Nitrous Oxide Mitigation in Dentistry

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Authors Declaration

I declare that this thesis is my own work and has not been submitted, in whole or in part, for any other qualification. All sources have been appropriately acknowledged, and the research was conducted in accordance with approved ethical standards and institutional guidelines.

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Dedication

This work is dedicated to my late father, Ahmad Abdulsamad, whose memory continues to guide me. Though he will never read these words, his support and love made them possible.

Abstract

Nitrous oxide (N_2O) remains a cornerstone of paediatric dental sedation, valued for its safety profile, anxiolytic effect, and ease of delivery. However, its high global warming potential presents a significant environmental challenge, particularly within the context of the NHS Net Zero agenda. This thesis aimed to evaluate whether paediatric sedation can be delivered more sustainably without compromising patient care, and to provide practical tools to support this transition.

The research was conducted in three interlinked phases. First, a literature review and scoping review were undertaken to assess the range of sedation options for children, explore emerging alternatives to N_2O, and evaluate their clinical effectiveness, safety, and potential environmental impact. Second, a multi-cycle local quality improvement project (QIP) was implemented at a UK dental hospital, measuring N_2O use, justification, success rates, carbon dioxide equivalent (CO_2e) emissions, and wastage over four audit cycles. The QIP achieved a 20% reduction in CO_2e emissions, aligning with national sustainability targets. Third, drawing on these findings, a simplified N_2O mitigation toolkit was developed, refined through peer review, and piloted with UK-based dental professionals using qualitative feedback gathered via focus groups.

Results indicated that baseline awareness of N_2O's environmental impact was limited, yet participating clinicians demonstrated strong motivation to adopt sustainable practices when provided with clear, practical, and visually intuitive resources. The toolkit was regarded as relevant, usable, and implementable, with feedback highlighting minor adjustments to improve accessibility. Key barriers to widespread adoption included time constraints and limited visibility of national guidance.

This thesis demonstrates that sustainable paediatric sedation is achievable and deliverable without compromising safety or clinical outcomes. By integrating evidence synthesis, real-world audit, and co-designed implementation tools, it provides a scalable, evidence-based pathway for reducing N_2O emissions in dentistry, contributing to both patient wellbeing and environmental stewardship.

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Key Words

Dental Anxiety; Paediatric Dentistry; Behaviour Management; Conscious Sedation; Inhalation Sedation; Nitrous Oxide; Carbon Footprint; Sustainability.

List of Abbreviations

AAPD	American Academy of Paediatric Dentistry
ADA	American Dental Association
AMA	American Medical Association
ASA	American Society of Anaesthesiologists
BSPD	British Society of Paediatric Dentistry
CNS	Central Nervous System
COSHH	Control of Substances Hazardous to Health
CO,e	Carbon dioxide emissions
CPD	Continuing Professional Development
DDent	Doctorate of Dentistry
EAPD	European Academy of Paediatric Dentistry
EDH	Eastman Dental Hospital
ENT	Ears, Nose, and Throat
FIS	Facial Imaging Scale
GA	General Anaesthesia
GABA	Gamma-Aminobutyric Acid
GWP	Global Warming Potential
HSE	Health and Safety Executive
IACSD	Intercollegiate Advisory Committee for Sedation in Dentistry
IM	Intramuscular
IN	Intranasal
IOSN	Index of Sedation Need
IPCC	Intergovernmental Panel on Climate Change
IS	Inhalation Sedation
IV	Intravenous
KPI	Key Performance Indicator

LA	Local Anaesthetic
LPM	Litres per Minute
MAC	Minimum Alveolar Concentration
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NMDA	N-methyl-D-aspartate
NPBMT	Non-Pharmacological Behaviour Management Techniques
N_2O	Nitrous Oxide
O_2	Oxygen
PONV	Postoperative Nausea and Vomiting
PPM	Parts Per Million
QIP	Quality Improvement Project
RCSE	Royal College of Surgeons of England
SDCEP	Scottish Dental Clinical Effectiveness Programme
UK	United Kingdom
WEL	Workplace Exposure Limit
WHO	World Health Organization

Impact Statement

Nitrous oxide (N_2O) remains one of the most widely used agents for inhalation sedation in paediatric dentistry, providing an effective and well-tolerated means of managing dental fear and anxiety (Hosey, 2002). However, nitrous oxide is also a potent greenhouse gas, with environmental consequences that are increasingly difficult to ignore (Ryan and Nielsen, 2010). As the healthcare sector faces mounting pressure to reduce its carbon footprint, dentistry must examine how essential services like sedation can be delivered more sustainably—without compromising patient care (Duane *et al.*, 2020).

This DDent project addresses a critical gap in the intersection between clinical practice and environmental responsibility. Recognising that inhalation sedation remains essential for many children, this research does not aim to eliminate its use, but to optimise it. Through a three-part structure, the project explores whether alternatives to nitrous oxide are viable (Part 1), evaluates how nitrous oxide is currently being used through a quality improvement project (Part 2), and culminates in the development and piloting of a practical toolkit to support more sustainable sedation practice (Part 3).

By combining a review of the available evidence, clinical audit, and qualitative feedback from practitioners, this work offers a structured, realistic pathway for dental services to reduce nitrous oxide related emissions while maintaining high standards of paediatric care. It also contributes to a growing conversation around sustainability in healthcare and demonstrates how even small, context-specific behavioural changes can lead to measurable environmental gains. The outcomes of this project support broader NHS goals to make healthcare more environmentally responsible and demonstrate how sustainability can be embedded into daily practice in a way that is achievable, effective, and aligned with patient care (Chakera *et al.,* 2021).

Chapter 1

Introduction

1.1 Sustainability in Dentistry

Climate change, largely driven by rising greenhouse gas emissions, is widely regarded as one of the greatest threats to global public health, with profound implications for future generations (Royal College of Surgeons of England, 2023). In the United Kingdom alone, air pollution is estimated to contribute to over 28,000 premature deaths each year (Public Health England, 2019). Without urgent intervention, the health impacts of climate change are expected to worsen, with more frequent heatwaves, flooding, and pollution episodes increasing the risk of respiratory disease, water-borne illness, and premature mortality (World Health Organization, 2015).

In response, the United Kingdom introduced the Climate Change Act in 2008, and the National Health Service (NHS) has since committed to becoming the world's first net-zero health system (National Health Service, 2022). Under the Delivering a Net Zero NHS plan, the NHS has pledged to reduce its carbon footprint to net-zero by 2040 for emissions it directly controls, and by 2045 for the wider supply chain and services it influences (National Health Service, 2020).

Dentistry, like all healthcare services, contributes to this footprint (Duane *et al.*, 2020). A national analysis identified that staff commuting and patient travel account for the majority of dental-related emissions—33.4% and 31.1% respectively—followed by procurement, energy use, and the use of nitrous oxide (Royal College of Surgeons of England, 2023).

Among these, anaesthetic gases stand out as a modifiable source of emissions within direct clinical control**.** Nitrous oxide alone accounts for approximately 75% of all anaesthetic gas emissions in healthcare settings (Royal College of Anaesthetists, 2020). Although 70% of nitrous oxide emissions are of natural origin, the remaining

30% result from human activity, including medical and dental use (Charlesworth and Swinton, 2017). With a global warming potential (GWP) of 298, nearly 300 times that of carbon dioxide, nitrous oxide is now recognised as the third most abundant greenhouse gas in the atmosphere after carbon dioxide (CO_2) and methane (IPCC, 2023).

In recent years, there has been a visible cultural shift towards more sustainable practice. Clinicians are being encouraged to reduce single-use plastics, limit unnecessary travel, adopt digital workflows, and reconsider procurement and decontamination practices (Duane et al., 2021). Life cycle assessments have helped identify "hot spots" in dental workflows, such as disposable instruments, that could be targeted for meaningful change (Duane et al., 2021). These efforts reflect a growing recognition that dental sustainability is not limited to recycling policies but includes a broader re-evaluation of how care is delivered.

This creates a particular challenge for paediatric dentistry, where nitrous oxide has long played a central role in behaviour management and pain control. Yet its significant environmental burden offers a unique opportunity for meaningful, measurable improvement. It is one of the few areas where clinicians can directly influence sustainability outcomes without compromising patient safety or experience.

Before examining the clinical role of nitrous oxide in more detail, it is important to first explore the reasons why children may require sedation—including how they experience dental care, their perception of pain, and the behavioural strategies commonly used to support them. This context is essential to understanding the balance between clinical benefit and environmental responsibility.

1.2 Child Cognitive Development and Key Milestones

Theorists such as Piaget and Vygotsky developed cognitive development theories to help better understand the child development and cognitive abilities. Jean Piaget’s theory proposed that young children think differently from adults and pass through discrete, identifiable stages of development (Mcleod, 2009). These four stages are: sensorimotor stage, pre-operational stage, concrete operational stage, and formal operational stage. However, Piaget’s model does not account for the influence of cultural and social context. In contrast, Lev Vygotsky’s theory suggests that all

children begin with basic mental functions such as attention, sensation, perception, and memory (Mcleod, 2009). As the child has interactions within their socio-cultural environments, they achieve higher level of mental functions.

While these theories offer valuable frameworks for understanding how children think and behave at different ages, they remain theoretical models. In clinical settings, recognising key developmental milestones can provide a more practical reference for anticipating a child's behavioural and emotional responses during dental treatments. **Table 1** summarises key developmental milestones in childhood (Albadri and Stevens, 2021). A child's age, maturity, and attainment of developmental milestones influence which behaviour management strategies are appropriate and likely to be effective. For example, if inhalation sedation is considered, the child's ability to understand and cooperate with nasal breathing is critical for the technique's success (Albadri and Stevens, 2021). Furthermore, these developmental considerations underpin how children perceive and respond to pain, which is central to the delivery of dental care.

Age	Gross motor	Vision and fine motor	Hearing, speech and language	Social, emotional and behavioural
Newborn	Flexed posture	Fixes and follows faces	Still to voice Startles to loud noise	Smiles by 6 weeks
7 months	Sits without support Crawls	Transfers objects from hand to hand	Turns to voice Babel	Finger feeds
1 year	Stands independently	Pincer grip Points Puts blocks in cup	One to two words Understands name	Indicates wants Waves
15-18 months	Walks independently	Immature grip of pencil Random scribble	Six to 10 words Points to body parts	Feed self with spoon Beginning to help with dressing
2 ½ years	Runs and jumps Kicks ball Climbs stairs	Draws	Three to 4 word sentences Understands joined commands	Parallel play

Table 1: Key milestones in child development

Adapted from Albadri and Stevens (2021)

1.3 Perception of Pain in Children

Pain is defined as “an unpleasant sensory and emotional experience arising from actual or potential tissue damage” (Committee on Advancing Pain Research and Care, 2011). Pain functions to protect tissues by triggering changes in the central nervous system (CNS) before or during a potentially harmful event (Clark and Brunick, 2015). Pain receptors (nociceptors) are the first to detect a stimulus (Stoelting and Hillier, 2012). These are nerve endings that record the occurrence, intensity duration and location of the sensation. Pain signals originate at the site of

tissue injury and travel through the peripheral nerves to the spinal cord and ultimately to the brain, where they are processed and perceived as pain (Hirst, 1985).

This pathway can be influenced by various physiological mechanisms. One such mechanism involves endogenous opioids, natural chemicals like endorphins and enkephalins, that bind to opioid receptors in the brain and spinal cord; modulating the pain response (Clark and Brunick, 2015). Anaesthetic agents such as nitrous oxide contribute to pain modulation by interacting with the body's endogenous opioid system.

Assessing pain in children is particularly challenging, as it is often reported by parents. A range of individual factors can influence how a child experiences and expresses pain. These include the child's age and developmental level, social and medical history, and previous pain experiences (Cameron and Widmer, 2013). A child's cognitive maturity is especially important in shaping their perception of pain; for instance, children under the age of two are generally unable to distinguish between pressure and pain, often necessitating treatment under general anaesthesia (GA) (O'Rourke, 2004).

Between ages two and ten, most children begin to differentiate pain from other sensations, but many may still require general anaesthesia for invasive procedures. Older children, typically over ten years of age, are usually better able to understand explanations, cooperate with local anaesthesia, and respond well to treatment, especially when supported by appropriate sedation strategies.

Effective pain management is essential in paediatric dentistry, not only to improve immediate outcomes, but also to prevent the development of dental fear and anxiety. Any past experience involving pain is likely to increase anxiety at future visits (Twycross *et al.,* 2009).

1.4 Dental Anxiety in Children

Anxiety is defined as “a vague, unpleasant emotional state with qualities of apprehension, dead, distress and uneasiness” (Venes, 2005). Fear, by contrast, is the emotional response to an identifiable threat, while phobia refers to a persistent and irrational fear of a specific object, activity, or situation that results in avoidance behaviours (Venes, 2005). Although these terms are sometimes used interchangeably, fear is generally considered a more intense reaction to a specific stimulus**,** whereas anxiety reflects a more diffuse emotional state.

Dental anxiety in children is shaped by both intrinsic and extrinsic factors. While anxiety is a recognised personality trait, certain influences can increase its expression in the dental setting, including parental anxiety, past traumatic experiences, temperament, and a lack of coping strategies (Campbell *et al.*, 2011).

Internationally, a systematic review by Grisolia *et al.,* (2021) found a pooled global prevalence of 24% among children. This has profound implications as it can delay dental visits, reduce adherence to preventive care, and exacerbate disease progression, particularly in vulnerable populations. Children with dental anxiety are at higher risk of caries and are less likely to benefit from early interventions.

Dental anxiety also affects dental professionals. While clinicians report a sense of responsibility to support children with anxiety, managing such cases is frequently a source of occupational stress and can result in longer appointment times, lower treatment efficacy, and higher costs. An anxious patient may require up to 20% more clinical time, and anxiety can lead to increased likelihood of pain reporting.

Dental anxiety often begins in early childhood and, if unaddressed, can persist into adulthood (Chadwick and Hosey, 2017). It can lead to avoidance of care, reduced cooperation, and poorer oral health outcomes. Therefore, assessing dental fear and anxiety early allows clinicians to choose an appropriate treatment modality and avoid reinforcing negative experiences. If the treatment approach is poorly matched to the child’s needs, it can not only fail but also exacerbate existing anxiety.

Given this, understanding and identifying anxiety levels early is critical to selecting the most suitable behavioural or pharmacological strategies.

1.5 Measuring Dental Anxiety

Dental anxiety can be assessed using several approaches: parental or child reports, behavioural observation, physiological indicators (e.g. heart rate) and validated self-report scales when possible (Chadwick and Hosey, 2017). Parental reports are often unreliable, as they may underestimate or overestimate a child's feelings, while physiological measures require equipment and can themselves provoke anxiety. Behavioural observation (such as restlessness or gripping the dental chair) provides useful clues but lacks consistency across children and situations. For this reason, standardised self-report scales remain the most widely used and validated tools for assessing dental anxiety in children (Porritt *et al.*, 2013).

The Facial Image Scale (FIS) (**Figure 1**) is one of the simplest instruments, consisting of a row of five faces ranging from very happy to very unhappy (Buchanan and Niven, 2002). Children are asked to point to the face that best represents how they feel about dental treatment (Buchanan and Niven, 2002). It is quick, requires no reading ability, and can be used from as young as three years. However, while highly practical, the FIS provides only limited information, as it does not identify specific sources of anxiety (Porritt *et al.*, 2013).

The Modified Child Dental Anxiety Scale (MCDAS) is a validated questionnaire suitable for children aged eight years and older. It comprises eight questions relating to common dental procedures, each rated on a five-point Likert scale from 1 (relaxed) to 5 (very worried) (Porritt *et al.*, 2013). The MCDASf (**Figure 2**) is a visual format that incorporates facial expressions to make it more accessible for younger children or those with limited literacy (Howard and Freeman, 2007). Both versions are practical in clinical settings and can be used to monitor changes in anxiety over time, supporting tailored behaviour management strategies.

The Venham Picture Test (VPT) (**Figure 3**) is another child-friendly measure (Buchanan and Niven, 2002). It consists of paired cartoon figures portraying contrasting emotions, where the child selects the figure that best reflects how they feel. It is easy to administer, requires minimal verbal explanation, and has been validated for use in children as young as five years. Unlike the FIS, it provides slightly richer information, although interpretation can still be subjective (Porritt *et al.*, 2013).

Collectively, these scales provide dentists with structured, reproducible tools for recognising and addressing anxiety in children. By helping to identify the most appropriate behaviour management modality, they not only support the child's immediate comfort but also improve the likelihood of treatment success. This has relevance to conscious sedation with nitrous oxide, where identifying the right candidates is significant to both clinical outcomes and the responsible use of resources. In this way, dental anxiety measurement forms an important bridge between child psychology, behaviour management, and sustainable clinical practice.

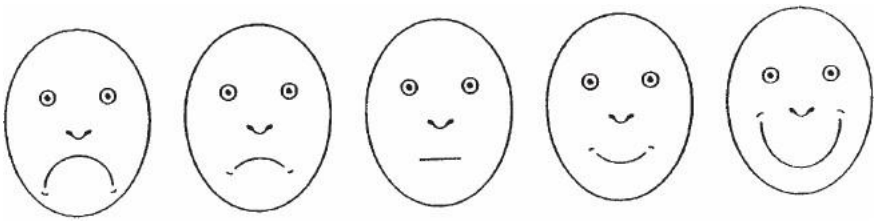


Figure 1: Facial Imaging Scale (FIS)

For the next eight questions I would like you to show me how relaxed or worried you get about the dentist and what happens at the dentist. To show me how relaxed or worried you feel, please use the simple scale below. The scale is just like a ruler going from 1 which would show that you are relaxed, to 5 which would show that you are very worried.

1 would mean : relaxed/not worried
2 would mean : very slightly worried
3 would mean : fairly worried
4 would mean : worried a lot
5 would mean : very worried.

How do you feel about …					
…going to the dentist generally?	1	2	3	4	5
…having your teeth looked at?	1	2	3	4	5
…having your teeth scraped and polished?	1	2	3	4	5
…having an injection in the gum?	1	2	3	4	5
…having a filling?	1	2	3	4	5
…having a tooth taken out?	1	2	3	4	5
…being put to sleep to have treatment?	1	2	3	4	5
…having a mixture of “gas and air” which will help you feel comfortable for treatment but cannot put you to sleep?	1	2	3	4	5

Figure 2: Modified Child Dental Anxiety Scale (faces) (MCDASf)

Figure 3: Venham Picture Test (VPT)

1.6 Behaviour Management Techniques

Behaviour management is a fundamental part of paediatric dentistry, ensuring that children can receive dental care in a safe, supportive, and positive environment. It is no longer viewed purely as a means of securing compliance for treatment, but rather as a broader process of shaping long-term attitudes towards oral health. Effective management therefore extends beyond the surgery chair to include the atmosphere of the clinic, the consistency of communication from the entire dental team, and the trust established with both the child and their caregiver (Wright and Kupietzky, 2014). Wright described this collaborative approach as a “treatment alliance,” in which empathy, reassurance, and consistency foster cooperation and reduce anxiety. Modern approaches emphasise that behaviour management is not simply about getting through a single appointment but about encouraging children to develop

confidence and a willingness to return for future care. It begins even before the child enters the surgery. Tone of voice, body language, and positive reinforcement from the whole team—reception staff, nurses, and dentists—contribute to how the child perceives the dental experience. This shift reflects the recognition that children's behavioural responses are influenced not only by developmental and cognitive abilities, but also by their previous dental experiences, personality, anxiety levels, and coping strategies (Pinkham, 1995).

Behaviour management can broadly be divided into non-pharmacological and pharmacological techniques (Chadwick and Hosey, 2017). Non-pharmacological methods, such as communication strategies and behavioural interventions, are usually considered first-line and will be outlined in the following section, before progressing to pharmacological options when required (Wright and Kupietzky, 2014).

1.6.1 Non-Pharmacological Behaviour Management Techniques

Standard non-pharmacological behaviour management techniques (NPBMT) include widely used techniques such as tell-show-do, positive reinforcement, distraction, modelling, and systematic desensitisation (Campbell *et al.*, 2011). The tell-show-do method involves explaining procedures in age-appropriate terms, demonstrating the instruments or sensations, and then proceeding with treatment. Positive reinforcement, such as verbal praise ("well done for keeping your mouth open"), strengthens desired behaviours. Distraction strategies may involve storytelling, cartoons, interactive games, or simple physical actions such as raising legs during radiographs. Modelling, whether live or via video, encourages compliance by allowing the child to observe peers who cope successfully and are rewarded. Systematic desensitisation gradually introduces anxiety-provoking stimuli, supporting children to tolerate feared procedures over time (Campbell *et al.*, 2011).

Less commonly used techniques include voice control, selective parental exclusion, and historically aversive methods such as hand-over-mouth (HOM). These are now discouraged or prohibited in many regions, these have historically been used to gain control in highly disruptive scenarios. The use of physical restraint, such as papoose boards or clinical holding, raises ethical concerns and should only ever be considered when absolutely necessary to prevent harm or ensure safety. The BSPD's 2016 guidance on clinical holding emphasises that restraint should only be

used when all other techniques have failed, with explicit parental consent, trained staff, and meticulous documentation (BSPD, 2016). The guiding principles are to do no harm, act in the child's best interest, and respect the child's right to refuse treatment (Adewale, 2012). In practice, NPBMT should always be considered firstline (Wright and Kupietzky, 2014). Escalation to pharmacological methods is only appropriate when the child's behaviour, medical status, or treatment complexity requires additional support.

