Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 18 July 2026
Revised 24 Aug 2026
Accepted 10 Sep 2026

Natural Resources for Human Health 2026, Vol. 6 (21s): 161–175

KEYWORDS:
obstructive sleep apnea; CPAP adherence; personalized medicine; motivational interviewing; telemonitoring; artificial intelligence; endotype

Personalized Treatment Strategies to Improve Continuous Positive Airway Pressure (CPAP) Adherence in Patients with Obstructive Sleep Apnea

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ABSTRACT: Continuous positive airway pressure (CPAP) is the standard treatment for moderate to severe obstructive sleep apnea (OSA), which affects almost one billion persons worldwide. Its therapeutic benefit is critically dependent on the extent of nightly use, yet adherence has improved little over two decades of device refinement, with long-term use frequently below 50%. The disparity between the efficacy of CPAP under controlled trial conditions and its effectiveness in routine clinical practice is attributable predominantly to non-adherence. This narrative review examines CPAP therapy personalization to promote adherence. It critically appraises conflicting findings, examines methodological limitations, and delineates evidence gaps rather than merely cataloguing the literature. Four converging personalization levels are investigated. Behavioral tailoring using motivational interviewing, cognitive behavioral therapy, motivational enhancement therapy, and individualized feedback; technology-enabled personalization through telemonitoring, mobile health, and cloud-connected devices; device-level and algorithmic personalization, which matches interface, pressure mode, and flow-generator response profile to the individual; and phenotype- and endotype-driven care. Machine-learning models can now predict non-adherence from the first 30 nights of device telemetry with clinically useful discrimination. Behavioural interventions increase nightly use by approximately one hour and telemonitoring by approximately forty minutes, although these effects attenuate over time and are seldom stratified by baseline readiness to change. Evidence on major cardiovascular endpoints remains contested, largely because trial cohorts achieved sub-therapeutic exposure. Personalization appears most effective when behavioural, technological, and physiological approaches are combined. Effectiveness is the product of efficacy and sustained use. A stepped, patient-centred approach that characterises the patient before initiation, intervenes intensively during the first month, re-optimises the device before discontinuing CPAP, and applies phenotyping to guide selection of alternatives offers the most coherent strategy. Standardized adherence indicators, treatment-fidelity reporting, prospective endotype-guided allocation validation, explainable AI, and targeted equity are priorities.

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1. INTRODUCTION

Obstructive sleep apnea (OSA) is a chronic sleep-related breathing disorder in which there is repetitive narrowing or closure of the pharyngeal airway. Each obstructive event initiates a characteristic pathophysiological sequence comprising intermittent hypoxaemia, marked swings in intrathoracic pressure, sympathetic activation, and a cortical arousal sufficient to restore airway patency. Repeated hundreds of times per night and sustained over years, this cyclical process results in progressive end-organ injury. Benjafield et al. (2019) estimated that globally there are about 936 million adults aged between 30 and 69 years with mild to severe disease and about 425 million with moderate to severe disease, with the greatest burdens being in China, the United States, Brazil and India, based on data from 16 countries. These numbers continue to rise with an ageing population and the increasing prevalence of obesity (Peppard et al., 2013), yet approximately 80% of cases remain undiagnosed (Van Daele et al., 2024).

OSA is not attributable to a single mechanism. Upper-airway anatomy is important but is rarely sufficient to account for the disorder in isolation. In a significant study that changed the way the disease is conceptualized in the field, Eckert et al. (2013) revealed that most patients also have one or more non-anatomical traits: a poorly responsive pharyngeal dilator muscle, a respiratory arousal threshold that is too low, or an over-reactive ventilatory control system (high loop gain). The clinical implications are considerable.

Two patients may share an identical apnea-hypopnea index (AHI) yet differ in their predominant pathophysiological mechanisms, symptom profiles, and probability of tolerating a given therapy. The resulting sequelae are correspondingly heterogeneous and include excessive daytime sleepiness, motor-vehicle and occupational accidents, cardiac arrhythmia, systemic hypertension, coronary and cerebrovascular disease, neurocognitive impairment, insulin resistance, depression, and impaired quality of life (Marin et al., 2005; Lévy et al., 2015; Garbarino et al., 2020).

Continuous positive airway pressure (CPAP) is the first-line treatment for moderate to severe OSA. It acts as a pneumatic splint, keeping the airway open, eliminating obstructive events, restoring oxygenation, consolidating sleep, reducing sleepiness and blood pressure, and improving sleep-related quality of life (Giles et al., 2006; Patil et al., 2019). However, these benefits are contingent upon the extent of device use. The therapeutic response increases progressively with nightly use rather than emerging at a discrete threshold, and the exposure required differs by outcome, with approximately 4 hours needed to improve daytime sleepiness and 6 hours or more required for objective vigilance and cardiometabolic outcomes (Weaver, 2019; Gay et al., 2006).

