-Tuval T, Reuveni H, Greenberg-Dotan S, Oksenberg A, Tal A, Tarasiuk A. Low socioeconomic status is a risk factor for CPAP acceptance among adult OSAS patients requiring treatment. Sleep. 2009;32(4):545-52.

42. Weaver TE, Sawyer AM. Adherence to continuous positive airway pressure treatment for obstructive sleep apnoea: implications for future interventions. Indian J Med Res. 2010;131:245-58.

43. Egolf RJ, Begole EA, Upshaw HS. Factors associated with orthodontic patient compliance with intraoral elastic and headgear wear. Am J Orthod Dentofacial Orthop. 1990;97(4):336-48.

44. El-Mangoury NH. Orthodontic cooperation. Am J Orthod 1981;80(6):604-22.

45. Southard KA, Tolley EA, Arheart KL, Hackett-Renner CA, Southard TE. Application of the Millon Adolescent Personality Inventory in evaluating orthodontic compliance. Am J Orthod Dentofacial Orthop. 1991;100(6):553-61.

46. Woolass KF, Shaw WC, Viader PH, Lewis AS. The prediction of patient co-operation in orthodontic treatment. Eur J Orthod. 1988;10(3):235-43.

47. Lee SJ, Ahn SJ, Kim TW. Patient compliance and locus of control in orthodontic treatment: a prospective study. Am J Orthod Dentofacial Orthop. 2008;133(3):354-8.

48. Denollet J. Type D personality. A potential risk factor refined. J Psychosom Res. 2000;49(4):255-66.

49. Denollet J, Sys SU, Stroobant N, Rombouts H, Gillebert TC, Brutsaert DL. Personality as independent predictor of long-term mortality in patients with coronary heart disease. Lancet. 1996;347(8999):417-21.

50. Dieltjens M, Vanderveken OM, Van den Bosch D, Wouters K, Denollet J, Verbraecken JA, et al. Impact of type D personality on adherence to oral appliance therapy for sleep-disordered breathing. Sleep Breath. 2013;17(3):985-91.

51. Broström A, Strömberg A, Mårtensson J, Ulander M, Harder L, Svanborg E. Association of Type D personality to perceived side effects and adherence in CPAP-treated patients with OSAS. J Sleep Res. 2007;16(4):439-47.

52. Lyons EK, Ramsay DS. A self-regulation model of patient compliance in orthodontics: implications for future design of a headgear monitor. Semin Orthod. 2000;6:224-30.

53. Ramsay DS, Soma M, Sarason IG. Enhancing patient adherence: the role of technology and its application to orthodontics. In McNamara Jr JA, Trotman CA (eds.). Creating the compliant patient. Craniofacial growth series, vol. 33. Ann Arbor: Center for Human Growth and Development, University of Michigan; 1997:141-65.

54. Northcutt M. The high-pull timing headgear. J Clin Orthod. 1976;10(12):918-20.

55. Northcutt ME. Updating the timing headgear. J Clin Orthod. 1975;9(11):713-7.

56. Banks PA, Read MJ. An investigation into the reliability of the timing headgear. Br J Orthod. 1987;14(4):263-7.

57. Cureton SL, Regennitter F, Orbell MG. An accurate, inexpensive headgear timer. J Clin Orthod 1991;25(12):749-54.

58. Schott TC, Göz G. Wearing times of orthodontic devices as measured by the TheraMon® microsensor. J Orofac Orthop. 2011;72(2):103-10.

59. Lyons EK, Ramsay DS. Preliminary tests of a new device to monitor orthodontics headgear use. Semin Orthod. 2002;8(1):29-34.

60. Savage M. A preliminary report into the development and use of soluble controlled-release glass timing discs implanted into orthodontic appliances. Br J Orthod. 1982;9(4):190-3..

61. Schott TC, Göz G. Color fading of the blue compliance indicator encapsulated in removable clear Invisalign Teen® aligners. Angle Orthod. 2011;81(2):185-91.

62. Tuncay OC, Bowman SJ, Nicozisis JL, Amy BD. Effectiveness of a compliance indicator for clear aligners. J Clin Orthod. 2009;43(4):263-8; quiz 273-4.

63. Sahm G, Bartsch A, Witt E. Micro-electronic monitoring of functional appliance wear. Eur J Orthod. 1990;12(3):297-301.

64. Schott TC, Göz G. Applicative characteristics of new microelectronic sensors Smart Retainer® and TheraMon® for measuring wear time. J Orofac Orthop. 2010;71(5):339-47.

65. Lowe AA, Sjöholm TT, Ryan CF, Fleetham JA, Ferguson KA, Remmers JE. Treatment, airway and compliance effects of a titratable oral appliance. Sleep. 2000;23 (Suppl 4):S172-8.

66. Dieltjens M, Verbruggen AE, Braem MJ, Wouters K, Verbraecken JA, De Backer WA, et al. Determinants of objective compliance during oral appliance therapy in patients with sleep-disordered breathing: a prospective clinical trial. JAMA Otolaryngol Head Neck Surg. 2015 Oct;141(10):894-900.

67. Kirshenblatt SJ, Hui C, Lowe A, Pliska B, Almeida FR. Microsensor technology to monitor adherence with removable oral appliances. Baltimore: American Academy of Dental Sleep Medicine Conference; 2013.

68. Doruk C, Ağar U, Babacan H. The role of the headgear timer in extraoral co-operation. Eur J Orthod. 2004;26(3):289-91.

69. Ackerman MB, Thornton B. Posttreatment compliance with removable maxillary retention in a teenage population: a short-term randomized clinical trial. Orthodontics (Chic). 2011;12(1):22-7.

70. Schott TC, Ludwig B, Glasl BA, Lisson JA. A microsensor for monitoring removable-appliance wear. J Clin Orthod. 2011;45(9):518-20; quiz 516.

71. Grote L, Hedner J, Grunstein R, Kraiczi H. Therapy with nCPAP: incomplete elimination of sleep related breathing disorder. Eur Respir J. 2000;16(5):921-7.

72. Phillips CL, Grunstein RR, Darendeliler MA, Mihailidou AS, Srinivasan VK, Yee BJ, et al. Health outcomes of continuous positive airway pressure versus oral appliance treatment for obstructive sleep apnea: a randomized controlled trial. Am J Respir Crit Care Med. 2013;187(8):879-87.

73. Vanderveken OM, Braem MJ, Dieltjens M, De Backer WA, Van de Heyning PH. Objective measurement of the therapeutic effectiveness of continuous positive airway pressure versus oral appliance therapy for the treatment of obstructive sleep apnea. Am J Respir Crit Care Med. 2013;188(9):1162