1.6.2 Pharmacological Behaviour Management

Pharmacological behaviour management in paediatric dentistry encompasses three key approaches:

- Local anaesthesia (LA).
- Sedation (inhalation, oral, transmucosal, intravenous, intramuscular, or rectal routes).
- General anaesthesia (GA).

The decision to use one or more of these techniques depends on several factors including the child's cognitive development, medical status, anxiety level, and the complexity and invasiveness of the proposed dental procedure (Adewale, 2012). While non-pharmacological techniques are always preferred as a first-line approach, pharmacological methods play a crucial role in enabling treatment for children who cannot tolerate care otherwise.

1.7 Local Anaesthesia

Local anaesthesia remains a fundamental component of pain control in paediatric dental care. Commonly used agents include lidocaine and prilocaine, often combined with vasoconstrictors such as epinephrine or felypressin to enhance haemostasis and prolong the anaesthetic effect (**Table 2**) (Adewale, 2012). While the techniques used mirror those in adult dentistry, the anatomical differences in children—particularly reduced bone density—allow for quicker diffusion, a faster onset, and typically a shorter duration of action. As a result, smaller volumes of anaesthetic are generally required. However, the effectiveness of local anaesthesia can be significantly reduced in the presence of infection, due to changes in tissue pH that

impair drug absorption. Maximum recommended doses vary by agent, and safe dosing must be adjusted according to the child's weight and age.

Local anaesthetic solution	Maximum dose
2% lidocaine/1:80 000 epinephrine	4.4 mg kg^{-1}
3% prilocaine/felypressin	6.6 mg kg^{-1}
4% prilocaine	5 mg kg^{-1}

Table 2: Maximum dosage of local anaesthetic agents commonly used for paediatric dentistry

Adapted from Adewale (2012)

1.8 Sedation

1.8.1 Indications of Sedation

Sedation plays a valuable role in supporting dental treatment when conventional NPBMT are insufficient. It most often considered for children who experience significant dental anxiety or phobia, those requiring extensive or potentially distressing procedures, and for patients with medical or behavioural conditions that limit cooperation (Scottish Dental Clinical Effectiveness Programme, 2017). Sedation may also be indicated if unmanaged stress could exacerbate an underlying medical condition, or for patients with additional care needs (SDCEP, 2017).

Professional responsibilities are clearly defined within national guidance. The assessing clinician must complete a comprehensive assessment and explore all appropriate alternatives before recommending sedation (SDCEP, 2017). Where sedation is justified, conscious sedation is the preferred option (see section 1.8.2), and the rationale must be documented with relevant clinical information. Parents or carer should be fully involved in treatment planning and informed about what to expect.

For the clinician providing sedation, whether as an operator-sedationist or as part of a separate sedation team, responsibilities include:

- conducting a thorough pre-sedation assessment,
- selecting the most appropriate technique,
- obtaining informed consent, and

- delivering the sedation safely while maintaining clear communication with both child and parent throughout.

1.8.2 Definitions and Levels of Sedation

Terminology differs internationally. In the United States (US), the American Society of Anesthesiologists (ASA) describes a continuum of sedation- minimal, moderate, deep and general anaesthesia (**Table 3**) (American Society of Anesthesiologists, 2018). These levels represent progressive depression of consciousness with decreasing ability to maintain airway control, respond to stimuli, or sustain cardiorespiratory function.

In contrast, United Kingdom (UK) guidance centres on conscious sedation as the safe and acceptable boundary within dentistry (Scottish Dental Clinical Effectiveness Programme, 2017). While deep sedation and general anaesthesia remain part of the continuum, they are restricted to hospital-based practice where enhanced monitoring and support are available (Intercollegiate Advisory Committee on Sedation in Dentistry, 2020).

Conscious sedation is defined in UK practice as:

“A technique in which the use of a drug or drugs produces a state of depression of the central nervous system enabling treatment to be carried out, but during which verbal contact with the patient is maintained throughout the period of sedation. The drugs and techniques used should carry a margin of safety wide enough to render loss of consciousness unlikely” (SDCEP, 2017).

This definition deliberately avoids prescribing specific drugs or delivery methods. Instead, it emphasises the safety margin and the central principle that the patient remains conscious, cooperative, and responsive throughout.

	Minimal Sedation (Anxiolysis)	Moderate Sedation/Analgesia ("Conscious Sedation")	Analgesia	General Anaesthesia
Responsiveness	Normal response to verbal stimulation	Purposeful** response to verbal or tactile stimulation	Purposeful** response following repeated or painful stimulation	Unarousable even with painful stimulus
Airway	Unaffected	No intervention required	Intervention may be required	Intervention often required
Spontaneous Ventilation	Unaffected	Adequate	May be inadequate	Frequently inadequate
Cardiovascular Function	Unaffected	Usually maintained	Usually maintained	May be impaired

Table 3: Continuum of depth of sedation. Adapted from American Society of Anesthesiologists (2018)

1.8.3 Guidelines for use

The safe delivery of paediatric dental sedation is underpinned by several national and international guidelines. In the UK, the Scottish Dental Clinical Effectiveness Programme (SDCEP, 2017) provides broad guidance on all types of dental sedation in children and adults. While it does not prescribe specific clinical techniques, it introduces key terminology, including definitions for age categories (e.g. a "child" as under 12, and a "young person" as 12–16 years), as well as the roles of sedation team members (**Table 4**).

Child	A person under 12 years of age
Young person	A person aged 12-16 years
Adult	A person aged 16 years or over
Dental sedation team	Clinical staff involved directly in sedation, including dedicated sedationist (dental professional, medical practitioner, anaesthetist), operator-sedationist and dental sedation nurse (or other sedation assistant)
Clinical team	Dental sedation team members and any additional clinical staff involved in the care and management of patients having sedation for dental treatment

Table 4: Definitions adapted from SDCEP (2017)

The Intercollegiate Advisory Committee for Sedation in Dentistry (IACSD, 2020) provides a more detailed national framework, addressing training requirements, clinical documentation, and governance. Although it applies across all sedation techniques, it specifically recognises nitrous oxide inhalation sedation (IHS) as the only technique that can be safely delivered by operator-sedationists without a separate sedationist, provided appropriate training and governance structures are in place.

The National Institute for Health and Care Excellence (NICE, 2010) offers broader guidance across medicine and surgery, classifying nitrous oxide as a form of minimal sedation. Although not dental-specific, it emphasises patient assessment, preparation, and intraoperative monitoring, reinforcing many of the safety principles later embedded in UK dental guidelines.

The European Academy of Paediatric Dentistry (EAPD) policy (Ashley et al., 2021) replaced earlier guidance by Hallonsten et al. (2005). It focuses on patient selection, safe technique, and the efficacy of sedative agents in children. Although not exclusive to nitrous oxide, it provides important context for paediatric practice.

Historically, Hosey's (2002) UK guidelines provided detailed recommendations for inhalation sedation in children. While superseded by the IACSD (2020) framework, they remain widely cited in paediatric dentistry literature and continue to inform current practice.

Internationally, the American Society of Anesthesiologists (ASA, 2018) Practice Guidelines for Moderate Procedural Sedation and Analgesia provide a multidisciplinary framework applicable across dentistry and medicine. These guidelines also describe sedation as a continuum, influencing how the UK situates conscious sedation within defined safety margins.

Most recently, the SDCEP surveillance review (2022) confirmed that the 2017 guidance remains valid and aligned with national standards, including IACSD (2020). Taken together, these documents demonstrate a high level of consensus: nitrous oxide inhalation sedation remains a safe, effective, and accessible technique when delivered within clear clinical, ethical, and governance frameworks. **Table 5** provides a summary of the most cited guidelines for paediatric dental sedation, highlighting their scope, applicability and relevance to nitrous oxide.

Guideline	Scope	Key Relevance	Nitrous Oxide (N_2O) Specifics
SDCEP (2017; 2022 update)	All types of dental sedation in both adults & children	Standards for assessment, staff training, facilities, and record keeping. Does not include clinical techniques.	Recognises N_2O as 'basic sedation technique'
IACSD (2020)		Comprehensive guidance including patient/ escort information, and detailed learning outcomes for training	For all conscious sedation techniques other than IS with N_2O/ O_2, competence in cannulation is mandatory
NICE (2010)	Sedation in medicine & surgery in children	Assessment, preparation, training and monitoring. Does not include specific dental-specific guidance	Classifies N_2O as minimal sedation
EAPD (Ashley *et al.*, 2021)	Dental sedation in children	Patient selection, safe clinical technique, sedative efficacy	
Hosey (2002)	All types of dental sedation in children	Indications/contraindications of sedation routes, and recommendations	Recommends N_2O sedation as the preferred technique
ASA (2018)	Sedation in medicine & surgery in children	Only addresses conscious "moderate" sedation	Classifies N_2O as minimal sedation when <50% administration & not combined with another sedative

Table 5: Summary of UK and international guidelines in conscious sedation (Author's own)

1.8.4 Pre-Assessment

A thorough pre-sedation assessment is fundamental to the safe and effective delivery of conscious sedation in children. It should be undertaken by appropriately trained healthcare professionals, with the findings fully documented in the clinical record (NICE, 2010; SDCEP, 2017; IACSD, 2020).

The primary aim is to establish the child's suitability for sedation by carrying out a structured evaluation of:

- Current medical condition and any surgical problems.
- Weight and growth status.
- Past medical history, including any adverse events during previous sedation or anaesthesia.
- Current and past medications, including allergies.
- Physical status- assessed using the American Society of Anesthesiologists (ASA) physical status classification (**Table 6**) - with particular attention to airway assessment.
- Psychological and developmental stage.

Where there is concern about potential airway or breathing compromise, if the child is classified as ASA physical status grade III or higher, or if the patient is an infant (including neonates), advice from a sedation or anaesthesia specialist should be sought prior to proceeding (SDCEP, 2017). In most primary care settings, only ASA I or II patients are considered suitable for conscious sedation (Hosey, 2002).

While formal assessment tools are well-established in adult sedation, there is currently no validated scale for assessing sedation need in paediatric patients. Coulthard et al. (2011) proposed the development of an Index of Sedation Need (IOSN), but this has not yet been adapted or validated for children. In practice, decision-making often relies on clinical judgment, supported by behavioural observations and past treatment history.

The assessment should also confirm that both an appropriately trained sedationist and an assistant will be present during the procedure, and that immediate access to appropriate resuscitation and monitoring equipment is available (IACSD, 2020).

The choice of sedation technique should be based on the complexity and nature of the planned procedure, the intended depth of sedation, any contraindications or anticipated side effects, and the preferences of the child and their parent or carer. Wherever possible, non-pharmacological behaviour management techniques (Section 1.6.1) should be considered before progressing to sedation.

To enable informed decision-making, families should be given verbal and written information about the proposed sedation method, available alternatives, and the associated risks and benefits (SDCEP, 2017). This discussion should ideally occur at a separate appointment before the day of treatment, allowing time for reflection and questions. Valid written consent must be obtained and recorded prior to sedation, covering the dental procedure itself, the sedation technique, and all relevant risks, benefits, and alternatives (SDCEP, 2017).

ASA Grade	Definition
ASA I	A normal healthy patient
ASA II	A patient with mild systemic disease
ASA III	A patient with severe systemic disease
ASA IV	A patient with severe systemic disease that is a constant threat to life
ASA V	A moribund patient who is not expected to survive without the operation
ASA VI	A declared brain-dead patient whose organs are being removed for donor purposes

Table 6: American Society of Anesthesiologists (ASA) Physical Status Classification System (2020)

1.8.5 Routes of administration, Equipment, and Training

The delivery of conscious sedation in paediatric dentistry can be achieved through several routes, each with distinct clinical considerations, advantages, and limitations. The Scottish Dental Clinical Effectiveness Programme (SDCEP, 2017) defines

standard techniques for children as inhalation sedation with nitrous oxide and oxygen, and for young people and adults as either inhalation sedation with nitrous oxide/oxygen or midazolam administered via any route. Any other sedation technique is classified as advanced (**Table 7**) and requires enhanced operator competencies, more extensive monitoring, and the ability to establish intravenous (IV) access in case of emergencies (IACSD, 2020).

Technique	Definitions and Associated Routes/Drugs
Standard sedation techniques Also known as: basic techniques	For all ages: IS with N_2O/O_2 For young people/adults: midazolam by any route (oral, IV, transmucosal)
Advanced sedation techniques **Also known as: alternative techniques**	For a child: midazolam by any route For all ages: drugs like ketamine, propofol, sevoflurane Combinations of drugs (e.g. midazolam + opioid or sevoflurane + N_2O) Combined routes of administration (oral + IV)

Table 7: Standard and advanced sedation techniques in dentistry. Adapted from SDCEP (2017)

Inhalation sedation (IHS) with nitrous oxide/oxygen remains the only standard sedation technique recommended for children in the UK. It requires purpose-designed machines with active scavenging, adequate room ventilation, and appropriate oxygen supply systems (IACSD, 2020). Monitoring is based on clinical signs alone (SDCEP, 2017), and the associated equipment and training requirements are minimal compared to advanced techniques.

Advanced techniques include oral, transmucosal, intravenous (IV), intramuscular (IM), and rectal routes. Transmucosal delivery covers both intranasal and buccal

administration, offering rapid absorption via the mucosa and avoiding the need for swallowing. This can be advantageous in patients with limited cooperation or when a rapid onset is desirable. Oral sedation, typically with midazolam, is easy to administer but has unpredictable absorption and depends on patient compliance. In some cases, oral sedation is used in combination with IV sedation to help anxious children tolerate cannulation; however, this remains an advanced technique requiring the same level of monitoring and competency.

Rectal administration also allows fast onset but is not used in the UK due to limited acceptance (Hosey, 2002). Intramuscular sedation provides predictable absorption but is invasive, may distress the child, and is difficult to titrate. Intravenous sedation (IV) allows careful titration to the patient's response but requires cannulation skills and is associated with increased monitoring requirements, including pulse oximetry and blood pressure recording.

For all conscious sedation techniques other than inhalation sedation with nitrous oxide/oxygen**,** the operator must be competent in IV access, even if IV delivery is not planned, to enable the prompt administration of reversal agents if required (IACSD, 2020). These techniques also require additional monitoring beyond clinical observation, typically including pulse oximetry and blood pressure measurement, and in some cases capnography, depending on patient risk and sedation depth. The most recent SDCEP (2022) surveillance report notes that routine capnography is not recommended for ASA I–II paediatric dental patients. Emergency preparation across all advanced techniques involves immediate access to an emergency cart, oxygen delivery systems, and appropriately trained personnel.

Table 8 summarises the main sedation routes, their delivery methods, associated equipment for monitoring and emergencies, and the additional clinical competencies required for safe provision in paediatric dental settings (SDCEP, 2017; IACSD, 2020; EAPD, 2021).

<table>
<tr><th>Route</th><th colspan="3">Equipment</th><th>Additional Clinical competencies [c]</th></tr>
<tr><th></th><th>Delivery</th><th>Monitoring [a]</th><th>Emergency [b]</th><td rowspan="8">For all conscious sedation techniques other than inhalation sedation with nitrous oxide/oxygen, competence in cannulation is mandatory</td></tr>
<tr><td>Inhalation (IHS)</td><td>Dedicated purpose designed machines, gas cylinders, room ventilation and active scavenging, oxygen delivery system, nasal mask OR nasal cannula OR inhaler</td><td rowspan="6">Inhalation with nitrous oxide/oxygen:
Clinical signs only

All other sedation routes: in addition to clinical signs, pulse oximeter and blood pressure monitor</td><td>Inhalation with nitrous oxide/oxygen:

Emergency cart and oxygen equipment</td></tr>
<tr><td>Transmucosal</td><td>Mucosal atomiser device, nasal applicators, nasal sprays/drops Syringes</td><td rowspan="5">All other sedation routes: emergency cart, oxygen equipment, cannula, labels, reversal agents</td></tr>
<tr><td>Oral</td><td>Tablet or drink</td></tr>
<tr><td>Intravenous (IV)</td><td>Topical local anaesthetic, syringe, needle, labels, surgical wipes tourniquet, cannula</td></tr>
<tr><td>Intramuscular (IM)</td><td>Syringe, needle, surgical wipes</td></tr>
<tr><td>Rectal</td><td>Syringes, rectal applicator</td></tr>
</table>

Table 8:Routes of administration, delivery methods, monitoring and emergency equipment, and additional clinical competencies required (Author's own)

a: *"Clinical signs include checking the level of consciousness/depth of sedation, airway patency, respiration (rate and depth), skin colour, capillary refill, pulse rate, rhythm and volume as appropriate to the clinical situation, sedation technique used, patient status and sedation response" (SDCEP, 2017).*

b: *Emergency equipment must accommodate children of all ages and sizes, and should be capable of resuscitating a non-breathing, unconscious patient until trained emergency personnel arrive (American Society of Anesthesiologists, 2018).*

c: *All practitioners involved in sedation must complete theoretical and practical training relevant to conscious sedation, including drug and equipment knowledge and management of sedation-related complications (Ashley et al., 2021). Basic training includes age-appropriate Immediate Life Support (ILS) or Paediatric ILS. Advanced techniques require additional training and a dedicated sedationist when agents such as sevoflurane, ketamine, or propofol are used. The sedation team must have immediate access to protocols and facilities equivalent to NHS Acute Trust standards for emergency management (IACSD, 2020).*

1.8.6 Choice of Technique in Paediatric Conscious Sedation

Delivering safe and effective sedation in children requires an understanding of both paediatric anatomy and developmental psychology, as these factors directly influence cooperation, airway management, and drug response (Chadwick and Hosey, 2017). Children's ability to cope with dental procedures is closely linked to their developmental stage. Many are pre-cooperative or have limited coping strategies, particularly in unfamiliar clinical settings. Anxiety may be heightened in those with no previous dental experience, and parental anxiety can also influence a child's response to sedation (Chadwick and Hosey, 2017).

From an anatomical perspective, children present unique challenges that require careful consideration when selecting a sedation technique. They have shorter necks and reduced thyromental distance, limiting neck mobility and increasing the risk of airway obstruction during flexion (Chadwick and Hosey, 2017). Their relatively large head can cause positional instability, and the combination of a small mandible, large tongue, and increased oropharyngeal soft tissue can compromise airway patency during sedation. The larynx lies higher and more anterior in the neck than in adults, making airway access more difficult, especially in emergencies. Narrow nasal passages can be easily obstructed by secretions or enlarged adenoids and tonsils, while the subglottic region remains the narrowest part of the paediatric airway, predisposing to stridor and increased airway resistance (Chadwick and Hosey, 2017). **Figure 4** illustrates these key anatomical differences between paediatric and adult airways (Zeretzke-Bien, 2018).

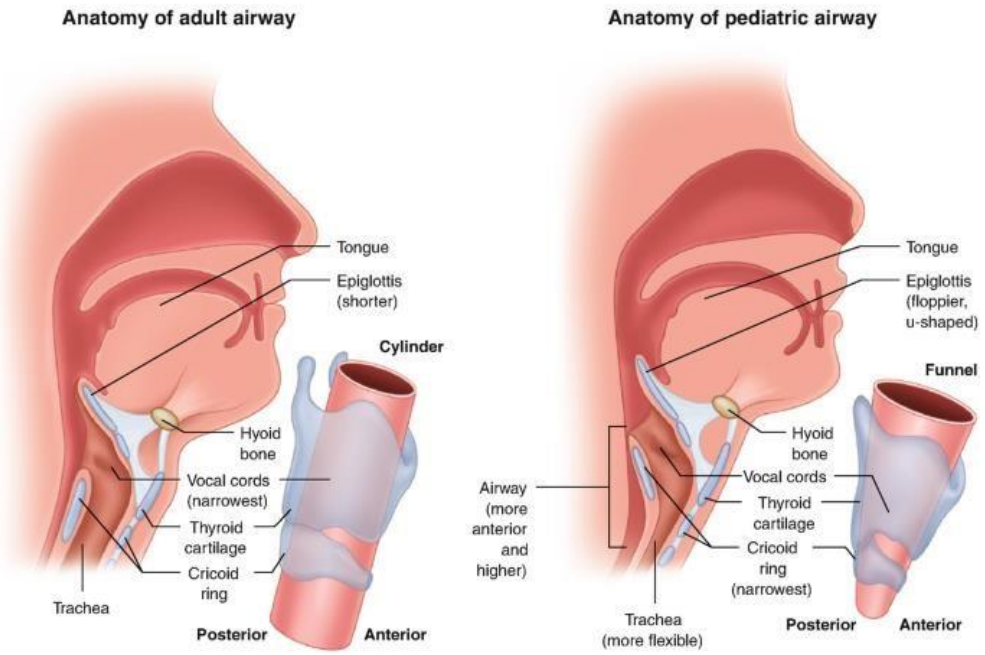


Figure 4: Differences between Adult and Paediatric Airway

Evidence comparing sedation techniques in children remains limited. A Cochrane review by Ashley *et al.* (2018) concluded that oral midazolam was the most consistently effective option for paediatric dental procedures, although this was supported only by moderate-certainty evidence. The review highlighted substantial variability in study designs, outcome measures, and drug combinations, making it difficult to determine the single most effective approach. Similarly, the EAPD (2021) policy statement endorsed oral midazolam as the preferred sedative based on current evidence, while noting that nitrous oxide/oxygen remains widely used despite very low-certainty evidence. More recent SDCEP guidance (2022) has acknowledged the introduction of newer agents such as remimazolam, reflecting the ongoing evolution of sedation practice. These uncertainties and ongoing developments have informed the rationale for further investigation in this thesis, which will explore existing and emerging sedatives in greater depth in Chapter 3.