This constitutes the central challenge in sleep medicine. CPAP demonstrates near-complete efficacy under controlled conditions yet yields disappointing effectiveness at the population level, principally because a substantial proportion of patients discontinue therapy. Between 8% and 15% of patients decline therapy after the first night, and at least half discontinue within one year (Rapelli et al., 2021). Rotenberg et al. (2016) reviewed two decades of published data and reported an essentially unchanged adherence rate despite sustained engineering advances. A French national database analysis reported a comparable pattern, with almost half of users having discontinued therapy by three years (Pépin et al., 2021). Interventions that address side effects alone, or that deliver uniform education to all patients, have generally produced modest and transient improvement. Collectively, these findings indicate that non-adherence is not a single problem amenable to a single solution but a constellation of problems whose composition varies between patients.

This framing of the problem places CPAP adherence firmly within the context of precision medicine. If OSA is heterogeneous in mechanism, symptom expression, psychological context, and social circumstance, then the support provided, the configuration of the device, and the therapy ultimately selected should each be individualised to the patient. The review has three aims. The first is to synthesise and critically appraise the current evidence on personalized strategies for CPAP adherence. The second is to identify where that evidence is contradictory, methodologically limited, or absent. The third is to propose a clinically applicable framework together with a research agenda prioritised by clinical importance.

2. CPAP ADHERENCE: CURRENT STATUS

2.1 Definition and international criteria

It is a long-standing convention that a patient is considered adherent if the device records at least 4 hours of use on at least 70 per cent of nights. The threshold has its roots in the objective monitoring work of Kribbs et al. (1993), was subsequently

codified into United States Centers for Medicare and Medicaid Services policy and has been implemented, with local variations, by payers around the world.

This threshold is administrative rather than physiological in origin. It is not derived from a dose-response relationship and classifies a patient who uses CPAP for 5 of 8 hours in bed as adherent, despite one-third of the sleep period remaining untreated. Alternative metrics, including mean hours per night, the proportion of nights used, and use expressed as a proportion of time in bed, capture different aspects of the same behaviour and are not readily interchangeable. This absence of a common metric is arguably the principal obstacle to quantitative synthesis of the literature, as effect estimates derived from different denominators cannot be pooled without distortion.

2.2 Global adherence statistics

Adherence rates are reported as widely varying and often cited at anything between 17 and 54 per cent under the 4-hour definition (Yamauchi et al., 2024; Weaver & Grunstein, 2008). Real-world telemetry from large device populations typically yields higher estimates than older clinic-based series, partly because connected devices incorporate automated engagement prompts and partly because patients who never initiate therapy are frequently excluded from the denominator. This optimism bias warrants greater attention.

Longitudinal data are less favourable, and the adherence trajectory is established early. First-week use predicted adherence at three months (Budhiraja et al., 2007), and two-week use predicted adherence at the three-month mark (Roecklein et al., 2010). Because this trajectory is largely determined within the first weeks, personalized intervention is likely to yield the greatest benefit during the first month of therapy.

2.3 Clinical and economic consequences of non-adherence

The clinical consequences of non-adherence are most clearly, and most contentiously, illustrated by the cardiovascular trials. In the SAVE trial, 2717 patients with established cardiovascular disease and moderate to severe OSA were randomised to CPAP plus usual care or usual care alone and, after a mean follow-up of 3.7 years, there was no reduction in the primary composite cardiovascular endpoint (McEvoy et al., 2016). A critical feature of this result is the low mean nightly use of 3.3 hours. A propensity-matched analysis of patients who did achieve at least 4 hours of use suggested fewer cerebrovascular events and a subsequent meta-analysis linked good adherence with a lower risk of recurrent cardiovascular events (Sánchez-de-la-Torre et al., 2023).

Two interpretations remain plausible: either OSA is not causally cardiotoxic in the secondary-prevention setting, or the trials failed to deliver a therapeutic dose of treatment. The balance of mechanistic and observational evidence favours the latter interpretation, establishing adherence as the rate-limiting step for the entire evidence base rather than a secondary consideration. A trial that cannot achieve adequate therapeutic exposure cannot adequately test its primary hypothesis.

The economic rationale is equally compelling. Analyses commissioned by the American Academy of Sleep Medicine estimated the annual cost of undiagnosed OSA in the United States at about $149.6 billion, including $86.9 billion in lost productivity and $26.2 billion attributable to motor-vehicle accidents, compared with an estimated $12.4 billion spent on diagnosis and treatment (Watson, 2016). Device-telemetry data linked to claims indicate that adherent patients have significantly fewer emergency visits and lower total costs compared to non-adherent patients (Sterling et al., 2024), and untreated OSA in Medicare beneficiaries is associated with significantly higher annual costs (Wickwire et al., 2020). Improving adherence therefore represents not only a clinical objective but also a health-system investment with a plausible return.

3. DETERMINANTS OF CPAP ADHERENCE

Personalization is only rational if the determinants of adherence are heterogeneous and at least partly modifiable. Both conditions are satisfied. Determinants can be categorised into patient-related, device-related, disease-related, and healthcare-system domains (Figure 1), but the domains interact and do not work independently.

Natural Resources for Human Health
eISSN: 2583-1194

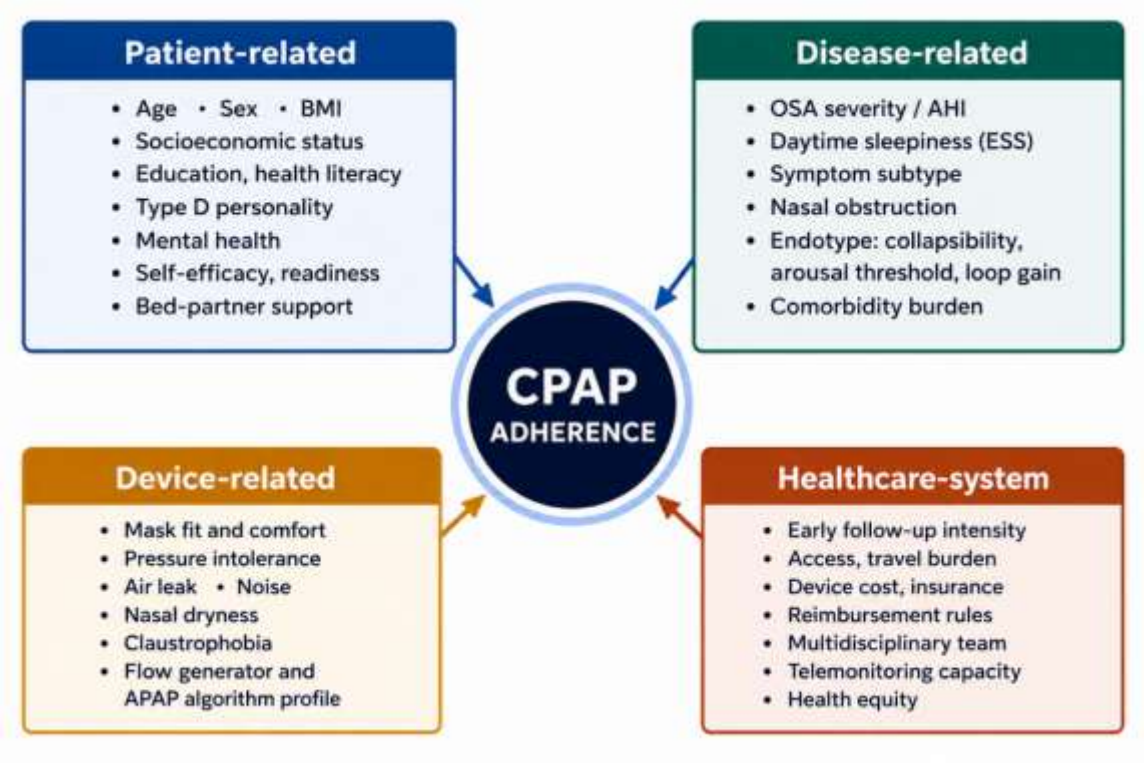


Figure 1. Multilevel determinants of CPAP adherence.

3.1 Patient-related factors

Demographic predictors are weak and inconsistent. No reliable linear relationship exists between age and adherence. Older patients are sometimes more adherent, possibly reflecting routine and retirement; cognitive impairment and reduced manual dexterity limit use in the very elderly. Sex effects are also equivocal, although women are underdiagnosed, have more complaints of mask discomfort and claustrophobia, and are underrepresented in most adherence trials, limiting external validity of pooled estimates. Body mass index and socioeconomic status do behave differently; the latter is among the stronger predictors and lower adherence is associated with neighbourhood-level deprivation and minority residence (Borker et al., 2021). A particularly instructive example is given by Roecklein et al. (2010). In a largely low-income Black sample, a customised feedback intervention produced medium to large effect sizes at two weeks, but no overall significant benefit, and the potential influence of income on whether a patient received a machine at all was large. The authors argued persuasively that structural and economic barriers can override individual-level motivational factors. This is an important corrective to a literature that has tended to psychologize a problem that is, in part, material.