1.8.7 Risks and Complications

Based on the paediatric anatomical and physiological differences outlined in the previous section, sedation in children is less predictable than in adults (Chadwick and Hosey, 2017). Variations in airway size, respiratory rate, oxygen demand, and developmental stage can influence drug uptake, effect, and recovery, increasing the potential for adverse events (Zeretzke-Bien, 2018). These factors, combined with behavioural variability, mean that the clinical team must remain alert to complications and be fully prepared to intervene when necessary.

When delivered appropriately by trained and competent clinicians in a suitably equipped environment, conscious sedation remains a safe and valuable technique in paediatric dentistry. However, risks still exist, and patients and their carers must be made aware of them during the consent process. The term ‘rescue’ describes the management of adverse events that may occur during conscious sedation, whether they are medical, dental, or directly sedation-related (IACSD, 2020).

All members of the sedation team must be competent in age-appropriate life support, with clearly defined roles for managing complications (IACSD, 2020). These roles should be rehearsed regularly through scenario-based training, ensuring that emergencies can be managed swiftly and effectively until emergency services arrive, if required. The sedationist—whether a dentist, doctor, or dental hygienist/therapist—must be capable of managing both sedation-related events and wider medical emergencies (IACSD, 2020).

Recognised sedation-related complications in children include:

- Over-sedation, potentially progressing to loss of consciousness.
- Respiratory depression.
- Airway obstruction.
- Vomiting with the risk of aspiration.
- Anaphylaxis.
- Delayed recovery, delaying discharge.

- Failure of conscious sedation, where the desired cooperative state is not achieved.

The likelihood and severity of these complications can be reduced through meticulous pre-assessment, careful drug titration, vigilant monitoring, and immediate access to age-appropriate resuscitation and emergency equipment (IACSD, 2020).

1.8.8 Recovery and Discharge Criteria

The decision to discharge a child following conscious sedation must be based on structured, objective clinical criteria to ensure recovery is both safe and complete. These criteria, adapted from the IACSD (2020) standards, must be applied consistently by staff with appropriate training and experience in paediatric sedation. Assessment should confirm that the child is fully alert, orientated, and free from residual sedative effects that could impair responsiveness. Vital signs, including heart rate, respiratory rate, oxygen saturation, and blood pressure, must be stable and within the normal range for the individual, with no evidence of respiratory compromise. Pain or discomfort should be effectively addressed prior to discharge, and any surgical site reviewed to confirm haemostasis. If intravenous access has been used, the cannula should be removed safely, and the insertion site checked for bleeding or infiltration. Discharge must only occur when a responsible adult escort is present, with clear verbal and written post-operative instructions provided. These should outline any activity restrictions, guidance on analgesia, and contact information for urgent or out-of-hours support. **Table 9** summarises the key recovery and discharge criteria for children undergoing conscious sedation (IACSD, 2020).

Recovery and Discharge Criteria	
Consciousness	The patient must be fully alert and appropriately orientated to time, place, and person, with no residual sedative effects impairing awareness or responsiveness.
Vital Signs	All vital signs: including heart rate, respiratory rate, oxygen saturation, and blood pressure should be stable and within normal limits for that individual. Respiratory status must be uncompromised, and the child should be breathing comfortably without assistance.
Pain and Discomfort	Any discomfort or pain should be assessed and managed effectively before discharge. Arrangements for appropriate post-operative analgesia must be made and communicated clearly.
Haemostasis	Where applicable, the surgical site must be checked to confirm that haemostasis has been achieved, and there is no active bleeding.

Cannula Removal	If a cannula was placed, it must be safely removed prior to discharge and the site assessed for bleeding or infiltration.
Escort and Supervision	The child must be discharged into the care of a responsible adult who is present at the time of recovery. Adequate supervision must be ensured for the immediate post-operative period, as advised by the sedationist.
Information Provision	Clear and age-appropriate written and verbal post-operative instructions should be provided to the patient and their escort or carer. This must cover both the sedation and the dental treatment received.
Activity Restrictions	Patients and their escorts must be advised on important post-sedation precautions. These include avoiding alcohol, refraining from driving, operating machinery, making important decisions, or engaging in unsupervised activities for a specified period, depending on the sedation method used.
Post-Operative Pain Management	Where necessary, guidance on suitable analgesia should be included, along with instructions on when and how to administer it at home.
Emergency Support	Patients and their carers should be provided with contact details for post-operative support, including clear instructions for accessing out-of-hours advice or emergency care if required.

Table 9: Recovery and discharge criteria. Adapted from IACSD (2020)

1.9 General Anaesthesia

General anaesthesia (GA) remains an essential part of the pharmacological behaviour management spectrum for children who are unable to tolerate dental treatment under local anaesthesia or conscious sedation. It may be indicated when local anaesthesia is contraindicated or inappropriate (e.g. in the presence of acute infection), when sedation or previous treatment attempts have failed, or where the child is unable to cooperate because of age, developmental delay, communication barriers, or extreme dental anxiety (Adewale, 2012). It is also considered appropriate for extensive or complex dental procedures requiring multiple extractions or restorations in a single session. However, it should be avoided if possible, due to the associated drisk of death (Ashley *et al.,* 2018). It is also a very costly procedure, and it must only be provided in hospital settings that meet defined safety and staffing criteria. This includes the availability of trained anaesthetic and resuscitation teams, designated recovery areas, and appropriate airway and emergency support in line with guidance from the Royal College of Anaesthetists and the Association of Anaesthetists of Great Britain and Ireland (The Royal College of Anaesthetists, 2025) (Checketts *et al.*, 2015). Day-case surgery is typically suitable for otherwise healthy children (ASA I–II), whereas inpatient care may be warranted for patients with complex medical histories or conditions such as bleeding disorders, cardiac disease, or craniofacial syndromes affecting airway management.

1.9.1 Preoperative Assessment

Similar to pre-assessment for conscious sedation, a thorough evaluation is critical to minimising risks and ensuing success when delivering general anaesthesia to children. However, given the greater physiological impact and risks associated with GA, this assessment is typically more extensive and multidisciplinary. Ideally conducted during a separate visit, it should encompass detailed medical, dental, and anaesthetic evaluation, allowing confirmation of the treatment plan, tailored preoperative advice, and optimisation of the child's physical and psychological readiness for GA (Adewale, 2012).

A comprehensive medical history must be obtained, supplemented by physical examination and any necessary investigations (e.g. radiographs, blood tests). Particular attention is given to airway assessment, as craniofacial anomalies, large tonsils, or facial swelling can complicate intubation and ventilation. Anaesthetists also assess fasting status, recent illness, and previous anaesthetic history (Adewale, 2012). In selected cases, input from psychologists or play therapists may reduce the need for GA by improving patient cooperation.

Consent discussions should explain the GA process, outline its risks, and clarify postoperative care requirements. Families must also be informed about fasting protocols, escorting arrangements, and the need for appropriate analgesia following discharge (Tochel *et al.*, 2004). On the day of the procedure, the anaesthetist reassesses the child to ensure no changes in health status and finalises the anaesthetic plan, including choice of induction method and airway management strategy.

1.9.2 Premedication

Premedication may be used to reduce preoperative anxiety and facilitate smoother induction. Topical anaesthetic creams (e.g. Ametop®, EMLA®) can be applied to aid intravenous cannulation (Adewale, 2012). In children with significant anxiety, neurodiversity, or behavioural challenges, sedative premedication may be administered via oral, buccal, intranasal, or intramuscular routes. Selection of agent depends on the child's age, medical status, and anticipated response.

Table 10 summarises commonly used premedication agents, including their mechanisms of action, dosing, onset and duration profiles, advantages, and limitations (Anderson *et.al*, 2019).

According to SDCEP (2017), low-dose oral benzodiazepines may be prescribed to aid sleep the night before or to ease the journey to the treatment center under supervision (SDCEP, 2017)**.** However, any higher doses or additional agents would fall within the scope of oral sedation rather than premedication and are explored in greater detail in Chapter 3.

Drug, formulation, and route	Mechanism	Age group	Dose	Onset	Duration	Advantages	Limitations / Adverse effects
Oral midazolam (2.5 mg/mL)	GABAA agonist	1 mo–18 yrs	0.25–0.5 mg/kg (max 20 mg)	30–45 min	45–60 min	Reduced PONV	Paradoxical agitation, unpleasant taste
Buccal midazolam (10 mg/mL)	GABAA agonist	6 mo–18 yrs	0.3 mg/kg (max 10 mg)	20 min	30–45 min	Quick onset; better compliance	Paradoxical reactions, post-anaesthetic excitation
Dexmedetomidine (buccal/intranasal)	α2-agonist	>1 yr	2 µg/kg (max 200 µg)	25 min	40–135 min (dose-dependant)	Non-IV option; shorter half-life than clonidine	Caution in cardiac patients
Oral clonidine (100 µg tablets or 10 µg/mL)	α2-agonist	6 mo–18 yrs	4 µg/kg (max 200 µg)	45–60 min	45–90 min	Tasteless; long window of action	Cardiovascular caution
Temazepam (10 mg tablets or 2 mg/mL)	GABAA agonist	12–18 yrs	10–20 mg (max 10 mg)	60 min	12–140 min	Alternative if midazolam limit exceeded	Long onset
Ketamine (oral/IM/IV)	NMDA antagonist	2–18 yrs	Oral: 5–8 mg/kg in combo with midazolam; I.M: 4-5 mg/kg; IV: 1-2 mg/kg	10–15 min	3 h	Quick onset; Useful with midazolam	Increased salivation, hallucinations, PONV at higher doses, anaesthetist must always be present if IM/IV
Morphine (1 mg/mL)	µ-opioid agonist	6 mo–18 yrs	0.2 mg/kg (max 10 mg)	20–30 min	1–2 h	Analgesia; combo use	Respiratory depression; rarely solo

Table 10: Commonly used premedication agents in paediatric dentistry. Adapted from Adewale (2012)

1.9.3 Delivery of General Anaesthesia

General anaesthesia for dental procedures is most commonly induced either by inhalation, typically with sevoflurane, or intravenously with agents such as propofol. Regardless of the induction route, establishing early intravenous access is prioritised to allow rapid administration of emergency drugs or fluids if required.

Once anaesthesia is established, the airway is secured and spontaneous ventilation is often maintained using sevoflurane in oxygen, sometimes in combination with nitrous oxide (Adewale, 2012). For longer or more complex procedures, short-acting opioids (e.g. remifentanil, alfentanil) or muscle relaxants may be used to facilitate intubation and maintain anaesthesia. While some of these agents are also used in conscious sedation, in this context they serve the distinct purpose of sustaining deep anaesthesia and will not be a focus of this thesis.

Throughout the procedure, monitoring adheres to national anaesthetic standards, with continuous assessment of oxygenation, ventilation, circulation, and depth of anaesthesia. Dental GA presents the additional challenge of a shared airway between the surgical and anaesthetic teams, necessitating close coordination. Local anaesthetic with a vasoconstrictor (e.g. lidocaine with epinephrine) is frequently administered intraoperatively to aid haemostasis and reduce postoperative discomfort (Adewale, 2012), although a Cochrane review found the supporting evidence for pain reduction in children under GA to be inconclusive and of very low certainty (Parekh *et al.*, 2014).

Pain management is tailored to the procedure: simple extractions may be managed with paracetamol or NSAIDs, while more invasive treatment can require intraoperative opioids such as morphine or fentanyl. Antiemetics and corticosteroids may be given to reduce postoperative nausea, vomiting, and swelling, depending on the clinical circumstances (Adewale, 2012).

1.9.4 Recovery

Recovery takes place in a dedicated post-anaesthetic care unit, with continuous monitoring until the child has emerged fully from anaesthesia. Oxygen

supplementation, effective analgesia, and prophylaxis or treatment for postoperative nausea and vomiting (PONV) are standard (Adewale, 2012). Discharge criteria are consistent with those used for other GA procedures, and all staff involved must be trained in paediatric life support.

Minor complications following GA may include sore throat, headache, vomiting, or soft tissue trauma. More serious risks, such as airway obstruction, aspiration, cardiac arrhythmias, or laryngospasm, are more likely in the presence of bleeding or suboptimal positioning (Adewale, 2012). These potential complications emphasise the importance of robust preoperative assessment, appropriate facilities, and care by a trained multidisciplinary team.

While GA remains an important option for certain cases, its risks, costs, and resource requirements reinforce the value of safe, effective alternatives. The next chapter will focus on nitrous oxide/oxygen sedation—currently the most widely used and least invasive pharmacological sedation technique in paediatric dentistry.

Chapter 2

Nitrous Oxide Use in Paediatric Dentistry

2.1 Overview and Scope

Nitrous oxide (N_2O) remains the most widely used sedation agent in paediatric dentistry in the United Kingdom (IACSD, 2020). Within the SDCEP (2017) framework, it is defined as a “standard” or “basic” technique for children, reflecting its favourable safety profile, rapid onset and offset, titratability, and minimal recovery time (Pedersen *et al.*, 2013). Inhalation sedation with nitrous oxide and oxygen provides a mild form of anaesthesia suitable for short, minimally invasive dental procedures.

Its use in dentistry is supported by decades of clinical experience and a strong foundation of national guidance, including the National Institute for Health and Care Excellence (2010), the Scottish Dental Clinical Effectiveness Programme (2017), and the Intercollegiate Advisory Committee for Sedation in Dentistry (2020).

This chapter focuses specifically on the role of nitrous oxide in paediatric dental sedation, building on the general principles of conscious sedation discussed in Chapter 1. It will examine the agent’s properties, clinical indications and contraindications, delivery techniques, safety features, as well as its governance requirements, occupational exposure risks, and environmental impact. In doing so, it aims to provide a comprehensive, evidence-based account of why nitrous oxide remains a cornerstone of paediatric behaviour management in the UK, while acknowledging the challenges and responsibilities that come with its use.

2.2 History of Nitrous Oxide (N_2O)

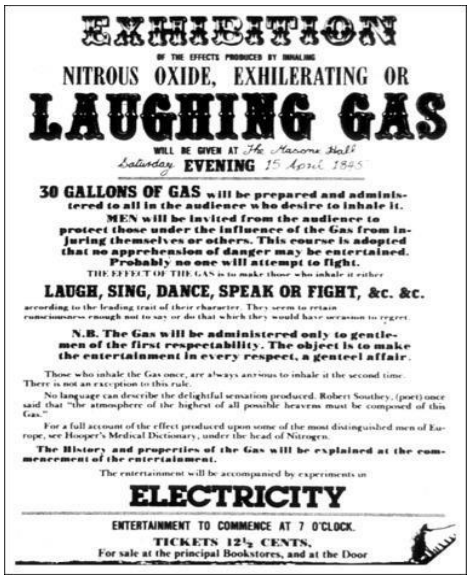
2.2.1 Discovery of Nitrous Oxide

Nitrous oxide (N_2O) is a colourless, almost odourless gas composed of nitrogen and oxygen, naturally occurring within the atmospheric nitrogen cycle (Adel, 1951). The synthesis of nitrous oxide is credited to Joseph Priestley, who, while studying “nitrous air,” also identified another gas he termed “good air,” now recognised as oxygen (O_2) (Clark and Brunick, 2015).

In 1798, Humphry Davy, with a particular interest in medical applications, became the first to chronically inhale pure nitrous oxide. He reported intense euphoria and laughter, publishing his experiences in 1800, where he described the sensation as “the ultimate pleasure” (Davy, 1800). After self-administering nitrous oxide for toothache and noting significant pain relief, Davy speculated on its potential as an anaesthetic agent. However, despite this early insight, medical uptake did not immediately follow.

2.2.2 Popular Entertainment and Public Exhibition

For several decades, nitrous oxide use remained outside clinical medicine. Gardner Colton, a medical student, popularised “laughing gas shows,” inviting volunteers to inhale the gas on stage and experience euphoria, disinhibition, and altered pain perception (Langa, 1976). Such demonstrations became fashionable entertainment at universities and social gatherings (**Figure 5**) (Malamed, 2017). The anaesthetic potential first recognised by Davy was largely overlooked during this period.



EXHIBITION

OF THE EFFECTS PRODUCED BY INHALING

NITROUS OXIDE, EXHILERATING OR

LAUGHING GAS

WILL BE GIVEN AT The Masonic Hall

Saturday EVENING 15 April 1845

30 GALLONS OF GAS will be prepared and administered to all in the audience who desire to inhale it.

MEN will be invited from the audience to protect those under the influence of the Gas from injuring themselves or others. This course is adopted that no apprehension of danger may be entertained. Probably no one will attempt to fight.

THE EFFECT OF THE GAS is to make those who inhale it either

LAUGH, SING, DANCE, SPEAK OR FIGHT, &c. &c.

according to the leading trait of their character. They seem to retain consciousness enough not to say or do that which they would have occasion to regret.

N.B. The Gas will be administered only to gentlemen of the first respectability. The object is to make the entertainment in every respect, a genteel affair.

Those who inhale the Gas once, are always anxious to inhale it the second time. There is not an exception to this rule.

No language can describe the delightful sensation produced. Robert Southey, (poet) once said that "the atmosphere of the highest of all possible heavens must be composed of this Gas."

For a full account of the effect produced upon some of the most distinguished men of Europe, see Hooper's Medical Dictionary, under the head of Nitrogen.

The History and properties of the Gas will be explained at the commencement of the entertainment.

The entertainment will be accompanied by experiments in

ELECTRICITY

ENTERTAINMENT TO COMMENCE AT 7 O'CLOCK.

TICKETS 12½ CENTS.

For sale at the principal Bookstores, and at the Door

Figure 5: Poster advertising a nitrous oxide exhibition

Source: Malamed SF. Sedation: A Guide to Patient Management. 5th ed. St Louis: Mosby; 2010.

2.2.3 Pain Control Before Anaesthesia

In the early 19th century, surgery and dentistry were performed without effective anaesthesia, resulting in high mortality and extreme suffering (Dormandy, 2006). Amputations, tooth extractions, and drainage of abscesses were often carried out rapidly to limit shock and exhaustion. Available methods—alcohol, opium, physical restraint, and tourniquets—were inconsistent, unpredictable, and often traumatic (Fenster, 1996). Patients frequently faced the choice between enduring unbearable pain during surgery or surrendering to untreated disease.

2.2.4 Early Clinical Use of Nitrous Oxide as an Anaesthetic

In 1844, Colton staged a demonstration in Hartford, Connecticut, where a volunteer injured his leg under the influence of nitrous oxide yet displayed no reaction to pain (Jacobsohn, 1994). This caught the attention of Horace Wells (**Figure 6**), a dentist, who arranged to have a tooth extracted under nitrous oxide the following day. Wells declared it “the greatest discovery ever made” (Jacobsohn, 1994) and began performing extractions with nitrous oxide successfully in multiple patients.

However, during a public demonstration at Harvard Medical School, a patient cried out mid-procedure, leading observers to dismiss the technique as ineffective (Menczer *et al.*,1985). Despite this setback, Wells continued advocating for nitrous oxide's use, and the event is now regarded as an important milestone in the development of anaesthesia (Chancellor, 1994).

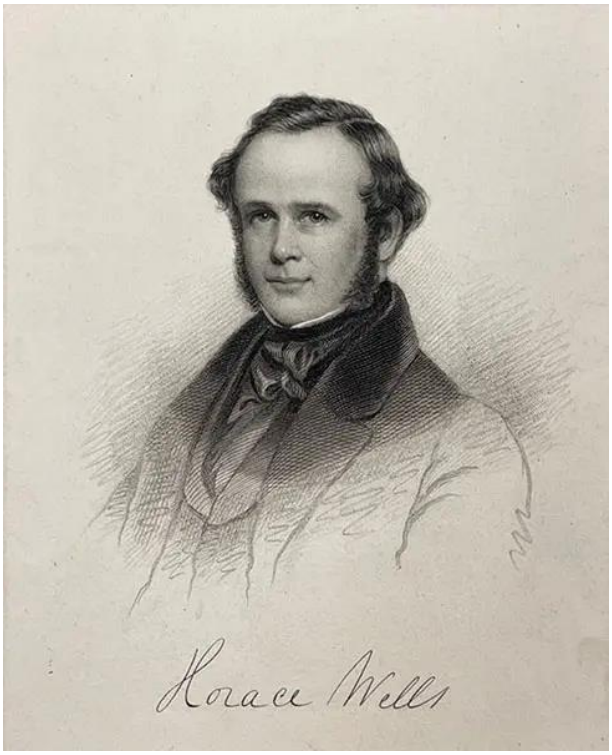


Figure 6: Horace Wells (1815–1848), pioneer of dental nitrous oxide anaesthesia

Source: Public domain image.