Psychological determinants are stronger and more amenable to intervention. Personality type D, characterised by negative affectivity and social inhibition, has been associated with increased perceived side effects and poorer adherence (Broström et al., 2007; Copur et al., 2018). Claustrophobia is an early predictor of rejection (Chasens et al., 2005). Evidence regarding depression and anxiety is genuinely inconsistent, with studies reporting associations in both directions (Cayanan et al., 2019), which may be because untreated OSA causes and is worsened by mood disturbance, resulting in reciprocal causation that cannot be disentangled with cross-sectional designs. The best psychological predictor is CPAP self-efficacy, the patient's belief in their ability to successfully use the device (Aloia et al., 2005; Baron et al., 2011; Sawyer et al., 2011). The natural target of behavioural personalisation is self-efficacy, because it is modifiable. All of the above are moderated by health literacy and whether a bed partner or family member is present (Xu et al., 2020; Gentina et al., 2019; Luyster, 2017).

3.2 Disease-related factors

Patients with more severe disease might be expected to demonstrate greater adherence, and this is supported in part. A higher baseline AHI and, more consistently, greater daytime sleepiness are associated with better use, as patients who experience

immediate symptomatic benefit are more likely to continue therapy. This reinforcement mechanism underlies one of the most clinically useful findings in the field, namely the identification of symptom subtypes. These cluster analyses, first performed in the Icelandic Sleep Apnea Cohort and then validated internationally, have robustly identified three phenotypic clusters: one characterised by excessive sleepiness, one by disturbed sleep, and one with minimal symptoms (Ye et al., 2014; Keenan et al., 2018). These clusters are not defined by AHI. The sleepy group has the highest cardiovascular risk (Mazzotti et al., 2019) and the most obvious symptomatic relief from treatment, while the minimally symptomatic group, despite a substantial burden of comorbidity, has little immediate incentive to persist. The corollary is clinically important: the patients who derive the greatest prognostic benefit from CPAP are often the least motivated to use it, and correspond precisely to the populations enrolled in SAVE and RICCADSA. Endotype introduces an additional dimension: patients with a low arousal threshold may awaken in response to the delivered pressure, while those with high loop gain may develop the ventilatory instability that therapy must then counteract (Eckert et al., 2013; Edwards et al., 2012).

3.3 Device-related factors

The most commonly reported adverse effects by patients are discomfort with the mask, air leak, pressure intolerance, nasal congestion and dryness. However, a remarkable and repeatedly reproduced observation is the poor correlation of technical alleviation of these problems with improved adherence (Zozula & Rosen, 2001; Broström et al., 2009). Heated humidification, for example, reliably improves comfort but has an inconsistent effect on hours of use. The most coherent interpretation is that side effects are necessary but not sufficient causes of discontinuation; they are mediated by the patient's motivation, expectations, and self-efficacy before culminating in abandonment of therapy. An important but less explored dimension of the device is the flow generator itself. Bench testing demonstrates that auto-titrating devices from different manufacturers can respond to the same simulated events with remarkably different pressure trajectories, and that the algorithmic modes within a single device vary greatly in their rate of pressure escalation (Yamauchi et al., 2024; Isetta et al., 2015). In clinical practice, patients intolerant of one device are frequently able to tolerate a device from another manufacturer. Until recently, this observation was regarded as anecdotal rather than as evidence of a modifiable, personalizable parameter.

3.4 Healthcare-system factors

Healthcare-system factors are the most frequently overlooked and potentially among the most influential. System-level determinants of adherence include the intensity and timing of early follow-up, device and consumable costs, geographic access, insurance and reimbursement rules, and the availability of a multidisciplinary team. Reimbursement policy is a double-edged instrument: adherence-contingent funding creates an incentive to use the device but also risks penalising precisely those patients whose non-adherence reflects socioeconomic disadvantage or comorbidity rather than individual choice. The determinants are listed in Table 1.

Table 1. Determinants of CPAP adherence, with direction of effect, strength of evidence, modifiability

Domain	Determinant	Direction of effect	Strength of evidence	Modifiable? Implication	Key evidence
Patient	CPAP self-efficacy; readiness to change	Higher self-efficacy predicts greater use	Strong and consistent	Yes. Primary target of MI and CBT; measure before initiation	Aloia et al. (2005); Baron et al. (2011); Sawyer et al. (2011)
Patient	Socioeconomic status; neighbourhood deprivation	Lower status predicts lower use and device acquisition	Moderate to strong	Partly. Needs structural intervention, not messaging alone	Roecklein et al. (2010); Borker et al. (2021)
Patient	Type D personality; claustrophobia	Both predict poorer adherence and more side	Moderate	Yes. Desensitisation, graded exposure, alternative interface	Broström et al. (2007); Copur et al. (2018); Chasens et al.