2.2.5 Integration into Anaesthesia and Dentistry

By the mid-19th century, ether and chloroform emerged as general anaesthetics, though ether was flammable and irritant, and chloroform carried significant toxicity and arrhythmic risk (Chancellor, 1994). Following Wells' death, the Medical Society of Paris honoured him as a pioneer in vapour and gas anaesthesia (Fenster, 1996) and both the American Dental Association and the American Medical Association formally recognised his contribution in 1864 (Jacobsohn, 1994).

In 1868, Edmund Andrews introduced the practice of combining nitrous oxide with oxygen, recommending that at least 20% oxygen (O_2) be administered to prevent hypoxia (Bause, 2009). Purpose-built delivery equipment for nitrous oxide/oxygen (N_2O/O_2) soon followed (MacAfee, 1989).

2.2.6 Decline and Revival in the 20th Century

Nitrous oxide use diminished in the early 1900s due to unreliable equipment, inconsistent results, and limited understanding of optimal technique (Clark and Brunick, 2015). Other agents, such as cyclopropane (discovered 1929) and intravenous barbiturates (1935), gained popularity, while local anaesthetics like lidocaine (1940s) reduced reliance on nitrous oxide for dental pain control (Goodman, 1996).

Nonetheless, nitrous oxide persisted as a valuable adjunct in general anaesthesia, particularly when combined with muscle relaxants like curare in high-risk patients. The introduction of halothane in 1956, a safer non-flammable volatile agent, further transformed anaesthesia practice, but nitrous oxide retained an important role in rapid induction and analgesia (Goodman, 1996).

By the late 1950s, dental schools incorporated inhalation sedation training into curricula, and in 1962 the American Dental Society of Anesthesiology issued guidelines for pain and anxiety control in dentistry (Clark and Brunick, 2015).

2.2.7 Modern Use in Paediatric Dentistry

Despite fluctuations in popularity, nitrous oxide has remained in continuous use longer than any other sedative agent. Today it is widely used across healthcare, including emergency medicine, maternity and paediatric dentistry. A 2007 American Dental Association survey found that 70.3% of dentists using sedation chose inhalation methods, with younger dentists and specialists more likely to administer nitrous oxide (American Dental Association, 2007). In paediatric dentistry specifically, routine use is reported by approximately two-thirds of practitioners (Davis, 1988), with provision in some regions extending to dental hygienists and assistants.

2.3 Pharmacology and Mechanism of Action

2.3.1 Properties

Nitrous oxide (N_2O) is a colourless, almost odourless, non-irritant gas with a molecular weight of 44 and a specific gravity of 1.53, making it heavier than air (Stone and Fawcett, 2013). It remains chemically stable under normal conditions and, although non-flammable, supports combustion in the presence of hydrocarbons. At ambient temperature, it exists as a gas but is stored under pressure as a liquid. The oxygen atom in the N_2O molecule is not biologically available; therefore, supplemental oxygen must always be administered concurrently to maintain adequate oxygenation (Malamed, 2017).

In dentistry, nitrous oxide is delivered in combination with oxygen using dedicated inhalation sedation (IHS) machines, equipped with safety mechanisms that ensure a minimum oxygen concentration—typically ≥30% in UK practice (IACSD, 2020). These devices incorporate fail-safes, reservoir bags, and active scavenging systems to optimise safety for both patients and operators.

2.3.2 Pharmacokinetics

Nitrous oxide is characterised by a low blood–gas partition coefficient (0.47), resulting in rapid alveolar–blood equilibration and swift onset of clinical effects, typically within 3–5 minutes (Stone and Fawcett, 2013). Uptake occurs via passive diffusion along partial pressure gradients from the lungs into the bloodstream and then to the brain.

The gas is not significantly metabolised; approximately 99% is eliminated unchanged through the lungs (Stoelting and Hillier, 2012). A negligible fraction (~0.004%) is reduced by gut bacteria such as Pseudomonas spp., with no clinical consequence (Linde and Avram, 1980). Unlike other stronger anaesthetic gases, nitrous oxide is not stored in the body or processed by the liver. This minimises the risk of long-term side effects and makes it especially suitable for use in children and outpatient settings (Morris Clark and Ann Brunick, 2015). Its low solubility in fat and muscle means there is no significant tissue storage, facilitating rapid recovery once administration ceases.

Because nitrous oxide is ~31 times more soluble than nitrogen, it diffuses readily into closed, air-filled spaces, potentially increasing pressure and volume within rigid cavities such as the middle ear or paranasal sinuses (Morris Clark and Brunick, 2015). This property underlies several of its contraindications (Section 2.5.2).

2.3.3 Pharmacodynamics

The precise mechanism of action of nitrous oxide is not fully understood, but evidence suggests a combination of analgesic, anxiolytic, and sedative effects mediated through multiple neural pathways (Clark and Brunick, 2015).

- Opioid System Modulation: nitrous oxide appears to activate the endogenous opioid system, stimulating the release of β-endorphins and possibly binding directly to μ-opioid receptors in the brain and spinal cord (Gillman, 1986). This dampens nociceptive transmission, contributing to its analgesic properties. The reversal of analgesia by naloxone supports this opioid-mediated mechanism (Yaksh and Wallace, 2017).
- NMDA Receptor Antagonism: nitrous oxide also inhibits N-methyl-D-aspartate (NMDA) receptors, reducing excitatory neurotransmission and contributing to both analgesia and anxiolysis (Ashley *et al.,* 2021).

This dual mechanism may explain its effectiveness in paediatric dental care, where management of both procedural pain and anxiety is critical (Clark and Brunick, 2015). Its low potency as an anaesthetic agent—which precludes loss of consciousness at concentrations ≤50%— is in fact a strength when used for paediatric conscious sedation as it is unlikely to cause unconsciousness when used appropriately (Becker and Rosenberg, 2008). Its role in modulating pain pathways is illustrated in **Figure 7** which portrays the interaction between nitrous oxide administration, endogenous analgesic systems, and pain signal transmission (Clark and Brunick, 2015). Unlike general anaesthesia, the concept of Minimum Alveolar Concentration (MAC) is not directly applicable in conscious sedation (Stoelting and Hillier, 2012). In dental practice, effective titration typically falls within 20–40% N_2O, with an upper recommended limit of 50% (SDCEP, 2017; IACSD, 2020).

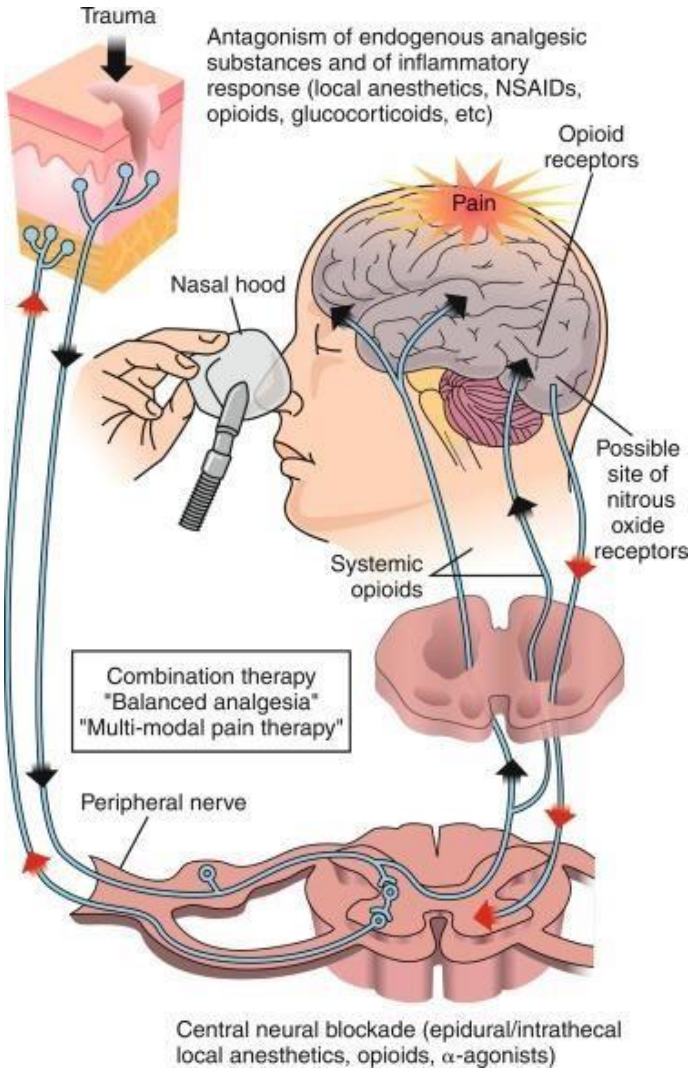


Figure 7: Action site of various analgesics

Source: Clark, M., & Brunick, A. (2015). Handbook of Nitrous Oxide and Oxygen Sedation (4th ed.). Elsevier Health Sciences.

2.3.4 Drug Interactions and Governance Considerations

Nitrous oxide produces deeper anaesthesia and central nervous system (CNS) depression when combined with other sedatives such as benzodiazepines or opioids (Anderson *et al.,* 2019). Such combinations move beyond the “standard” technique described in UK guidance and are categorised as advanced sedation (IACSD, 2020; SDCEP, 2017). Advanced techniques require additional equipment, enhanced monitoring, additional training, and the presence of a dedicated seditionist as explained in **Table 8**.

2.3.5 Clinical Relevance in Paediatric Dentistry

For paediatric patients, the rapid onset, titratability, and short recovery time of nitrous oxide are advantageous, particularly for short procedures requiring cooperation under mild anaesthesia. The absence of metabolism and quick clearance reduce the risk of residual sedation and enable rapid recovery and discharge. Its non-irritant nature allows for smooth inhalation via nasal hoods, and the minimal impact on cardiovascular and respiratory parameters supports its strong safety profile in ASA I–II children when used in accordance with recognised guidelines (SDCEP, 2017; IACSD, 2020). The key pharmacokinetic characteristics and associated clinical effects of nitrous oxide relevant to paediatric inhalation sedation are summarised in **Table 11**. This table provides a concise reference to support the clinical and governance considerations outlined in Section 2.3.

Parameter	Characteristic	Clinical Relevance
Physical form	Colourless, non-irritant gas	Well tolerated during inhalation
Molecular weight	44	—
Blood–gas partition coefficient	0.47	Rapid onset (3–5 min) and recovery
Solubility	Low in blood, fat, and muscle	Minimal tissue storage, rapid clearance
Metabolism	Negligible (<0.004%)	Eliminated unchanged via lungs
Onset of action	3–5 minutes	Quick onset, useful for children
Duration of effect	Maintained with continued inhalation	Flexible titration
Potency	Low (not sufficient for surgical anaesthesia)	Oversedation unlikely
Analgesic mechanisms	Endogenous opioid activation, NMDA antagonism	Combined pain relief and anxiolysis
Typical dental sedation range	20–40% N_2O (max 50%)	Maintains consciousness and protective reflexes
Recovery time	3–5 minutes after cessation	Enables quick recovery and discharge

Table 11: Clinical effects of nitrous oxide in paediatric conscious sedation (Author's own)

2.4 Physiological Effects of Nitrous Oxide

2.4.1 Cardiovascular System

Nitrous oxide, when used at sub-anaesthetic concentrations for inhalation sedation, has minimal impact on cardiovascular function and does not produce any significant adverse physiological changes (Clark and Brunick, 2015). Research has examined its influence on cardiac contractility, output, stroke volume, heart rate, and arrhythmia incidence, with the consensus that these effects are negligible in healthy patients (Eisele, 1985). In fact, nitrous oxide administered with oxygen may have mild cardiotonic properties and, through supplemental oxygenation, can be beneficial in situations of myocardial ischaemia (Thompson and Lown, 1976).

Blood pressure is generally unaffected at the concentrations used in ambulatory dentistry; a slight reduction may occur due to patient relaxation rather than a direct myocardial effect. At these doses, nitrous oxide may cause minor depression of cardiac output with a slight increase in peripheral vascular resistance, thereby maintaining overall haemodynamic stability (AAPD, 2024). Heart rate likewise remains stable or may decrease slightly as anxiety is alleviated (Becker and Rosenberg, 2008). In line with these findings, there are no cardiovascular conditions that, in themselves, warrant postponement of nitrous oxide sedation, provided the patient meets standard conscious sedation criteria and falls within ASA I–II (**Table 6**).

2.4.2 Respiratory System

Nitrous oxide is non-irritant to the bronchial mucosa, making it safe for use in patients with asthma and other reactive airway conditions, where its anxiolytic effect may reduce the risk of stress-induced bronchospasm (AAPD, 2024). Airway patency is essential for effective delivery and upper respiratory infections, congestion, and sinusitis can reduce efficacy and comfort; elective sedation should be postponed until resolution (AAPD, 2024). In minimal sedation, nitrous oxide does not depress ventilation (Becker and Rosenberg, 2008). However, in patients with chronic respiratory disease such as COPD or cystic fibrosis with bullous lung disease, the expansive property of the gas can pose significant risks, including bulla enlargement and pneumothorax (AAPD, 2024).

Silent regurgitation and aspiration are rare but recognised risks if the patient is inadvertently over-sedated (Clark and Brunick, 2015). Dye studies have shown no aspiration in children receiving up to 65% N_2O, but careful titration and continuous verbal contact are essential safeguards (Roberts and Wignall, 1982). To minimise rare events such as diffusion hypoxia, it is recommended to administer 100% oxygen for ≥5 minutes after discontinuation of nitrous oxide (AAPD, 2024).

2.4.3 Central Nervous System

Nitrous oxide produces a mild and reversible depression of central nervous system (CNS) activity, which underlies its sedative and anxiolytic properties (Stoelting and Hillier, 2012). At the subanaesthetic concentrations used in paediatric dentistry, effects on cerebral blood flow, intracranial pressure, and cerebral oxygen consumption are minimal and clinically insignificant in healthy patients (Hancock *et al.,* 2005*)*. The mechanism is thought to involve modulation of N-methyl-D-aspartate (NMDA) receptors and activation of endogenous opioid pathways, resulting in analgesia and anxiolysis without loss of consciousness.

A recognised CNS effect during administration is mild, transient cognitive slowing, which may include delayed reaction times (Anderson *et al.,* 2019). These changes are dose-related, subtle at sedation concentrations, and considerably less pronounced than with many alternative sedative agents (Anderson *et al.,* 2019). Recovery is rapid, with most patients returning to baseline cognitive performance within 5–10 minutes of discontinuation when followed by oxygen administration.

2.4.4 Other Systemic Effects

Haematopoietic system – Nitrous oxide can inactivate the vitamin B_{12}–dependent enzyme methionine synthase, impairing DNA synthesis and erythrocyte production (Stoelting and Hillier, 2012). This is rarely clinically significant at dental sedation doses but can precipitate or worsen megaloblastic anaemia or neuropathy in patients with untreated vitamin B_{12} or folate deficiency, pernicious anaemia, or certain malabsorption syndromes (Myles *et al.*, 2004).

Endocrine, hepatic, genitourinary systems – Nitrous oxide has no adverse effects on endocrine function and is safe in hepatic impairment as it is not metabolised by the liver (Becker and Rosenberg, 2008). It also poses no risk to the genitourinary system, and no conditions involving these systems necessitate medical consultation solely for sedation purposes (Anderson *et al.*, 2019).

Gastrointestinal system – Due to its rapid diffusion into air-filled spaces, nitrous oxide can expand gas within the bowel. In patients with bowel obstruction, this can exacerbate distension, pressure, and discomfort; sedation should be postponed until resolution (Stoelting and Hillier, 2012).

2.5 Indications and Contraindications for Nitrous Oxide Inhalation Sedation in Paediatric Dentistry

2.5.1 Indications

In addition to the general indications for conscious sedation discussed in chapter 1, nitrous oxide (N_2O) inhalation sedation is indicated in specific situations. Unless otherwise specified, the indications listed are adapted from Ashley *et al.* (2021).

Indications:

- Children able to follow instructions and tolerate nasal breathing (typically >3 years old).
- Patient with a pronounced gag reflex.
- Patients with muscular tone disorders (e.g., cerebral palsy).
- Require aid to cannulation for intravenous sedation or medical procedures (only if N_2O is discontinued prior to IV midazolam administration to remain within “standard” sedation as defined by IACSD, 2020) (SDCEP, 2017).

2.5.2 Contraindications

While nitrous oxide sedation is considered safe when delivered in accordance with guidelines, its use is contraindicated in the following cases.

Unless otherwise specified, the contraindications listed are adapted from Ashley *et al.* (2021).

Contraindications:

- Pre-co-operative patients.
- Upper airway infections (e.g., common cold, tonsilitis, or nasal blockage)
- Patients with sinusitis or recent ENT surgery (within 14 days).
- Tympanic membrane middle ear surgery, cochlea implants.
- Severe COPD or other advanced respiratory compromise.
- Cystic fibrosis (risk of bullae formation) (American Academy of Pediatric Dentistry, 2024b).
- Pneumothorax (risk of gas expansion) (AAPD, 2024).
- Untreated vitamin B_{12} or folate deficiency (risk of haematological and neurological effects).
- Raised intraocular pressure, retinal surgery, intestinal obstructive surgery.
- Recent bleomycin chemotherapy (risk of pulmonary toxicity).
- First trimester of pregnancy (AAPD, 2024).
- Significant psychiatric disorders impairing cooperation.
- Use of medications with additive CNS depressant effects (benzodiazepines, opioids).

2.4.3 Link to Patient Selection

These indications and contraindications should be considered alongside the broader patient assessment framework outlined in Chapter 1. Nitrous oxide IHS is generally appropriate for ASA I–II patients when delivered as a standard technique (IACSD, 2020). Whenever possible and clinically appropriate, consultation with the relevant medical specialist is recommended before administering nitrous oxide to patients with significant underlying medical conditions, to ensure safe delivery (Ashley *et al.,* 2021).

2.6 Safety

2.6.1 Patient Safety

An ideal sedative agent for conscious sedation should have a wide margin of safety (SDCEP, 2017). When administered alone, nitrous oxide is highly unlikely to induce deep sedation and, in healthy patients, has minimal impact on respiratory or cardiovascular function (Sections 2.4.1 & 2.4.2) (AAPD, 2024). Large-scale clinical data support its safety profile: in over 7,000 paediatric cases using up to 70% nitrous oxide via nasal mask, 95.7% experienced no adverse effects (Zier and Liu, 2011). The most frequently reported side effects, nausea and vomiting, were mild and self-limiting. Serious adverse events were rare (0.1%) and included transient oxygen desaturation, which resolved promptly with supplemental oxygen. A systematic review by Pedersen *et al*., (2013) reported similar findings.

Physiological studies have confirmed the stability of oxygenation during treatment. In one study of 24 healthy children undergoing inhalation sedation, oxygen saturation did not fall by more than 1% in any case (Dunn-Russell *et al.*, 1993). Biochemically, nitrous oxide can inactivate the vitamin B_{12}–dependent enzyme methionine synthase, but at the doses and durations typical in dentistry, such effects are not clinically significant for otherwise healthy patients (Nunn, 1987).

Its superior safety profile is reflected in reports of no deaths in over one million clinical administrations (Lyratzopoulos and Blain, 2003); a record unmatched by most alternative sedation techniques. In contrast, deaths linked to nitrous oxide are almost exclusively associated with non-clinical, unregulated use. Between 2001 and 2020, there were 56 registered deaths in England and Wales—45 of them since 2010—according to a UK government report (BBC News, 2023). Many of these cases occurred in recreational settings, often linked to secondary effects such as hypoxia from inhaling the gas in confined spaces or with a face covering that restricted oxygen intake. These figures underline that, when administered within a controlled dental environment by trained teams, nitrous oxide sedation remains one of the safest pharmacological behaviour management techniques in paediatric dentistry.

2.6.2 Operator Safety

Nitrous oxide is a recognised greenhouse gas; its environmental impact and mitigation measures are addressed separately in Section 2.11. In the clinical context, “pollution” refers to occupational exposure of staff during inhalation sedation, most often caused by leakage from the nasal hood, patient mouth breathing, talking, or poor scavenging efficiency (Clark and Brunick, 2015). Dental professionals involved in inhalation sedation may be exposed to two to three times more nitrous oxide than other hospital personnel, largely due to gas escaping via the patient’s open mouth during treatment (Cohen *et al.*, 1980).

Chronic occupational exposure, particularly in unscavenged environments, has been associated with a range of potential health effects. Reported risks include liver disease, bone marrow suppression, depression of vitamin B_{12} activity, miscarriage, birth defects, carcinoma, and, in some cases, dependency (Chadwick and Hosey, 2017). Biochemically, nitrous oxide inactivates the vitamin B_{12}–dependent enzyme methionine synthase, impairing DNA synthesis and potentially resulting in macrocytic anaemia (Clark and Brunick, 2015). Other possible effects include neurological, hepatic, and renal disorders, which appear to be dose- and duration-dependent, as well as potential impacts on fertility and reproduction. Much of the early evidence for reproductive risk comes from studies in unscavenged environments over long-term exposure; these findings have since been questioned (Clark and Brunick, 2015).

In the UK, nitrous oxide is regulated as a hazardous substance under the Control of Substances Hazardous to Health (COSHH) Regulations (COSHH, 2013). The Workplace Exposure Limit (WEL), set by the Health and Safety Executive (HSE) and published in EH40/2005 (updated 2020), is 100 parts per million (ppm) averaged over an eight-hour time-weighted period (Health and Safety Executive, 2020). International limits vary from 25 ppm to 100 ppm. COSHH requires employers to identify hazards, assess and control risks, and review control measures.

Exposure monitoring is not required if levels are kept below the WEL, but principles of good control practice are expected — including regular equipment servicing and adequate room ventilation. Nitrous oxide is not listed as requiring biological

monitoring and is not classified as a carcinogen, respiratory sensitiser, or capable of dermal absorption (Health and Safety Executive, 2020). The HSE also issues workplace pregnancy guidance, though no nitrous oxide-specific advice exists beyond general COSHH duties.

Studies have shown that exposure levels can vary significantly in clinical practice, with sedationists typically exposed to higher levels than assisting nurses (Girdler *et al.,* 2018). Higher exposure has been recorded in situations with poor ventilation, uncooperative patients, absence of fans, or multiple sedation sessions in sequence (Girdler *et al.,* 2018). Behavioural factors, such as excessive patient talking, can also increase leakage.

Practical steps to minimise occupational exposure include maintaining good general ventilation (e.g., fans, windows), ensuring nasal hoods are well-fitted and regularly maintained, and using efficient clinical techniques such as rubber dam isolation with high-volume suction where appropriate (Chadwick and Hosey, 2017). Active scavenging systems — set at approximately 45 L/min in accordance with National Institute for Occupational Safety and Health (NIOSH) guidance — are mandatory in UK practice. When used correctly, both active and passive scavenging systems are understood to eliminate significant risk to staff (NIOSH, 2023).

2.7 Equipment

Purpose-designed inhalation sedation machines must be available and maintained in accordance with manufacturer guidance (Department of Health, 2003). In the UK, dedicated dental units are connected either to a mains gas supply via a central manifold system or to individual cylinders of oxygen and nitrous oxide. An example of a Monitored Dial Mixer (MDM) by RA Medical used in UK dental hospital settings is shown in **Figure 8**. All sedation machines must have built-in safety features to prevent hypoxic gas delivery (Clark and Brunick, 2015). These include:

- An oxygen fail-safe that stops nitrous oxide flow if oxygen supply is lost.
- A minimum oxygen delivery of 30% at all times, with nitrous oxide limited to a maximum of 70%.

- Colour-coded cylinders and pipelines (oxygen: black or white; nitrous oxide: blue).
- An emergency oxygen flush to allow immediate delivery of 100% oxygen if needed.
- A reservoir bag for monitoring breathing and providing assisted ventilation in emergencies.

Gas is delivered to the patient through a well-fitting scavenging nasal hood, which has separate inspiratory and expiratory pathways to reduce leakage. Active scavenging is mandatory in the UK, using vacuum suction to vent waste gases outside the building (COSHH, 2013). A flow rate of approximately 45 L/min is recommended (NIOSH, 2023), supported by good room ventilation.

UK legislation regulates nitrous oxide under the Control of Substances Hazardous to Health (COSHH) Regulations. The Workplace Exposure Limit (WEL) set by the Health and Safety Executive (HSE) in EH40 is 100 ppm over an eight-hour timeweighted average (Health and Safety Executive, 2020). COSHH requires employers to assess and control risks, maintain equipment, and review measures regularly (COSHH, 2013). Exposure monitoring is not required if levels remain below the WEL, but good control practice—such as active scavenging, correct nasal hood fit, and regular leak testing—must be in place.

Figure 8: An example of a Monitored Dial Mixer (MDM) (Author's own)

2.8 Staff Training and Education

All major guidelines emphasise that dental professionals involved in the delivery of inhalation sedation must be appropriately trained. According to the IACSD (2020), clinicians who are new to the technique should complete at least ten supervised cases before practising independently. Furthermore, maintaining competence through continuing professional development (CPD) is essential. Both the IACSD (2020) and SDCEP (2017) recommend that practitioners undertake a minimum of 12 hours of sedation-specific, verifiable CPD every five years to ensure up-to-date knowledge and safe practice.

2.9 Clinical Technique and Administration

2.9.1 Patient Preparation and Fasting

Fasting is not recommended for minimal sedation with nitrous oxide/oxygen, provided protective reflexes and verbal contact are maintained (IACSD, 2020). The evidence supporting fasting for conscious sedation is limited, and that an individual

assessment should be made based on the procedure, the patient's medical status, and the sedation technique (Ashley *et al.,* 2021).

For most patients undergoing nitrous oxide sedation, fasting is not required; they may eat and drink normally on the day but should avoid alcohol and large meals. However, if there is a significant risk of aspiration or another specific clinical indication, pre-procedural fasting may be considered, following the 2–4–6 guidance (2 hours for clear fluids, 4 hours for breast milk, and 6 hours for solids or formula). In all cases, food and fluid intake on the day of sedation should be confirmed and documented in the clinical record (Ashley *et al.,* 2021).

2.9.2 Induction of Nitrous Oxide Inhalation Sedation

A well-fitting scavenging nasal hood should be selected prior to induction. Flow rates of 5–7 L/min are generally suitable for older children and adults, while younger children (three to four years) typically require 3–5 L/min. The reservoir bag should inflate and deflate gently with each breath, without over- or underinflation (AAPD, 2024). Under- or overinflation may suggest issues with flow rate or scavenging **Figure 9** shows the correct bag inflation.

Figure 9: Ideal Reservoir Bag Inflation (Author's own)

The standard titration technique begins with 100% oxygen for one to two minutes, followed by stepwise increases in nitrous oxide concentration in 5–10% increments until the desired clinical effect is achieved. This is typically in the range of 20–40% nitrous oxide, with an upper limit of 50% recommended in dentistry (AAPD, 2024). Concentrations above 60% are associated with increased risk of ataxia, dysphoria, excessive drowsiness, or patient discomfort, and do not necessarily improve behavioural outcomes during dental treatment (AAPD, 2024).

Nitrous oxide concentrations can be varied during the procedure—for example, reduced during less stimulating stages such as restoration, and increased during more anxiety-provoking interventions such as local anaesthetic administration. Effective sedation depends as much on psychological reassurance as on the pharmacological effect; therefore, behaviour guidance techniques should be maintained throughout treatment (AAPD, 2024). To optimise delivery, patient talking and mouth breathing should be minimised, and scavenging vacuum flow should be set so as not to compromise ventilation with nitrous oxide (Chadwick and Hosey, 2017).

2.9.3 Monitoring

For ASA I–II patients undergoing nitrous oxide/oxygen inhalation sedation alone, continuous clinical monitoring is sufficient (**Table 8**) (SDCEP, 2017). This includes observation of responsiveness to verbal contact, colour, respiratory rate, and rhythm throughout the procedure (SDCEP, 2017). If nitrous oxide concentrations exceed 50%, or if other sedative or analgesic agents are administered in combination, the likelihood of a deeper sedative effect increases; in such cases, monitoring must be escalated in accordance with IACSD (2020) and NICE (2010) standards.

2.9.4 Documentation

The patient's record should include (IACSD, 2020; AAPD, 2024):

- Confirmation of informed consent, including discussion of sedation rationale, benefits, and risks.
- Any pretreatment dietary instructions given to the parent or carer.

- The indication for nitrous oxide sedation.
- The nitrous oxide concentration and/or gas flow rates used.
- Duration of sedation and total procedure time.
- Details of post-treatment oxygenation.

In line with governance requirements, sedation logs should also record adverse events, recovery times, and whether the patient achieved full pretreatment responsiveness prior to discharge (IACSD, 2020).

2.10 Recovery and Discharge

Recovery following nitrous oxide inhalation sedation is typically rapid, with the agent eliminated almost entirely via the lungs within minutes of cessation (Clark and Brunick, 2015). After discontinuation of nitrous oxide, the patient should breathe 100% oxygen for a minimum of two to three minutes to prevent diffusion hypoxia, followed by a short observation period to confirm return to baseline responsiveness (AAPD, 2024).

The general discharge criteria outlined in **Table 9** (Section 1.8.8) for conscious sedation apply equally to nitrous oxide inhalation sedation (IACSD, 2020). In addition, the following nitrous oxide–specific points should be confirmed before discharge (Chadwick and Hosey, 2017):

- No significant headache, nausea, dizziness, or other discomfort.
- Patient is coherent, alert, and able to walk steadily without assistance.
- Patient demonstrates appropriate verbal interaction and orientation.

In most cases, complete recovery can be achieved within 10 minutes in the waiting area. Post-operative instructions should address both the sedation and the dental treatment provided. This includes caution regarding residual numbness after local anaesthetic, guidance following extractions, and advice on when normal activities such as returning to school may be resumed. Final decisions on activity should be made at the clinician’s discretion, taking into account the child’s recovery status and the nature of the procedure performed (Clark and Brunick, 2015).

As clinical recovery is achieved, the safe completion of care extends beyond the child in the dental chair. While nitrous oxide is fully exhaled and eliminated from the patient's lungs within minutes, the gas itself lingers far longer in the atmosphere, exerting an environmental impact that can persist for a very long time. This makes it important to consider not only the clinical aspects of inhalation sedation, but also its environmental implications and the measures now being implemented within the NHS and UK dentistry to reduce unnecessary emissions.

2.11 Nitrous Oxide and the Environment

2.11.1 Net Zero NHS framework

As established in Chapter 1, nitrous oxide is a significant source of healthcare related greenhouse gas emissions. Within the Delivering a Net Zero NHS framework, it is classified as a Scope 1 direct emission under the Greenhouse Gas Protocol, falling within the "Anaesthetics" category of the NHS Carbon Footprint (National Health Service, 2022). Scope 1 emissions are those produced by NHS-owned or controlled sources and are therefore a direct focus for reduction in the 2040 net zero target for emissions the NHS controls. **Figure 10** illustrates the three carbon reporting scopes in the NHS context and highlights where anaesthetic gases, including nitrous oxide, sit within this framework.

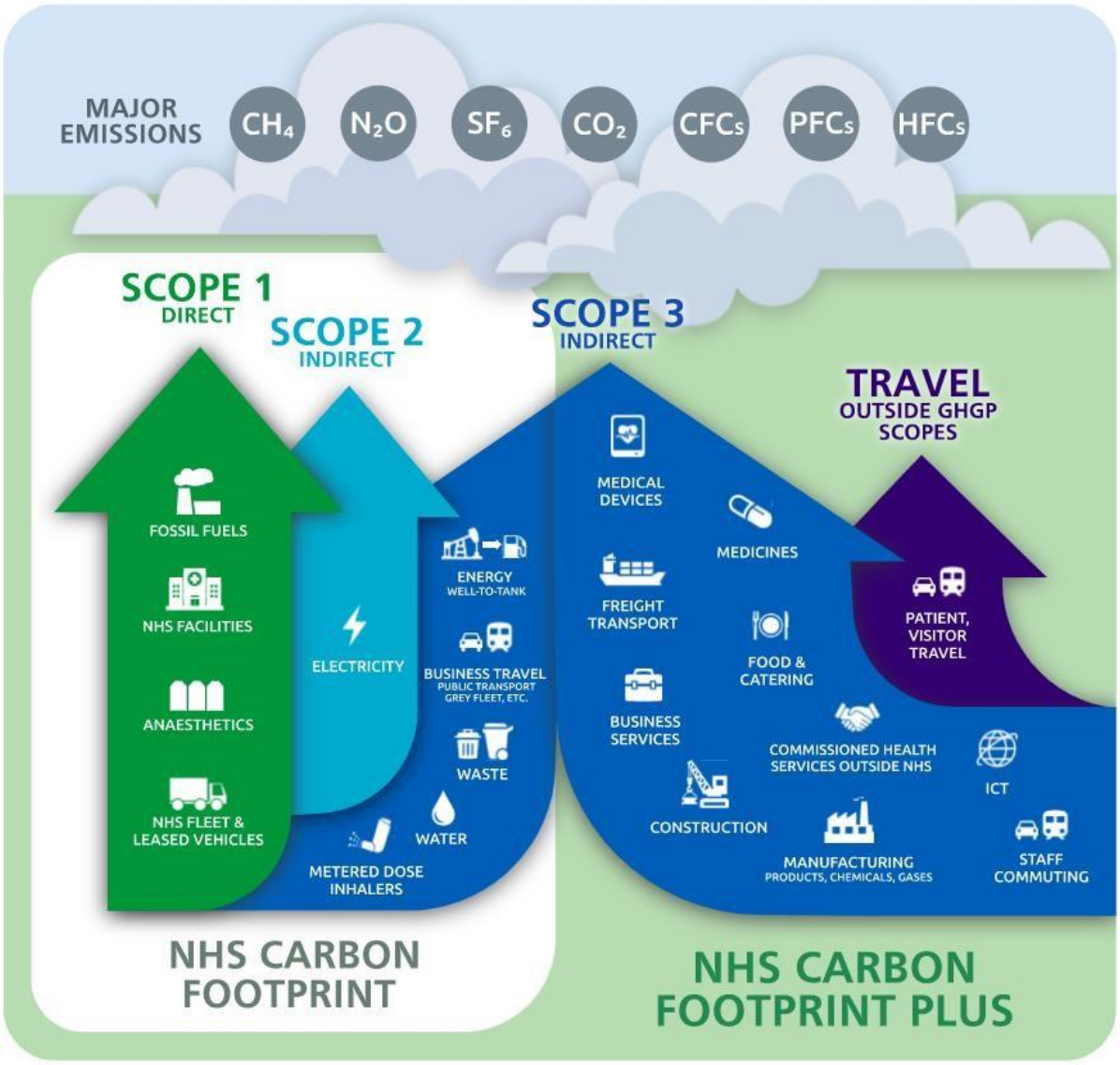


Figure 10: Greenhouse Gas Protocol (GHGP) scopes in the context of the NHS Carbon Footprint. Source: NHS England, Delivering a Net Zero NHS (2022)

2.11.2 Environment Impact of Inhaled Anaesthetics

Inhaled anaesthetic agents, including nitrous oxide, desflurane, sevoflurane, and isoflurane, are widely all recognised as potent greenhouse gases (American Society of Anesthesiologists, 2024). These agents are routinely used in both general anaesthesia and procedural sedation across medical and dental settings. However, their environmental burdens differ significantly depending on both their chemical properties and patterns of clinical use.

The potential (GWP_{100}) of anaesthetic gases is a mass-based measure reflecting their ability to trap heat in the atmosphere over a 100-year period, benchmarked against carbon dioxide (GWP = 1). Desflurane has the highest GWP among inhaled agents at 2,540, followed by isoflurane (539), nitrous oxide (273), and sevoflurane (144) (Ryan and Nielsen, 2010). However, GWP alone does not fully reflect clinical impact, as anaesthetic agents differ in potency and volume required for effect.

Nitrous oxide, for instance, has relatively low potency and thus requires significantly higher concentrations for sedation compared with volatile agents (American Society of Anesthesiologists, 2024). As a result, despite its moderate GWP per molecule, nitrous oxide often has a greater environmental impact in practice— especially in dental settings where intermittent high-flow use is common.

In addition to its higher usage volume, nitrous oxide remains in the atmosphere for over 100 years (compared to 1.9 years for sevoflurane), leading to cumulative and long-term effects (American Society of Anesthesiologists, 2024). **Table 12** outlines the key environmental characteristics of commonly used inhaled anaesthetics, incorporating both GWP_{100} and real-world equivalence in car miles driven per MAC-hour (American Society of Anesthesiologists, 2024).

Agent	MAC	Atmospheric Lifetime (years)	GWP_{100}	Car Miles Equivalent (per MAC-hour at 1L/min)
Desflurane	6.7%	14	2,540	190 miles
Nitrous Oxide	60% (0.6 MAC)	114	273	49 miles
Isoflurane	1.2%	3.6	539	8 miles
Sevoflurane	2.2%	1.9	144	4 miles

Table 12: Greenhouse Gas Emissions of Common Inhaled Anaesthetic Agents. Adapted from Ryan and Nielsen (2010)

2.11.3 Dentistry's Distinct Position

Medical specialities such as anaesthesia departments have focused on transitioning from piped to cylinder-based delivery and increasing the use of alternatives such as total intravenous anaesthesia (TIVA) (NHS, 2022). Maternity departments have started to invest in nitrous oxide capture and destruction technology (NHS, 2022). However, the way in which dentistry uses nitrous oxide differs considerably. As seen in section 2.9.2, dental inhalation sedation is delivered in brief, intermittent procedures, with direct control of the flow rate, duration, and concentration of gas administered. Infrastructure, patient case mix, and procedural protocols vary between dental services, meaning a one-size-fits-all mitigation strategy is unlikely to succeed. Additionally, for certain patient groups, particularly in paediatric and special care dentistry, viable alternatives to nitrous oxide remain limited or inaccessible as reflected in national guidance (IACSD, 2020)

2.11.4 From Clinical Use to System Waste

In dentistry, nitrous oxide's carbon footprint is expressed as carbon dioxide equivalents (CO_2e), which are calculated using the product of gas volume delivered, the global warming potential (GWP) of nitrous oxide, and a conversion factor for molar mass and density (Aqua-calc, 2025) (Greenhouse Gas Protocol, 2024). This metric enables services to monitor environmental impact in a standardised way and forms the basis for sustainability audit work and mitigation aid; described later in this thesis.

The environmental burden of inhalation sedation is influenced by several factors (Chakera et al., 2021)

- Type of delivery system (piped vs. cylinder supply).
- Gas wastage through leaks or inappropriate stock management.
- Clinical parameters including flow rate, concentration of N_2O delivered, and duration of N_2O exposure.

Wastage is a particularly important and modifiable driver. Gas lost through poorly sealed connections, ageing pipeline systems, or idle flow before mask placement

contributes directly to emissions without delivering any patient benefit. Comparing the volume of gas clinically administered to the total purchased or supplied can reveal substantial avoidable losses (Chakera and Pearson, 2022). Portable systems are also prone to inefficiency if “nearly empty” cylinders are returned with significant contents, as suppliers must vent these before refilling.

2.11.5 The NHS Mitigation Plan

National audits in secondary care have shown that targeted leak checks, stock control, and clinician education can lead to measurable reductions in nitrous oxide emissions (Chakera et al., 2021). The NHS mitigation approach applies a structured DMAIC (Define–Measure–Analyse–Improve–Control) quality improvement methodology, coordinated through each trust’s Medical Gases Committee and involving estates, pharmacy, clinical teams, and facilities management (Chakera, 2021). This framework enables services to track sedation activity, gas volumes, and CO_2e emissions over time, set local key performance indicators (KPIs)—for example, kg CO_2e per sedation case—and monitor progress against sustainability targets.

Key actions include (Chakera et al., 2021):

- Measuring true usage against turnover using supplier return data.
- Regular leak testing and maintenance of manifolds and outlets.
- Decommissioning piped systems.
- Avoiding premature cylinder changeover and enforcing stock rotation.
- Securing storage to prevent theft or diversion.
- Continuous improvement cycles.

2.11.6 Mitigation Strategies within Dentistry

Dental efforts have been initiated to address nitrous oxide emissions as the Scottish Dental Clinical Effectiveness Programme (SDCEP) has developed dedicated Nitrous Oxide Mitigation Guidance, which offers practical, service-level strategies for reducing environmental waste (SDCEP, 2024). These include regular leak checks,

appropriate stock rotation, improved cylinder handling, and better alignment of gas supply with actual sedation activity. The SDCEP guidance aligns closely with NHS recommendations but is tailored to the realities of dental settings; where sedation is intermittent and often clinician controlled.

Alongside national guidance, a multi-centre quality improvement project (QIP**)** was recently carried out to assess and reduce the environmental impact of nitrous oxide within dentistry. This represents the first study to quantify nitrous oxide related carbon emissions across different dental settings in the UK, marking a significant step in the profession's sustainability journey. Notably, this national QIP was carried out following the demonstrated success of a local four-cycle audit at the Eastman Dental Hospital, where a 20% reduction in CO_2e emissions was achieved through targeted interventions (Ahmad and Lyne, 2023). Results from the local QIP, along with key findings from the national project, will be discussed in Chapter 4.

2.11.7 Capture and Destruction Technologies

While efforts so far have focused on reducing unnecessary use and preventing waste, attention is also turning toward technologies that can actively remove nitrous oxide from the clinical pathway. One such solution is catalytic destruction technology, which captures exhaled nitrous oxide and breaks it down into nitrogen and oxygen (Chakera, 2021). These systems have been adopted in some Nordic countries and are gaining interest within NHS sustainability discussions. However, their role in dentistry remains uncertain (Chakera, 2021).

Unlike in anaesthesia or maternity settings, nitrous oxide use in dentistry is intermittent, low-flow, and clinician-controlled—making it less compatible with current capture designs. Moreover, these technologies are costly to implement and at present, no UK dental service has reported routine use of capture machines as there is little evidence on how effective they are in the dental setting (NHS, 2022). Even if effective, their benefit is limited if gas is lost before it reaches the patient, such as through leaks or open flow prior to mask placement (Chakera, 2021). In this context, simple measures like tightening connections, training staff, and monitoring stock remain far more impactful.