		effects			(2005)
Patient	Depression and anxiety	Inconsistent; bidirectional causation likely	Weak and conflicting	Yes, but evidence base inadequate for firm guidance	Cayanan et al. (2019); Garbarino et al. (2020)
Patient	Age, sex, BMI	Weak and inconsistent associations	Weak	No. Poor basis for allocation; women underrepresented	Mehrtash et al. (2019); Weaver & Grunstein (2008)
Disease	Daytime sleepiness (ESS); symptom subtype	Excessively sleepy subtype uses CPAP more, benefits most	Strong	No, but useful for stratification and expectation setting	Ye et al. (2014); Keenan et al. (2018); Mazzotti et al. (2019)
Disease	AHI severity	Weak positive association	Weak to moderate	No. Should not be the sole predictor of adherence	Weaver & Grunstein (2008)
Disease	Endotype (low arousal threshold, high loop gain)	Predisposes to pressure intolerance and instability	Emerging; mechanistically strong	Yes, in principle. Guides device and non-PAP choice	Eckert et al. (2013); Op de Beeck et al. (2021)
Device	Mask discomfort, leak, nasal dryness	Common, but weakly correlated with discontinuation	Moderate occurrence, weak causation	Yes. Necessary but not sufficient on its own	Zozula & Rosen (2001); Broström et al. (2009)
Device	Flow generator and APAP pressure algorithm	Pressure escalation differs markedly across devices	Emerging; bench strong, clinical sparse	Yes. Change device or mode before abandoning CPAP	Isetta et al. (2015); Yamauchi et al. (2024)
System	Intensity of early follow-up (first 30 days)	Early support strongly predicts long-term use	Strong	Yes. Highest-yield window for intervention	Budhiraja et al. (2007); Chen et al. (2020)
System	Cost, insurance, access, multidisciplinary care	Structural barriers depress use independently of motivation	Moderate to strong	Yes, at policy level. Central to equity	Wickwire et al. (2020); Watson (2016)

4. PERSONALIZED TREATMENT STRATEGIES

Personalization operates at four levels: who the patient is (phenotyping), what device they receive (hardware and algorithm), how they are supported (behavioural), and, when CPAP fails, what therapy replaces it. Figure 2 presents these as a stepped clinical pathway.