Research is urgently needed to assess whether these technologies can be adapted to dentistry, and whether they offer a meaningful return, both financially and environmentally. As the profession continues to re-evaluate its reliance on nitrous oxide, attention must also shift towards exploring safe and sustainable alternatives. The next chapter explores whether alternatives such as midazolam or newer agents may help meet clinical needs without the same environmental cost.

Chapter 3

Alternatives to Nitrous Oxide: A Literature and Scoping Review

3.1 Introduction

Nitrous oxide has, for decades, been the trusted companion of many paediatric dental teams. Its rapid onset, gentle anxiolytic and analgesic effects, and smooth recovery make it especially suited to treating children who are anxious, needle phobic, or simply too young to cooperate with conventional approaches (Pedersen *et al.*, 2013). As discussed in the previous chapters, the pharmacological profile of nitrous oxide makes it one of the safest and most predictable agents available. It requires minimal recovery time, does not depend on hepatic metabolism, and can be titrated with precision — all of which contribute to its enduring popularity in both hospital and primary care settings (Cameron and Widmer, 2013). For many, it is the ideal sedative, and guidelines reflect this confidence (SDCEP, 2017; IACSD, 2020). They support the use of inhalation sedation with nitrous oxide as a first-line pharmacological technique in children, citing its proven safety and ease of delivery. In real-world terms, it allows clinicians to manage challenging appointments without resorting to general anaesthesia or relying too heavily on behavioural strategies alone. For many children, it is the tool that makes dentistry possible.

Yet, in recent years, questions have begun to surface — not about its clinical value, but about its environmental cost. Nitrous oxide is now recognised as a potent greenhouse gas, and its long atmospheric lifespan means even small leaks or routine use can accumulate into significant environmental impact over time. As sustainability becomes a pressing concern in healthcare, nitrous oxide has increasingly come under inspection — not because it lacks clinical value, but because of its carbon footprint.

This tension, between clinical excellence and environmental responsibility, is what prompted the present project. If nitrous oxide is so effective, are there any alternatives that can offer a similar level of safety, ease, and child-acceptability, while

reducing harm to the planet? And if no clear alternative exists, is there at least an emerging field of sedatives that could evolve to meet this need?

While sedatives like oral midazolam, intranasal benzodiazepines, and more recently dexmedetomidine are already in limited use, the broader evidence base remains inconsistent. Even the most comprehensive Cochrane review to date, the Cochrane review by (Ashley et al., 2018), concluded that there is no clearly superior sedative agent in paediatric dentistry. Since then, newer sedative formulations, including alternative benzodiazepines such as remimazolam and ADV6209, have entered medical use, though their application in paediatric dental settings remains limited.

This chapter explores that gap. First, it presents a comparative overview of currently available sedatives used in paediatric dentistry — their routes of delivery, onset and recovery profiles, known side effects, and environmental relevance. This will be followed by a scoping review of the emerging literature on novel sedative agents, highlighting what's new, what's promising, and where further research is needed. Together, these sections aim to position nitrous oxide within the broader sedation landscape — not to challenge its value, but to explore whether anything else can measure up, now or in the near future.

3.2 Aim and Methods

3.2.1 Aim

To review current sedation agents used in paediatric dentistry and explore emerging alternatives through a comprehensive literature review and a scoping review.

3.2.2 Comprehensive Review of Available Sedatives

Sedative drugs were identified through a guideline-led approach. Three major evidence-based sources were used to inform the selection:

- The Intercollegiate Advisory Committee on Sedation in Dentistry (IACSD) guidance (2020).
- The American Society of Anesthesiologists (ASA) Practice Guidelines for Moderate Procedural Sedation and Analgesia (2018).

- The Cochrane Review on Sedation for children undergoing dental treatment (2018).

These guidelines were chosen as they collectively provide a robust and clinically relevant overview of sedation agents across different settings and levels of care. From this list, melatonin was excluded due to its primary use as a premedication rather than as an agent for procedural sedation. Etomidate was also excluded, as it is predominantly used to induce deep sedation or anaesthesia, making it inappropriate for inclusion within a conscious sedation-focused review.

Additional clinical and pharmacological data for each sedative were sourced from reputable organisations such as the American Academy of Pediatric Dentistry (American Academy of Pediatric Dentistry, 2024a), the American Society of Anesthesiologists (American Society of Anesthesiologists, 2018), peer-reviewed medical literature, standard pharmacology and anaesthesia textbooks, and regulatory information published by bodies such as the U.S. Food and Drug Administration (FDA) (Food & Drug Administration, 2025).

To facilitate meaningful comparison, each sedative was assessed in relation to nitrous oxide—regarded as the benchmark agent in paediatric dentistry for its safety, familiarity, and ease of use. A colour-coded classification system was developed to categorise sedatives based on three key domains: safety profile, ease of administration, and overall suitability for paediatric dental sedation.

- **Green** indicates agents with a high safety profile and ease of application equivalent to nitrous oxide.
- **Amber** denotes moderate safety and/or ease of use, where administration may be more complex or monitoring requirements higher.
- **Red** is reserved for agents that present a lower safety margin or greater practical challenges in paediatric settings.

3.2.3 Scoping Review of Recent Developments in Sedation

The second part of this review is a scoping review to ‘horizon gaze’ into the latest advancements in the field of paediatric conscious sedation. This search was carried

out to systematically map the research done in this area and was done in correspondence to the Joanna Brigs Institute for Scoping Reviews (JBI) and PRISMA-ScR checklist (Tricco *et al.*, 2018). The sections below detail the stages formulated for this scoping review.

3.2.3.1 Research Question

The research question was developed using the Population, Concept, Context (PCC) framework (Peters *et al.*, 2020).

Population: children from 0 to 18 years of age.

Concept: development of new sedatives, their pharmacological profiles, recent approvals by regulatory organisations, comparisons of safety and efficacy to existing standards, and any new approaches in administration or monitoring.

Context: provision of conscious sedation in medical and dental settings.

Based on the above PCC, we developed the following question:

"What are the most recent advancements in provision of paediatric conscious sedation and are there any newly approved sedatives in the scientific literature?"

3.2.3.2 Search Strategy

Three electronic databases PubMed**,** MEDLINE (Ovid)**,** and Embase (Ovid) were chosen, and the search was conducted in November 2023. The most frequently used keywords for this topic were identified and included the following descriptors in the search Medical Subject Headings (MESH): "new"; "sedative"; "sedation"; "children"**,** with the Boolean operators "AND". Original search articles (any methods) and review articles including systematic reviews, meta-analyses, meta-syntheses, narrative reviews, mixed-method reviews, qualitative reviews, and rapid reviews.

3.2.3.2 Search Parameters

Keywords: sedation, new, novel, drug, sedative, children, paediatric
Date range: January 2018 till November 2023.
Language restriction: English only.
Age group: Child 0-18 years.

3.2.3.3 Eligibility Criteria

Inclusion criteria:

- Studies presenting new updates on the use of existing sedatives to provide conscious sedation in children.
- Studies presenting new sedatives approved to provide conscious sedation in children.

Exclusion criteria:

- Articles with a focus on deep sedation/general anaesthesia, drug dose comparison studies, and long-term sedation use for critically ill children in ICU.

3.2.3.4 Article Selection

Initial Screening: Titles and abstracts were collated and uploaded into EndNote X9.3.3 (Clarivate Analytics, PA, USA) and duplicates removed to identify studies potentially relevant to our review. Initially, titles and abstracts were read, and articles were screened with accordance to the inclusion and exclusion criteria. Furthermore, the studies were then discussed with the team to identify which studies would be included in this review.

3.2.3.5 Data Extraction

Data extraction was undertaken by the investigator (SA) using a structured extraction form, developed in accordance with the JBI Data Extraction guidelines (JBI, 2024). This form captured key elements including the population, concept, context, and main findings of each included study. The tool was initially piloted on the first three eligible studies and reviewed by the primary supervisor (Paul Ashley), after which minor adjustments were made to ensure clarity and consistency. Data from the remaining studies were then extracted accordingly. Any uncertainties or discrepancies were resolved through discussion with the supervisory team. The finalised data extraction form is included in Appendix 1.

3.2.3.6 Results Presentation

The initial electronic search yielded a preliminary total of 183 records. Following the removal of duplicates and the study selection process, shown in **Figure 11**, a total of 6 articles met our criteria and were included in this review. Data relevant to the search were extracted from the included studies and presented in **Table 14** where the study characteristics are identified.

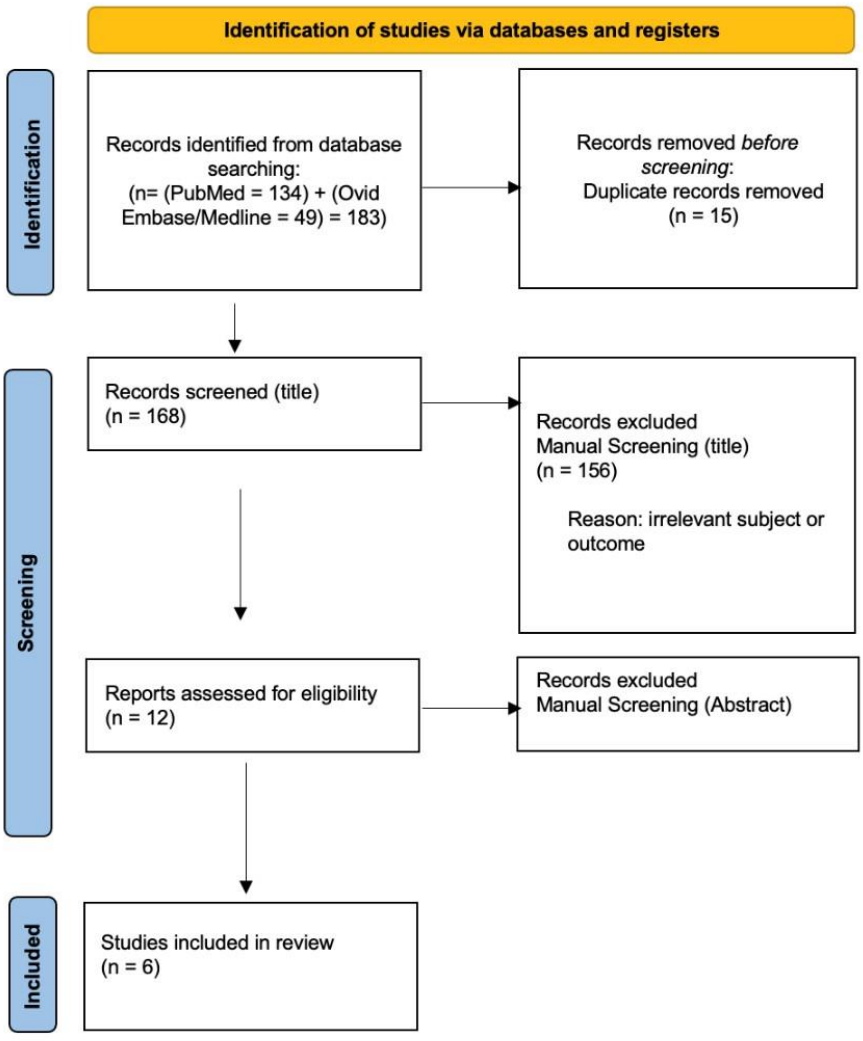


Figure 11: PRISMA 2020 flow diagram

3.3 Results

3.3.1 Overview of Current Sedatives

The following section presents the comparative review of sedative agents based on safety, ease of use, and suitability for paediatric dental sedation, using a colour coded system relative to nitrous oxide (**Table 13**).

A total of 19 sedative agents were identified through guideline-based review and categorised into three groups—green, amber, and red—based on their comparative safety, ease of use, and suitability for paediatric dental sedation relative to nitrous oxide.

Green Category

Nitrous Oxide was the only agent assigned to the green category. It remains the benchmark for conscious sedation due to its minimal depth of sedation, rapid onset (under 5 minutes), and short recovery time (approximately 5 minutes). Adverse effects were uncommon and primarily included mild nausea, vomiting, and headache. Contraindications were respiratory-related or anatomical in nature (e.g., sinusitis, middle ear surgery, or nasal obstruction).

Amber Category

A range of sedatives were classified as amber, indicating moderate safety or application concerns in comparison to nitrous oxide.

- Hydroxyzine**:** Administered orally, intramuscularly, or rectally, hydroxyzine demonstrated minimal sedation with a relatively long half-life (~7 hours). Notable adverse effects included tachycardia, dry mouth, and fever. It is contraindicated in patients with prolonged QT interval or cardiovascular disease.
- Chloral Hydrate**:** Taken orally or rectally, this sedative produced moderate sedation and had a longer half-life of 8–12 hours. Cardiopulmonary risks included oxygen desaturation and hypotension. Gastrointestinal side effects such as nausea and vomiting were also reported. Its use is contraindicated in patients with hepatic, renal, or cardiac impairment.

- Triclofos Sodium**:** A derivative of chloral hydrate, administered orally. It provided moderate sedation with a 9-hour half-life and shared similar risks of oxygen desaturation and vomiting. Hepatic or renal impairment was noted as a contraindication.
- Dexmedetomidine**:** Available via intranasal, intravenous, and intramuscular routes, it provided minimal to moderate sedation. It had a short half-life (2–3 hours) but showed dose-related adverse effects such as bradycardia and hypotension. It is contraindicated in cardiovascular conditions.
- Midazolam**:** Administered across five routes (oral, intranasal, intravenous, intramuscular, and rectal), it provided moderate sedation with a rapid onset and short half-life (~2 hours). Respiratory adverse effects included hypoventilation and oxygen desaturation. Contraindications were primarily related to benzodiazepine sensitivity and hepatic dysfunction.
- Diazepam**:** Provided moderate sedation across several routes, with a significantly longer half-life (24–57 hours). Drowsiness and respiratory depression were noted adverse effects, with multiple contraindications including CNS depression and sleep apnoea.
- Temazepam**,** Flunitrazepam, and Lorazepam**:** These benzodiazepines were also grouped as amber, with oral or intramuscular routes of administration and moderate depth of sedation. All had notable risks of respiratory depression and were contraindicated in similar populations with CNS or respiratory conditions.
- Nalbuphine**:** Delivered intravenously or intramuscularly, it produced moderate sedation with a short half-life (52 minutes). Respiratory depression and gastrointestinal symptoms were commonly reported.

Red Category

The following agents were assigned to the red category, reflecting deeper sedation profiles, increased monitoring needs, and/or greater safety risks:

- Meperidine**:** Administered via oral, IV, or IM routes, with moderate sedation and a 3-hour half-life. It is associated with tachycardia, seizures, and a range of contraindications, including comatose states or raised intracranial pressure.

- Fentanyl**:** Delivered intravenously or intranasally, fentanyl induced moderate to deep sedation with a short half-life (3.6 hours). Respiratory depression was the most significant concern.
- Alfentanil**:** An opioid with a very short half-life (1.5–1.8 hours), administered intravenously. It carried a high risk of respiratory depression.
- Remifentanil**:** Offered rapid onset (1 minute) and brief duration (10–20 minutes), but significant myocardial and respiratory depression were reported.
- Ketamine**:** Provided via multiple routes, ketamine produced moderate to deep sedation. Cardiovascular and respiratory effects were noted, along with behavioural side effects such as agitation or hypersalivation.
- Morphine**:** Delivered through oral, IV, or IM routes, morphine was associated with deep sedation, constipation, hypotension, and delayed gastric emptying. It was contraindicated in children with chronic lung disease or raised intracranial pressure.
- Propofol**:** An intravenous agent with rapid onset and short half-life (4–7 hours). It is associated with respiratory hypotension and myocardial depression, and it is contraindicated in children under 3 years.
- Sevoflurane**:** Inhaled volatile agent with a long half-life (15–23 hours). While potent and effective, it carries risks of laryngospasm and malignant hyperthermia.

Sedative	Route	Onset (min)	Depth of sedation	Recovery	Adverse effects		Contraindications
				Half life	Cardiorespiratory	Other	
Nitrous Oxide	Inhalation	<5	Minimal	5 mins	Uncommon	Nausea, vomiting, headache	COPD, Cystic Fibrosis, pneumothorax, nasal blockage, sinusitis, tonsillitis, tympanic membrane middle ear surgery, cochlea implants, vit B12 deficiency, recent eye surgery, psychotic patients, bleomycin chemotherapy
Hydroxyzine	Oral	15-30	Minimal	7 h	Tachycardia	Dry mouth, fever, skin rash	Prolonged Q-T interval, bradycardia, cardiovascular disease
	Intramuscular	15-30					
	Rectal	30-60					
Chloral Hydrate	Oral	15-30	Moderate	8-12 h	Airway obstruction Oxygen desaturation Hypotension	Gastric irritation, nausea, vomiting	Heart disease, hepatic or renal impairment, and gastritis.
	Rectal	30					
Triclofos Sodium	Oral	30	Moderate	9 h	Oxygen desaturation	Dizziness, irritability, and vomiting	Hepatic or renal impairment
Dexmedetomidine	Intranasal	20-30	Minimal to moderate	2-3 h	Bradycardia Hypotension	Nausea and vomiting	Acute cerebrovascular disorders, second- or third-degree AV block, uncontrolled hypotension
	Intravenous	<5					
	Intramuscular	10-30					
Midazolam	Oral	15-30	Moderate	2 h	Hypoventilation Oxygen desaturation Hypoxaemia	Hiccups, nausea, vomiting	Allergy to Benzodiazepines, Under the age of 1, myasthenia gravis, sleep apnoea, liver dysfunction, hepatic dysfunction
	Intranasal	10-15					
	Intravenous	2-3					
	Intramuscular	10-20					
	Rectal	10-30					

Diazepam	Oral	15-60	Moderate	24-57h	Respiratory depression	Drowsiness and ataxia	Allergy to Benzodiazepines, Myasthenia gravis, CNS depression, compromised airway, respiratory depression, hyperkinesis, hepatic
	Intranasal	<5					
	Intravenous	1-3					
	Rectal	5-10					insufficiency, sleep apnoea, chronic psychosis
Temazepam	Oral	30	Moderate	5 h	Respiratory depression	Dizziness, nausea	Allergy to Benzodiazepines, chronic psychosis, CNS depression, compromised airway; respiratory depression
Flunitrazepam	Oral	20-30	Moderate	20 h	Respiratory depression Oxygen desaturation	Dizziness, nausea	Allergy to Benzodiazepines, chronic psychosis, CNS depression, compromised airway; respiratory depression
	Intramuscular	10-20					
Lorazepam	Oral	20-30	Moderate	10-20h	Respiratory depression	Drowsiness and ataxia	Allergy to Benzodiazepines, CNS depression, compromised airway, respiratory depression
	Intravenous	1-2					
	Intramuscular	15-30					
Nalbuphine	Intravenous	2-3	Moderate	52 min	Respiratory depression	Drowsiness, nausea, and vomiting	Undiagnosed abdominal pain, acute or severe bronchial asthma
	Intramuscular	15					
Meperidine	Oral	40	Moderate	3 h	Tachycardia	Tremors, muscle twitches, hyperactive reflexes, seizures, nausea, and vomiting	Acute respiratory depression; comatose patients; raised intracranial pressure, risk of paralytic ileus
	Intravenous	2-4					
	Intramuscular	10-30					
Fentanyl	Intravenous	1	Moderate to deep	3.6 h	Respiratory depression	Nausea and vomiting	Acute respiratory depression, comatose patients, raised intracranial pressure, risk of paralytic ileus
	Intranasal	2					

Alfentanil	Intravenous	1-2	Moderate to deep	1.5-1.8h	Respiratory depression	Nausea and vomiting	Acute respiratory depression, comatose patients, raised intracranial pressure, risk of paralytic ileus
Remifentanil	Intravenous	1	Moderate to deep	10-20 min	Respiratory and myocardial depression	Muscular rigidity, nausea, and vomiting	Acute respiratory depression, comatose patients, raised intracranial pressure, risk of paralytic ileus
Ketamine	Oral	10-15	Moderate to deep	2-3 h	Tachycardia, hypertension, risk of laryngospasm	Mild agitation, hypersalivation, nausea, vomiting	Corneal lacerations, upper respiratory tract infections, hypertension
	Intranasal	11					
	Intravenous	1-2					
	Intramuscular	3-5					
	Rectal	5-10					
Morphine	Oral	5-10	Moderate to deep	2-4 h	Respiratory depression, vasodilation, hypotension	Nausea, vomiting, and constipation	Acute respiratory depression; comatose patients; raised intracranial pressure, risk of paralytic ileus delayed gastric emptying; heart failure secondary to chronic lung disease
	Intravenous	1-2					
	Intramuscular	10-30					
Propofol	Intravenous	<1	Moderate to deep	4-7h	Respiratory, hypotension, myocardial depression	Pain on injection	Children under the age of 3, known hypersensitivity to propofol
Sevoflurane	Inhalation	2-3	Moderate to deep	15-23h	Laryngospasm, myocardial depression	Excitement disinhibition, nausea, vomiting, coughing	Susceptibility to malignant hyperthermia, caution with renal insufficiency

Table 13: Overview of key sedatives colour-coded by safety profile (Author's own)

3.3.2 Scoping Review Results

3.3.2.1 Overview of included studies

A total of six studies met the inclusion criteria and were included in this scoping review. The characteristics and key findings of the included literature are summarised in **Table 14**. The studies comprised narrative reviews, a bibliometric analysis, and a randomised controlled trial. The focus was on recent developments in paediatric sedation, including newly approved drugs, reformulated sedatives, and shifts in preferred administration routes.