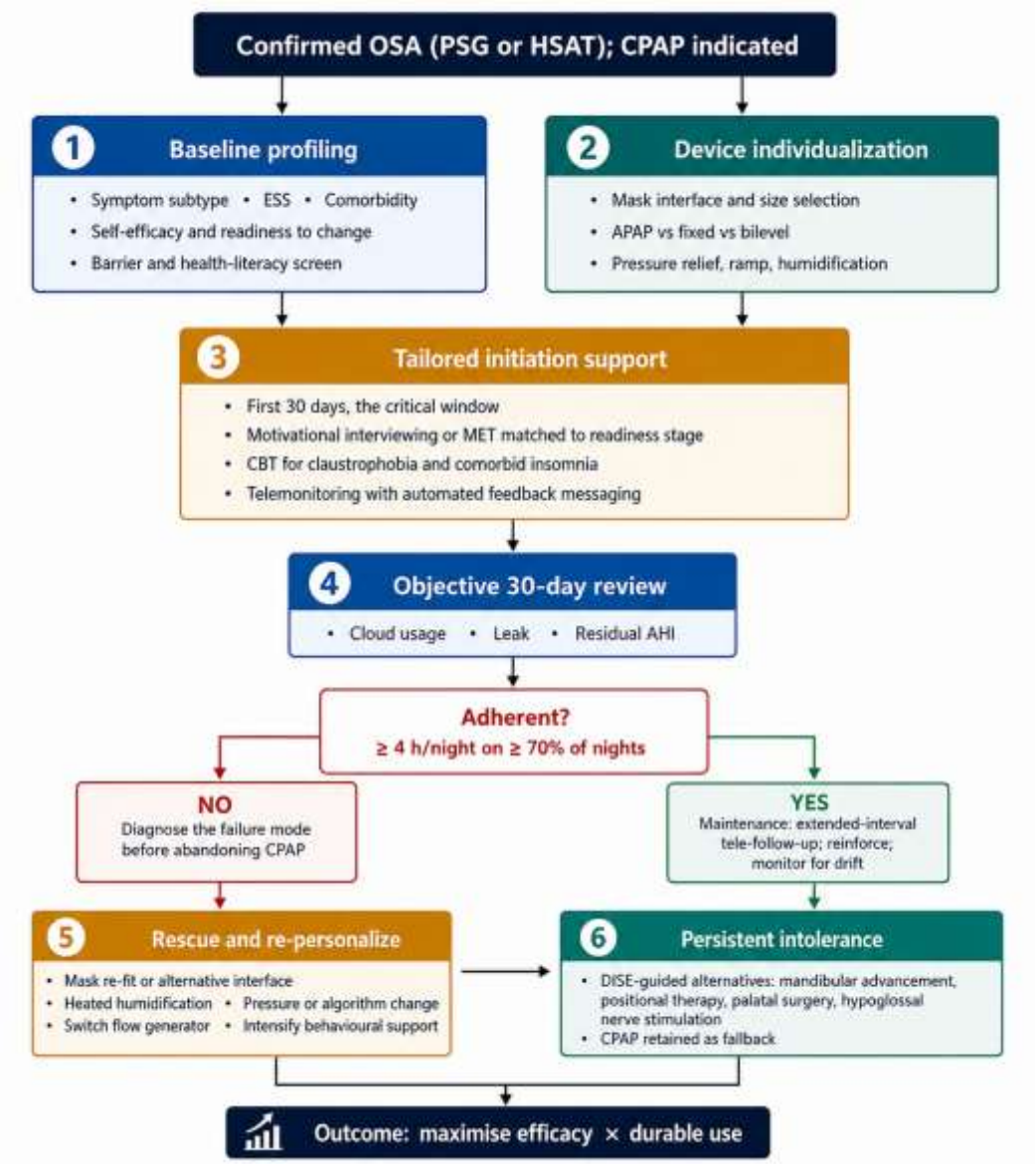


Figure 2. A stepped, personalized CPAP treatment pathway

4.1 Patient phenotyping and endotyping

Clinical phenotyping by cluster analysis has evolved from a statistical curiosity to a clinically meaningful stratification tool. The reproducibility of the excessively sleepy, disturbed sleep and minimally symptomatic clusters in ethnically and geographically diverse cohorts is impressive (Keenan et al., 2018) and the demonstration that these clusters are associated with different cardiovascular risk (Mazzotti et al., 2019) elevates them from description to prognosis. Nevertheless, a balanced assessment must acknowledge several limitations. The choice of cluster solutions depends on the variables entered and the number of classes specified, and studies differ considerably in both. The same structure is not obtained for all cohorts and contradictory evidence of the cardiovascular relevance of subtypes remains (Trzepizur et al., discussed by Mazzotti et al., 2021). Clusters are also derived at population level and are not yet validated as a decision rule at the individual level. The balanced conclusion is that symptom subtyping is ready to inform expectation setting and trial enrichment but not yet to dictate treatment allocation.

Endotyping is less clinically mature but mechanistically more fundamental. Eckert et al. (2013) have proposed the PALM framework to classify patients based on upper-airway collapsibility and the contribution of nonanatomical features and

plausibly predict that patients with modest collapsibility and low arousal threshold should respond to nonanatomical therapies. This concept has proven useful in at least one important applied context: endotypic analysis of the STAR trial showed that responders to hypoglossal nerve stimulation were characterised by a higher arousal threshold, lower loop gain, and better muscle responsiveness (Op de Beeck et al., 2021). This represents precisely the mechanistic patient selection that precision medicine aims to achieve. The principal barrier to routine adoption is measurement: gold-standard trait estimation requires research-grade physiological assessment across multiple nights. Simplified polysomnography-derived estimates are evolving (Sands et al., 2018), but need to be prospectively validated against treatment outcomes before being recommended for practice.

4.2 Personalized interface and pressure optimization

The most immediate and most neglected act of personalisation is mask selection. Nasal masks are better tolerated than oronasal masks. Oronasal interfaces require higher therapeutic pressures and are associated with greater leak, but are still reflexively prescribed for mouth-breathing patients without addressing nasal obstruction first. A rational sequence is to evaluate and treat nasal pathology, trial a nasal interface with a chin strap, and reserve the oronasal mask for genuine failure of this approach.

Pressure delivery provides further individualisation. Auto-titrating positive airway pressure (APAP) allows for dynamic pressure adjustments and is a reasonable default for uncomplicated OSA, although meta-analytic comparisons show broadly similar adherence between APAP and fixed CPAP with differences on the order of minutes (Chen et al., 2020). This finding tempers marketing claims: APAP is a convenience and titration tool rather than an adherence intervention in its own right. Bilevel therapy is indicated in pressure intolerance at high pressures, coexisting hypoventilation and obesity hypoventilation syndrome. Bilevel therapy is not better than CPAP for adherence in unselected patients. Expiratory pressure relief and ramp features increase comfort but, again, with inconsistent impact on hours of use. Heated humidification reduces nasal and oropharyngeal symptoms and should be offered liberally, especially in dry climates and to older patients, while recognising that comfort gains do not automatically translate into usage gains.