No.	Title	Author (s), Year	Study Type	Sedative/Focus	Key Finding
1	Bibliometric Analysis of Global Trends in Remimazolam-Related Research Over the Past 15 Years: Compared with Propofol	(Hu *et al.*, 2023)	Bibliometric (quantitative review)	Remimazolam	Low likelihood of hypotension, cardiorespiratory depression, and injection pain compared to propofol
2	A new view on old problems in paediatric anaesthesia: premedication, postoperative agitation and dosing	(Jöhr, 2023)	Literature Review	Dexmedetomidine (DEX)	Increased use of IN DEX
3	What's New for Pediatrics? A Narrative Review.	(Mahmoud et al., 2020)	Narrative Review	Dexmedetomidine (DEX)	• Increased use of IN DEX • Neuroprotective properties of DEX
4	Future of paediatric sedation: towards a unified goal of improving practice.	(Mason and Seth, 2019a)	Narrative Review	ADV6209 Remimazolam	• ADV6209 possible alternative to midazolam • Remimazolam exhibited faster onset, recovery and greater success when compared to midazolam in one study
5	The pearls of pediatric sedation: polish the old and embrace the new	(Mason and Seth, 2019b)	Narrative Review	ADV6209 Dexmedetomidine (DEX)	• ADV6209 approved in Europe for premedication • Monitoring necessary after sedation with DEX regardless of route
6	A novel, palatable paediatric oral formulation of midazolam: pharmacokinetics, tolerability, efficacy and safety.	(Salman *et al.*, 2018)	Randomised Controlled Trial	New formulation of midazolam (chocolate-based)	Improved tolerability

Table 14: Summary of study characteristics and findings

3.3.2.2 New Drug Developments

Recent studies have introduced significant advancements in paediatric sedation, particularly in the form of new drug formulations and updated clinical applications. A summary of the newly identified sedatives is presented in **Table 15**.

Remimazolam

Remimazolam, a new ultra-short acting benzodiazepine, emerged as a promising alternative to propofol. The bibliometric analysis identified its favourable safety profile, with a lower risk of hypotension, cardiorespiratory depression, and injection site pain (Hu *et al.*, 2023). While providing sedation quality comparable to midazolam, remimazolam's rapid metabolism and consistent performance across varied procedures make it particularly beneficial in medically complex children; including those with hepatic or renal impairment or reduced cardiovascular reserve.

ADV2609 – Oral Midazolam

ADV2609, a newly approved oral formulation of midazolam, has recently been authorised for paediatric sedation across Europe (Mason and Seth, 2019b, 2019a). It is intended for use in children aged 6 to 17 years and is supplied as a single-use aqueous solution containing 2 mg/mL of midazolam, packaged in a 5 mL glass ampoule with an integrated filter straw and oral applicator. The recommended dosage is 0.25 mg/kg, with a maximum dose of 20 mg. To improve palatability, ADV2609 features a "wild orange" flavour and sucralose, while a gamma-cyclodextrin complex is incorporated to mask bitterness and enhance solubility. Pharmacokinetic data indicate that over 75% of the drug is absorbed within 30 minutes, and it has a reported adult half-life of approximately 2.66 hours.

Chocolate-Based Chewable Midazolam Tablet

A randomised controlled trial (Salman *et al.*, 2018), investigated a novel chocolate-based chewable tablet formulation of midazolam for paediatric premedication. Compared to the conventional intravenous formulation administered orally, this chewable tablet demonstrated significantly improved tolerability. It also showed children are less likely to spit it out, a common issue with liquid forms. The study concluded that this formulation was both effective and well tolerated, offering a promising alternative for use in children.

Sedative	Route	Onset (min)	Depth of sedation	Half-life	Adverse effects	Training required	Contraindications
Remimazolam	IV	1-3	Moderate	0.92 h	Respiratory depression, bradycardia, hypotension	Cannulation competency for flumazenil if needed	Same as benzodiazepines
	IN	5-7					
ADV6209	Oral	27-30	Mild	2.6 h	Respiratory depression, bradycardia, hypotension	Cannulation competency for flumazenil if needed	Same as benzodiazepines

Table 15: Summary of new drug developments

3.3.2.3 New Trends in Paediatric Sedation

Dexmedetomidine (DEX)

Recent studies have highlighted the increasing use of dexmedetomidine (DEX), particularly via the intranasal route, in paediatric sedation (Jöhr, 2023) (Mahmoud, Barbi and Mason, 2020). Intranasal administration has demonstrated effective sedation with minimal mucosal irritation and reduced need for additional analgesics. Dosages ranging from 2–4 mcg/kg have successfully sedated a large proportion of paediatric patients, indicating potential advantages over traditional sedatives such as midazolam and propofol. However, cardiovascular effects, particularly bradycardia, remain a clinical consideration. Additionally, the neuroprotective properties of DEX continue to be explored, especially considering the ongoing concerns regarding anaesthetic-related neurotoxicity in children.

3.4 Discussion

3.4.1 Green Category: Nitrous Oxide as the Benchmark

Among all sedatives identified, nitrous oxide remains the only agent classified under the green category. This reflects its long-established reputation for safety, particularly in paediatric dental care (Pedersen *et al.*, 2013). Its favourable pharmacological profile, characterised by rapid onset and offset, minimal residual effects, and ease of titration, makes it a highly controllable agent. Importantly, nitrous oxide does not

require intravenous access or extensive staff training beyond basic sedation training (SDCEP, 2017). Moreover, routine monitoring of blood pressure or oxygen saturation is not mandated under conscious sedation protocols, setting it apart from agents that demand more complex perioperative care (IACSD, 2020).

Its adverse effects, though relatively uncommon, include nausea and vomiting, which are generally mild and self-limiting (Anderson *et al.,* 2019). This predictable safety margin supports its continued use in children undergoing dental procedures. Within the wider context of sustainable healthcare, nitrous oxide's environmental impact is an emerging concern; however, clinically, its minimal invasiveness and simplicity of use still render it the most practical option in many settings.

3.4.2 Amber Category: Moderately Safety Profile

Sedatives placed in the amber category exhibit moderate safety profiles and therefore require greater clinical caution. Benzodiazepines, particularly midazolam, have a well-established history in paediatric sedation and are frequently used due to their anxiolytic and amnestic effects (Ashley *et al.,* 2021). However, their use is associated with dose-dependent respiratory depression, necessitating careful patient monitoring and the presence of trained personnel equipped to manage airway compromise or reverse the sedation if needed (Stoelting and Hillier, 2012). In the event of over-sedation, clinical staff must also be competent in intravenous cannulation to administer flumazenil as a reversal agent (IACSD, 2020). Despite these considerations, oral midazolam remains the most widely supported sedative for conscious dental sedation in children. The 2021 EAPD review (Ashley *et al*., 2021), recommended oral midazolam as the first-line agent, citing it as the only sedative with sufficient evidence for paediatric use, while cautioning that the evidence for other routes and for nitrous oxide/oxygen was very low. Similarly, the Cochrane review, (Ashley *et al.,* 2018), reported moderate-certainty evidence for the effectiveness of oral midazolam, reinforcing its role as a reference standard in paediatric dental sedation studies.

Hydroxyzine, an antihistamine sometimes used for its sedative properties, demonstrated a controversial safety profile due to reports of tachycardia (Ashley et al., 2018). However, these findings are inconsistent, and the Cochrane review cited

high bias in much of the available evidence. More recent studies have suggested more favourable outcomes (Kim *et al.*, 2022).

Dexmedetomidine (DEX) is emerging as a promising agent, particularly via the intranasal route. It offers effective sedation with reduced agitation and minimal respiratory depression. However, its potential to cause bradycardia remains a concern, particularly in children with pre-existing cardiac conditions (Anderson et al.,2019). Its neuroprotective potential and unique pharmacological properties warrant further exploration, especially in paediatric settings where anaesthetic neurotoxicity is a concern.

Chloral hydrate, historically used in paediatric sedation, has largely fallen out of favour due to significant concerns around its safety profile. It is particularly associated with adverse airway complications, especially when combined with high concentrations of nitrous oxide (Hosey, 2002). Recognising these risks, the most recent SDCEP (2017) guidance explicitly recommends against the use of chloral hydrate, alongside meperidine and diazepam, in contemporary paediatric dental sedation protocols.

3.4.3 Red Category: Low Safety Profile

Sedatives in the red category, such as propofol, ketamine, sevoflurane, and opioids, carry significantly higher risks. Propofol is widely used in general anaesthesia due to its rapid onset and short half-life (Anderson *et al.,* 2019). However, it causes marked cardiorespiratory depression and is therefore unsuitable for use outside of deep sedation or anaesthetic settings. Ketamine, while offering effective dissociative sedation, presents concerns around airway safety, including a risk of laryngospasm and increased salivary secretions, particularly in dental procedures (Hosey, 2002).

Sevoflurane, a volatile agent sometimes used in dental theatres, is associated with intraoperative excitement and disinhibition, requiring administration by trained anaesthesia professionals. Although it has a lower global warming potential than nitrous oxide (Ryan and Nielsen, 2010), its clinical risk profile remains a limiting factor. Similarly, opioids, while effective in pain control, are associated with nausea,

vomiting, and respiratory depression (IACSD, 2020). In all cases, their use necessitates specialised staff and advanced life-support capabilities.

3.4.4 New Developments in Paediatric Sedation

Recent research has introduced promising advancements in paediatric sedation, particularly through the new formulations of established agents. Remimazolam, a short-acting benzodiazepine, has emerged as a promising alternative to propofol. It demonstrates a favourable safety profile with minimal respiratory or cardiovascular depression and a rapid recovery profile (Hu *et al.,* 2023). These attributes make it particularly suitable for vulnerable populations such as children with hepatic or renal impairment. However, a recent IACSD (2023) update, recommends that it requires to be administered under the same standards and training protocols as midazolam, including reversal preparedness using flumazenil.

ADV2609, a newly approved oral formulation of midazolam, addresses a key challenge in paediatric sedation: poor taste and acceptability (Mason and Seth, 2019b). Designed as a prefilled, flavoured ampoule with enhanced palatability, this formulation improves compliance and offers reliable absorption within 30 minutes. Its standardised dosing, improved solubility, and minimal invasiveness may support broader use. Similarly, a chewable chocolate-based midazolam tablet has demonstrated superior tolerability over the traditional oral solution in randomised trials (Salman *et al.*, 2018). Children were less likely to expel the tablet, addressing a common limitation of oral sedation in younger age groups. Parents and clinicians also reported improved satisfaction and ease of administration, making this a practical addition to preoperative regimens.

Finally, dexmedetomidine is becoming more popular in paediatric sedation especially through the intranasal administration, offering reliable sedation (Johr, 2023; Mahmoud *et al.,* 2020). Its mild side effect profile, including limited respiratory depression, is balanced against the need for cardiovascular monitoring due to bradycardia risk. Ongoing studies continue to explore its neuroprotective properties, which could influence future paediatric practice.

3.4.5 Emerging Alternatives Outside Scope: Methoxyflurane (Penthrox)

Although methoxyflurane (Penthrox) was not identified through the scoping review's search strategy, recent literature suggests it may hold potential as a paediatric sedation agent, particularly in dental care. Abdullah et al. (2011) reported high levels of patient satisfaction and preference for Penthrox over nitrous oxide in dental procedures, attributed in part to the degree of patient control it offers during sedation. The agent is self-administered via a handheld inhaler, allowing titration to effect and a degree of autonomy that can be appealing in both adult and adolescent populations.

However, Penthrox is primarily licensed for analgesia, and its dosing must be carefully restricted to avoid nephrotoxic effects—a legacy concern from its historical use as a volatile anaesthetic in higher doses. Dayan (2016) emphasised that renal complications are rare at low doses, but strict adherence to maximum dosing guidelines is essential. As such, while Penthrox may present a practical alternative in some dental settings, especially where nitrous oxide is unavailable or contraindicated, its current role remains limited by both licensing status and safety considerations.

3.5 Summary and Clinical Implications

Together, these findings reinforce the centrality of nitrous oxide as the benchmark against which newer agents are evaluated. While alternative sedatives present promising pharmacological profiles, they often introduce additional monitoring requirements, staff training, or administration barriers that limit their feasibility in routine dental settings.

As the landscape of paediatric sedation continues to evolve, the development of safer, more acceptable formulations is a positive step forward. However, widespread adoption hinges not only on efficacy but also on the practicality of use in clinical environments. Continued research and clinical trials are required to validate the long-term safety and acceptability of these newer agents.

Considering these trends, clinicians must weigh the relative safety, ease of use, and environmental impact of each sedative. Nitrous oxide, despite its ecological concerns, remains uniquely positioned due to its simplicity and track record. Emerging alternatives may offer valuable adjuncts, particularly when tailored to individual patient needs, but must be introduced with caution, appropriate governance, and robust training.

3.6 Conclusion

This chapter has explored the current and emerging sedative agents in paediatric dentistry, highlighting their relative advantages, limitations, and safety considerations. Although new formulations show promise, none currently offer the same combination of reliability, simplicity, and safety as nitrous oxide. Hence, no suitable alternative exists at present.

In light of this, the focus now shifts to addressing the environmental impact of nitrous oxide. Chapter 4 presents a quality improvement project designed to explore practical strategies for reducing nitrous oxide emissions while maintaining its essential role in dental sedation.

Chapter 4
Reducing the Environmental Impact of Nitrous Oxide: A Quality Improvement Project

4.1 Introduction

Building on the environmental and clinical context established in Chapters 1 and 2, this chapter presents a local quality improvement project (QIP) focused on enhancing the sustainability of inhalation sedation within a UK dental hospital. Nitrous oxide (N_2O), despite its longstanding role as a safe and effective agent for paediatric and special care dental sedation, remains a significant contributor to healthcare-related greenhouse gas emissions. In the NHS Net Zero framework (National Health Service, 2022), anaesthetic gases such as nitrous oxide (N_2O) are categorised as Scope 1 direct emissions and have been prioritised for urgent reduction (**Figure 10**).

As shown in chapter 3, newer sedative agents show emerging promise, however; many dental patients, particularly children and those with additional needs, still rely on nitrous oxide due to the absence of readily accessible alternatives. However, its continued use raises an unavoidable concern: its contribution to climate change. It has been estimated that a single dental sedation appointment results in a carbon footprint of up to 93-94 kg CO_2e which is equivalent to driving approximately 679 km by car (Fennell-Wells et al., 2024).

While previous chapters have explored the global warming potential of N_2O and its prolonged atmospheric lifespan, this QIP sought to move from conceptual impact to measurable local action. Unlike anaesthesia or maternity services, where mitigation efforts have focused on piped gas decommissioning and capture technologies, the nature of dental inhalation sedation — intermittent and clinician-controlled— demands a more tailored approach. Therefore, the emphasis within this project was not on eliminating N_2O use, but on improving its efficiency and reducing unnecessary waste.

The project was initially piloted at the Eastman Dental Hospital (EDH) and comprised four audit cycles conducted between 2022 and 2023. These cycles collected quantitative data across multiple departments — including paediatric, special care, and oral surgery — to evaluate sedation practices and identify opportunities for emission reduction. Metrics included gas justification, sedation success rates, estimated carbon footprint (CO_2e), and system inefficiencies such as stock wastage or leaks. The first cycle was initiated in October 2022 by the supervising consultant, Dr. Alexandra Lyne, and the subsequent three cycles led by the author (SA) over the following year.

Preliminary results demonstrated a 20% reduction in CO_2e emissions following implementation of targeted local changes. These included increased staff awareness and clinical recommendations. The outcomes were presented at the 2023 British Society of Paediatric Dentistry (BSPD) Annual Conference (Ahmad and Lyne, 2023), and later informed a broader national-level audit, which has since been submitted for publication. While the national results will be referenced for comparison, this chapter will focus on the local EDH data and its role in shaping the mitigation toolkit presented in Chapter 5.

Through this QIP, the aim was not only to quantify clinical gas use but also to demonstrate how routine service-led audits can align with NHS sustainability goals. The project illustrates how paediatric dental services — even within complex hospital settings — can contribute meaningfully to climate action without compromising patient care.

4.2 Aims and Objectives

The overarching aim of this quality improvement project was to reduce the global warming impact of nitrous oxide (N_2O) use within the Royal National ENT and Eastman Dental Hospitals (RNENTEDH) in line with the NHS Net Zero framework.

To achieve this aim, the following objectives were established:

1. To quantify the carbon footprint of nitrous oxide use in dental inhalation sedation, by estimating carbon dioxide equivalent (CO_2e) emissions across four audit cycles.
2. To evaluate patterns of clinical use and identify opportunities to minimise unnecessary administration of nitrous oxide without compromising patient care.
3. To assess nitrous oxide wastage, by comparing the amount of gas ordered versus the amount delivered to patients.
4. To support future sustainability planning, by providing baseline data for the development of targeted interventions, including the potential adoption of nitrous oxide capture-and-destruction technology.

These objectives were embedded within a broader institutional commitment to sustainability, including University College London Hospitals' (UCLH) ambition to achieve net zero carbon emissions by 2031 (UCLH, 2023) (Chakera, 2021).

4.3 Methods

4.3.1 Study Design and Setting

This quality improvement project (QIP) was conducted at the Royal National ENT and Eastman Dental Hospitals (RNENTEDH) to evaluate the clinical use and environmental impact of nitrous oxide (N_2O) during dental inhalation sedation. The study followed a retrospective audit design comprising four cycles, each capturing a one-month period of clinical activity.

All inhalation sedation appointments that took place during each selected month were included in the audit. Audit cycles were spaced at 3-month intervals, with the intention of capturing data across different seasons and financial quarters. This approach allowed for a more representative picture of annual sedation activity and environmental impact, accounting for variations in patient flow, staff availability (e.g. leave periods), clinical scheduling, and departmental operations.

The audit cycles were structured as follows:

- **Cycle 1**: October 2022 (conducted by the supervising consultant)
- **Cycle 2**: February 2023 (led by the author)
- **Cycle 3**: June 2023 (led by the author)
- **Cycle 4**: October 2023 (led by the author)

Departments included in the audit were Paediatric Dentistry, Special Care Dentistry, and Oral Surgery. The ENT department was excluded, as it did not use nitrous oxide during the audit period. Data were collected from all Procedure Zone (PZ) clinics on Levels 2 and B-1, as well as from IV sedation (IVS) clinics where nitrous oxide was occasionally used to facilitate cannulation.

4.3.2 Inclusion and Exclusion Criteria

All patient appointments involving nitrous oxide administration within the defined months were included. Appointments were excluded if inhalation sedation was planned but not delivered, or if patients did not attend (DNAs).

4.3.3 Data Collection

Data were collected retrospectively from clinical records, sedation logs, and the EPIC sedation documentation system across all audit cycles. For each audit month, a dedicated spreadsheet was populated, with each row representing one patient who received inhalation sedation (IHS) during that period. **Figure 12** illustrates an example of the data collection spreadsheet used.

The following variables were collected:

- Patient details**:** Age, ASA classification, and department (e.g., paediatric, special care, oral surgery).
- Sedation justification**:** Whether alternative sedation modalities (such as IV sedation) were considered, and whether the use of IS was clearly justified in the treatment plan.

- Treatment details**:** Planned procedures (e.g., restorations, extractions, acclimatisation), procedural success, and the number of IS appointments required.
- Sedation parameters**:** Maximum concentration of N_2O, total duration of administration (minutes), and flow rate (L/min).

	Name of department/ unit / service:	
	Month audited:	Feb-23
	Does this service use cylinders or piped gases?	
	Audit lead / contact:	

	Anonymous patient identifier				Alternatives & justification		Treatment details		
Specialty	Date / time of appointment	Clinician / clinic code / MRN	Age	ASA	Could your service have offered an alternative to IS? (e.g. IVS)	Was IS justified over other forms of sedation?	Planned procedure for this visit (XLA, Cons, RCT, Acclimatisation, Cannulation for IVS, Surgical)	Was procedure successful? (Y/N)	How many IS visits were needed (or will be needed) to complete treatment?
Paediatric	02/01/2023	EXAMPLE	9	1	N	Y	Restorations under IS	Y	4
Special Care	02/01/2023	EXAMPLE	9	2	N	Y	Extraction under IS	Y	3
Oral Surgery	02/03/2023	EXAMPLE	13	1	Y	Y	RCT under IS	N	Multiple
Paediatric	02/06/2023	EXAMPLE	8	1	N	Y	Surgical extraction under IS	Y	1
Oral Surgery	02/06/2023	EXAMPLE	11	1	N	Y	Extraction under IS	Y	2

Figure 12: Example of the monthly data collection spreadsheet used during the audit

Top: Clinical details for each patient.