Personalisation of the flow generator itself represents one of the more novel proposals in this field. Yamauchi et al. (2024) advocate individualised therapy with CPAP, in which device and algorithm selection precedes any change to alternative treatment. Their rationale is grounded in endotypic reasoning. A rapid rise in pressure can interrupt sleep in a patient with a low arousal threshold, while a gradual rise in pressure may fail to reopen the airway in a patient with a highly collapsible airway and impaired compensatory response. Bench data show that DreamStation, AirSense and Murata devices respond to the same simulated apneas with significantly different pressure trajectories. The hypothesis is compelling and immediately testable. Yet, as the authors themselves admit, no prospective trial has yet matched algorithm to endotype. This represents one of the highest-yield and lowest-cost research opportunities currently available in the field, requiring no new hardware but only a randomised comparison.

Table 2. Personalized interventions and their clinical effectiveness

Intervention	Best available evidence	Reported effect on adherence	Critical appraisal
Motivational interviewing / motivational enhancement therapy	Scoping review of 11 RCTs (Rapelli et al., 2021); RCT (Aloia et al., 2013)	9 of 11 RCTs favoured motivational arms; benefit up to ~1.5 h/night in some trials	Effects strongest short term and often not sustained. Only 4 of 11 trials tailored to readiness. Treatment fidelity assessed in 2 of 11. All enrolled naive users
Behavioural interventions pooled (educational, supportive, behavioural)	Cochrane review of 41 studies (Askland et al., 2020)	Behavioural therapy increased use by ~1.31 h/night; ESS reduced by ~2.42 points	Largest and most rigorous synthesis. Heterogeneity high; low to moderate certainty. Durability beyond 6 months poorly established
Personalized written	RCT (Roecklein et al.,	Non-significant on	Underpowered (n = 30).

feedback	2010)	objective use; d = 0.77 to 0.80 at 2 weeks	Demonstrates that tailoring cannot overcome structural and economic barriers. Effect sizes justify adequately powered replication
Telemonitoring with automated feedback	Meta-analysis of 19 RCTs, n = 2,464 (Chen et al., 2020); Tele-OSA RCT, n = 1,455 (Hwang et al., 2018)	+0.68 h/night (95% CI 0.48 to 0.89); Tele-OSA: +36 to 60 min/night at 90 days	Consistent, scalable, cost-effective. Tele-education alone did not improve usage, only clinic attendance. Long-term durability less certain
APAP versus fixed CPAP	Meta-analyses of RCTs	Differences of minutes per night; not clinically decisive	APAP is a titration convenience, not an adherence intervention. Should not be marketed as such
Heated humidification	RCTs and observational series	Improves comfort; inconsistent effect on hours of use	Illustrates the general rule that side-effect relief alone is insufficient to change behaviour
Device and algorithm re-personalization	Bench testing and clinical observation (Yamauchi et al., 2024; Isetta et al., 2015)	Not yet quantified in prospective trials	Mechanistically compelling, immediately testable, currently unproven. High-priority research gap
Mandibular advancement device (for CPAP failure)	Randomized crossover trial (Phillips et al., 2013)	Lower efficacy on AHI but superior adherence; equivalent health outcomes at 1 month	The clearest demonstration that effectiveness equals efficacy multiplied by use. Short follow-up; requires dental suitability
Hypoglossal nerve stimulation (for CPAP failure)	STAR trial (Strollo et al., 2014); endotypic analysis (Op de Beeck et al., 2021)	Median AHI 29.3 to 9.0 events/h at 12 months; high self-reported nightly use	Single-group design with therapy-withdrawal substudy. Strict selection criteria limit generalizability. Costly and invasive

5. DIGITAL HEALTH AND SMART CPAP TECHNOLOGIES

Modern CPAP machines are cloud-connected sensors that send daily data on usage, residual respiratory events, mask leak, and pressure delivered. This telemetry has transformed adherence from an inherently self-reported and therefore unreliable construct to a continuously measured digital biomarker, providing the substrate upon which scalable personalization can be built. The evidence for telemonitoring is among the most robust in this review. In a meta-analysis of 19 randomized trials in 2,464 patients, telemonitored care increased use by 0.68 hours per night compared with usual care, with moderate heterogeneity (Chen et al., 2020). The study with the clearest methodological implications was the Tele-OSA trial, a four-arm factorial RCT with 1,455 patients enrolled, where telemonitoring with automated feedback messaging increased ninety-day adherence by 36 to 60 minutes per night, but telemedicine-delivered education did not significantly improve usage at all (Hwang et al., 2018). The factorial design supports an inference that few other studies permit, namely that the feedback loop and accountability, rather than information transfer, drive behavioural change. Telemonitoring during habituation preserved adherence at one year while reducing care time and cost, according to Contal et al. (2021), and a systematic review of eHealth interventions found similar results (Aardoom et al., 2020).

Mobile health applications extend this logic into the patient's daily routine, providing education, troubleshooting, gamified goals and tailored motivational messaging. Libraries of motivational messages specific to CPAP have been developed and

content validated (Alismail & Olfman, 2020). Their effectiveness depends on content and on the presence of a feedback loop rather than on connectivity per se, and engagement declines over time, as is well documented across consumer digital health. Consumer-grade sleep trackers and wearables provide contextual information about sleep duration and regularity that is relevant to CPAP use because it is limited by time in bed and sleep timing irregularities are likely to threaten adherence. However, consumer devices are not validated for respiratory event detection and should not be used for diagnostic purposes. Digital technologies are summarized in Table 3.

Table 3. Digital health technologies in personalized CPAP management

Technology	Function	Evidence	Limitations and unresolved issues
Cloud-based telemonitoring	Nightly transmission of usage, leak, residual AHI and pressure; triggers proactive outreach	Meta-analysis: +0.68 h/night (Chen et al., 2020). Tele-OSA: +36 to 60 min/night (Hwang et al., 2018)	Requires connectivity and staff to act on alerts. Alert fatigue. Benefit may attenuate once novelty passes
Automated feedback messaging	Algorithmic, usage-triggered encouragement and troubleshooting prompts	Superior to tele-education in a factorial RCT (Hwang et al., 2018)	The active ingredient appears to be accountability. Optimal message frequency and tone not established
Smartphone applications and patient portals	Self-monitoring, education, gamification, motivational message libraries	Content-validated libraries (Alismail & Olfman, 2020); eHealth meta-analysis (Aardoom et al., 2020)	Engagement decays. Digital divide risks widening inequity in exactly the groups with lowest adherence
Smart CPAP and IoT-enabled devices	Auto-titration, adaptive algorithms, remote pressure adjustment	Bench data show large inter-device differences (Isetta et al., 2015; Yamauchi et al., 2024)	Remote pressure change is technically trivial but clinically unregulated in many systems. Endotype matching untested
Digital biomarkers	Usage trajectory, leak pattern, residual AHI, night-to-night variability	Early usage predicts long-term adherence (Budhiraja et al., 2007)	No consensus on which derived features are prognostically optimal. Not yet standardised across manufacturers
Wearables and consumer trackers	Sleep duration, regularity, contextual behavioural data	Useful for indexing usage to time in bed	Not validated for respiratory event detection. Should not replace HSAT or PSG

6. CONCLUSION

CPAP is a highly effective therapy whose real-world value is consistently limited by inadequate use. Two decades of device refinement have not altered the population adherence curve, and the reason is now well established: non-adherence is not a hardware limitation but a multifactorial behavioural problem. The evidence gathered here backs four kinds of personalization, each addressing a different layer. Behavioural tailoring, through motivational interviewing, motivational enhancement therapy and cognitive behavioural therapy, increases nightly use by approximately one hour, although these gains attenuate over time and the interventions have, notably, been evaluated predominantly in already-motivated patients. Telemonitoring with automated feedback offers a smaller benefit but scales cheaply, and the cleanest evidence suggests its active ingredient is accountability rather than information. Device-level personalization, encompassing mask selection and the matching of flow generator and pressure algorithm to the individual, is mechanistically sound yet largely untested, which is precisely why it

represents the most attractive near-term research target. And phenotype- or endotype-guided care, informed by drug-induced sleep endoscopy, gives a principled way to choose among CPAP, mandibular advancement, positional therapy, surgery and hypoglossal nerve stimulation once CPAP has truly failed.

Each of these levels is insufficient on its own, and the literature's consistent pattern of partial, transient benefit is exactly what one would anticipate from interventions that target a single layer of a multilayered issue. The clinical implication is a stepped, patient-centred pathway that profiles the patient before starting, intervenes intensively during the critical first month, re-personalizes the device before abandoning CPAP and then moves to alternatives. The organizing principle throughout is that effectiveness is the product of efficacy and durable use. The therapy that a patient will reliably use may be preferable to the therapy that performs optimally under laboratory conditions. Realising this vision will require standardized metrics, fidelity-aware behavioural trials, prospective validation of endotype-directed allocation, artificial intelligence evaluated on clinical outcomes rather than discrimination, and a sustained commitment to equity. Precision sleep medicine is not one technology. It is a disciplined synthesis of respiratory physiology, behavioral science and health-system design in service to the individual patient.

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