Bottom: CO_2e calculator and summary metric

Assumptions for CO2e calculation	
0.001984	kg of N2O is equivalent to 1L of N2O
265	is the GWP of 1kg N2O (IPCC ARF5 data)

Results		
Total CO2e for 1 month:	1961.15778	kg CO2e
Average per patient:	29.7145118	kg CO2e
Average flow rate:	5.99242424	LPM
Average max dose (% N2O):	32%	% N2O
Average mins with N2O:	31.2973846	minutes

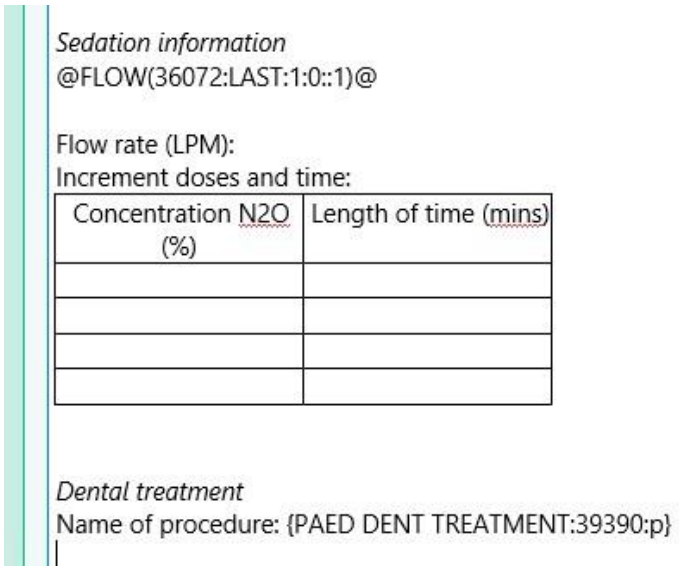
CO2e calculator				
Flow rate (LPM)	Max N2O %	Total time of N2O administration (minutes)	CO2e	Additional comments (if felt relevant)
6	70%	13.33	29.44212791	Increments and LPM not recorded
5.5	35%	39	39.48072291	Increments not recorded
6	40%	11	13.88333113	Increments not recorded
6	30%	13	10.41249835	
6	35%	10	11.04355886	Increments not recorded

4.3.4 Nitrous Oxide Administration Estimation

For each appointment, the volume of nitrous oxide administered was estimated using three variables:

- Maximum N_2O concentration (%).
- Total duration of administration (minutes).
- Recorded flow rate (L/min). If not specified, it was assumed to be 6 (L/min) as this is considered a standard flow rate setting.

In the Paediatric Dentistry department, individual nitrous oxide increments were recorded using structured templates (**Figure 13**), allowing for accurate gas delivery estimation. In other departments lacking pre-formatted logs, the highest recorded concentration was assumed across the total sedation duration, based on entries in the EPIC sedation narrator.


Sedation information
@FLOW(36072:LAST:1:0::1)@

Flow rate (LPM):
Increment doses and time:

Concentration N2O (%)	Length of time (mins)

Dental treatment
Name of procedure: {PAED DENT TREATMENT:39390:p}

Figure 13: Sedation template in paediatric department

4.3.5 Carbon Footprint Calculation

The environmental impact of N_2O use was expressed in carbon dioxide equivalents (CO_2e), calculated using the following formula:

CO_2e (kg) = [% concentration] × [minutes] × [L/min] × [conversion factor from volume (L) to weight (kg)] × [GWP of N_2O]

Where:

- N_2O's Global Warming Potential (GWP) was taken as 265, consistent with current IPCC guidance (IPCC, 2023).
- The conversion factor from litres to grams was derived from established physical properties of nitrous oxide. [1L of N_2O = 0.001984] (Aqua-calc, 2025).

4.3.6 Data Analysis

Data were analysed using Microsoft Excel. The following summary metrics were generated for each audit cycle:

- Total monthly CO_2e emissions.
- Average CO_2e per patient.
- Average flow rate, N_2O concentration, and administration time.
- Sedation success rate.
- Proportion of patients eligible for standard intravenous sedation (aged ≥12 years, ASA I–II).

Wastage was defined as the difference between the total volume of nitrous oxide delivered to the hospital and the total volume delivered to patients over a one-year period. The average monthly volume of gas supplied was calculated based on the number and size of cylinders delivered annually. Wastage was expressed as a percentage of total stock and used to identify inefficiencies in the supply and delivery system.

4.3.7 Audit Registration and Dissemination

This audit was formally registered under the Eastman Dental Hospital's clinical governance framework. The audit registration form, including the APAT (Audit Priority Assessment Tool) score and audit reference number, is included in **Appendix 2**.

The audit protocol was initially developed and presented by the supervising consultant, Dr Alexandra Lyne, ahead of the first audit cycle in October 2022. The author subsequently led Cycles 2 to 4 and was responsible for data collection, analysis, and reporting.

After each audit cycle, findings were presented at internal departmental staff meetings along with clinical recommendations. Findings from Cycles 1–3 were incorporated into the annual sedation refresher training and presented as part of the departmental CPD programme in July 2023. Preliminary findings from Cycles 1-3 were presented nationally at the 2023 British Society of Paediatric Dentistry (BSPD) Annual Conference, reflecting growing interest in environmentally responsible dental practice (Ahmad and Lyne, 2023).

4.4 Results

4.4.1 Overview of Audit Cycles

Across the four audit cycles, a total of 315 patients received inhalation sedation (IHS). The number of patients per cycle varied slightly, with Cycle 1 and Cycle 4 each recording 88 patients, Cycle 2 having 66, and Cycle 3 recording 73 patients (**Figure 14**).

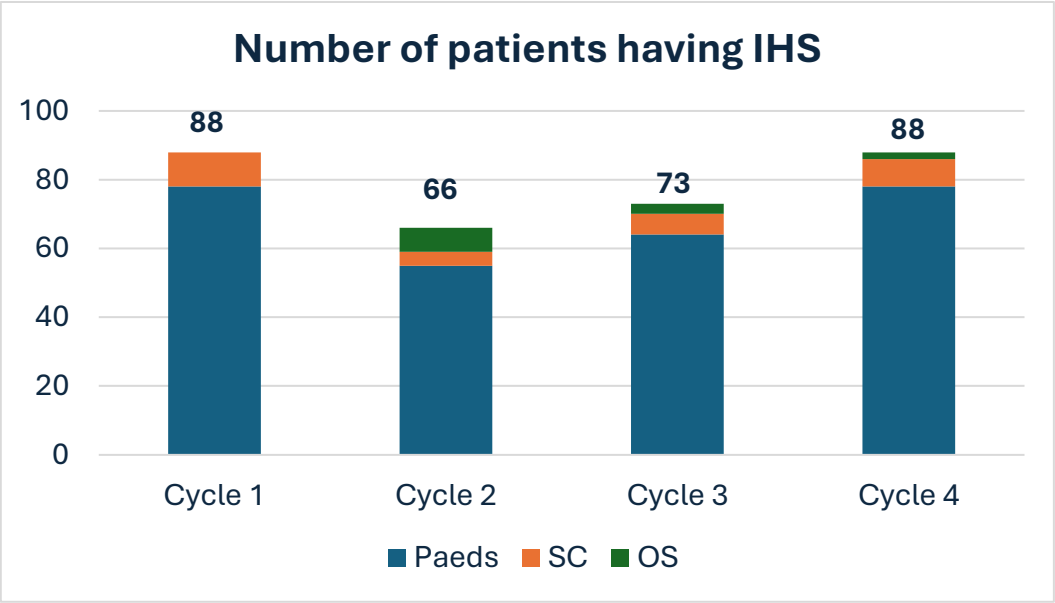


Figure 14: Number of patients receiving N_2O IHS across 4 cycles

A primary objective of this project was to reduce the carbon footprint associated with nitrous oxide (N_2O) sedation. As shown in **Figure 15**, the average CO_2e per patient decreased from 35.2 kg in Cycle 1 to 28.2 kg in Cycle 4 — a relative reduction of approximately 20%**.** Notably, this reduction was achieved even in Cycle 4, where the number of patients returned to initial Cycle 1 levels.

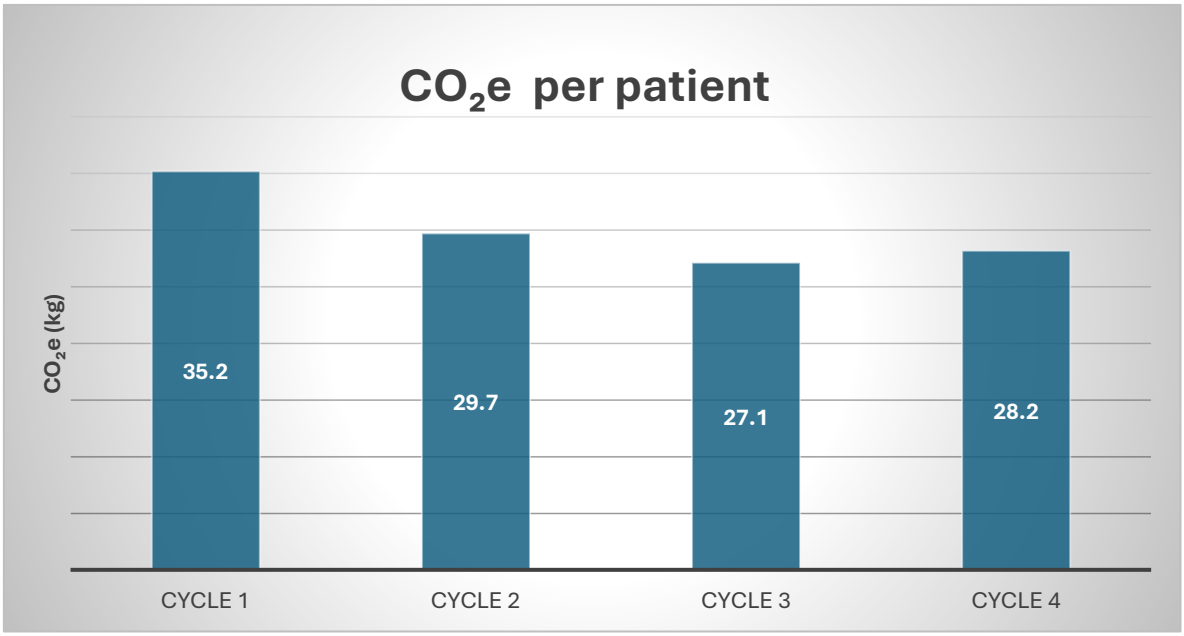


Figure 15: CO2e (kg) per patient reduction across 4 cycles

The progress made is summarised in **Table 16**, which compares all four cycles against key performance indicators (KPIs). These include:

- Total number of patients requiring IHS: remained stable overall.
- Average N_2O administered per patient: reduced from 35 kg to 28 kg.
- Total CO_2e emissions**:** reduced from 3101 kg to 2480 kg.
- Overall CO_2e reduction goal of 20%**:** successfully achieved by Cycle 4.

Progress Across 4 Cycles	
Reduction in number of patients needing IHS	Similar to cycle 1
Reduction in N_2O administration per patient	Yes. 35 kg→28 kg, even with the same number of patients having IHS
Reduction in overall CO_2e	Yes. 3,101 kg→2,480 kg
Reduction in overall CO_2e by 20% (KPI)	Exactly at 20% in comparison to 1st cycle results

Table 16: Progress across 4 audit cycles

4.4.2 Justification & Alternatives

Across all four audit cycles, justification for nitrous oxide (N_2O) administration was consistently high, showing improvement over time. In the first cycle, 94% of cases had clear documentation justifying the need for inhalation sedation (IHS), rising to 98% in cycle 2, and achieving 100% justification in both cycles 3 and 4. Additionally, the proportion of patients for whom intravenous sedation (IVS) may have been a viable alternative was monitored across cycles, based on screening criteria of age (≥12 years) and ASA classification (I or II). This proportion varied across the audit period, ranging from 30% to 45%**,** without a consistent trend.

4.4.3 Success Rate (%)

Success was defined as completion of the planned procedure without abandonment of treatment. Across all four audit cycles, the clinical success rate of inhalation sedation (IHS) using nitrous oxide remained consistently high, with evidence of gradual improvement over time. In the first cycle, 90% of cases were recorded as successful, rising to 94% in cycle 2, 96% in cycle 3, and reaching 97% by cycle 4.

4.4.4 Variation in Carbon Footprint by Speciality

Across all four audit cycles, most patients receiving inhalation sedation (IHS) were treated by the Paediatric Dentistry department. This trend remained consistent throughout the study, with only minor variation in contribution from Special Care Dentistry and Oral Surgery. In Cycle 4, for example, 89% of patients receiving IHS were managed within Paediatrics, compared with 11% managed by either Special Care or Oral Surgery (**Figure 16**).

Despite managing fewer patients, Special Care and Oral Surgery accounted for a disproportionately higher share of the total carbon footprint, approximately 17% of total CO_2e emissions, due to increased average N_2O exposure (**Figure 17**). These patients had longer sedation durations (mean: 32 minutes) and higher average N_2O concentration (41%), resulting in a per-patient CO_2e of 42 kg, compared with 26 kg in the Paediatric department (**Table 17**).

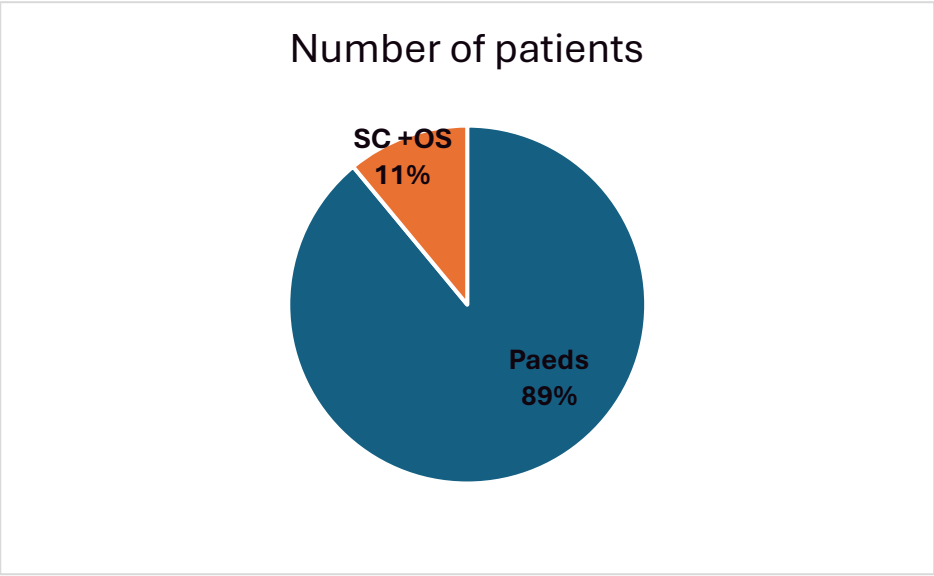


Figure 16: Number of patients seen by Paediatric/Special Care/Oral Surgery departments. Data derived from Cycle 4.

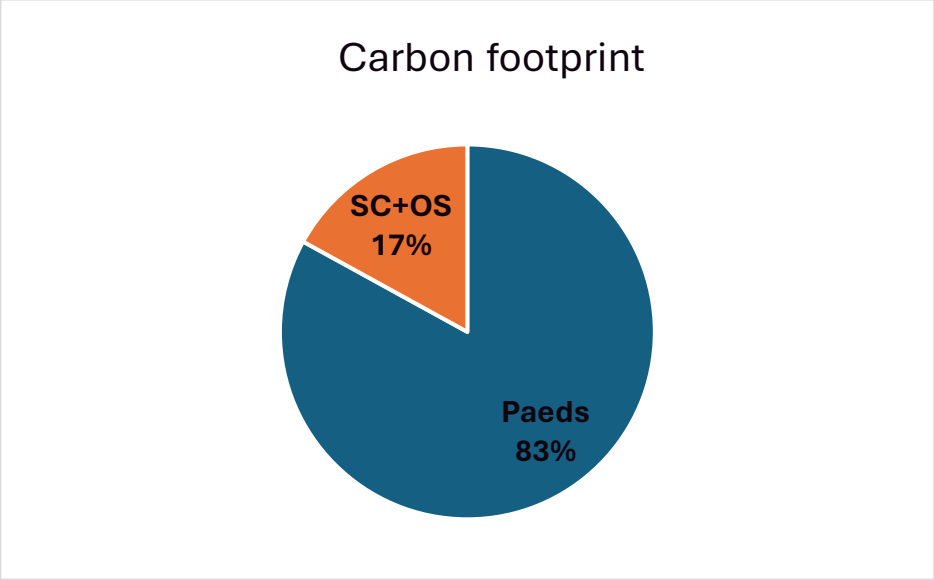


Figure 17: Carbon footprint (CO_2e) across specialities. Data derived from Cycle 4.

	Paediatric Dentistry	Other Specialties
Average CO_2e per patient (kg)	26 kg	42 kg
Average N_2O %	31%	41%
Average time (min)	28 mins	32 mins

Table 17: Comparison of average N_2O concentration, duration, and CO_2e emissions between paediatric and other specialties. Data derived from audit Cycle 4.

4.4.5 Variation in Carbon Footprint by Procedure Type

The carbon footprint associated with inhalation sedation (IHS) varied considerably depending on the dental procedure being carried out. This was primarily influenced by the duration of nitrous oxide (N_2O) delivery, rather than the concentration used. As shown in **Figure 18**, the average N_2O concentration remained relatively consistent across all procedures, ranging between 29% and 34%. However, the duration of exposure varied significantly, thereby impacting the total CO_2e emissions.

Conservative treatments “Cons” such as fillings contributed to the highest carbon footprint, with a total CO_2e of 923 kg and an average administration time of 38 minutes at 32% N_2O concentration. Extractions followed closely (834 kg CO_2e; 21 mins; 32% N_2O), alongside root canal treatments (500 kg CO_2e; 39 mins; 29% N_2O). Surgical procedures such as biopsies and other minor interventions (e.g., scaling and splint removal) contributed less to overall emissions, though still exhibited variable durations.

The lowest carbon impact was associated with brief procedures such as cannulation for intravenous sedation, with just 18 kg CO_2e generated over an average of 11 minutes at 30% N_2O. This pattern was consistent across all four audit cycles, where the mean N_2O concentration ranged narrowly between 28% and 32%.

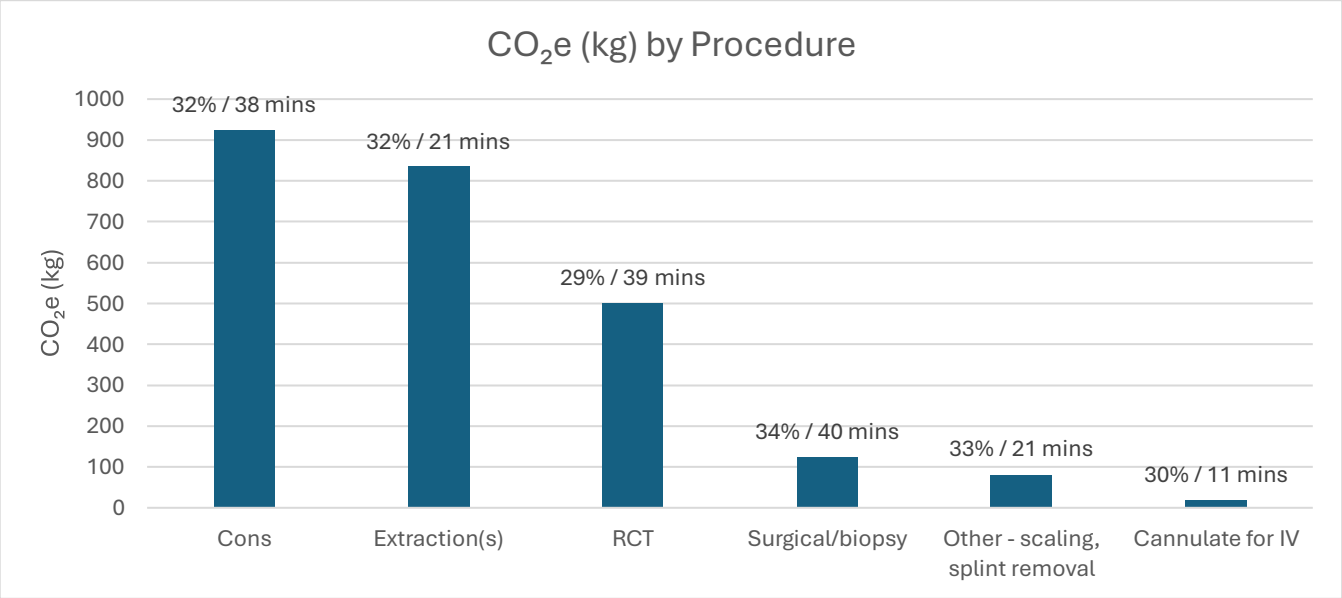


Figure 18: Total carbon emissions (CO_2e) by procedure type alongside corresponding average N_2O concentration (%) and exposure time. Data derived from Audit cycle 4.

4.4.6 CO_2e Per Patient

Across the four audit cycles, the average carbon footprint per patient showed a consistent downward trend, reflecting improvements in sedation efficiency and clinical justification. As shown above in **Figure 15**, the average CO_2e per patient reduced from 37.5 kg in Cycle 1 to 29.8 kg in Cycle 4, representing an overall reduction of approximately 20%. This finding supports the impact of targeted interventions and departmental engagement over time.

4.4.7 Total CO_2e Per Month

The total carbon emissions produced by N_2O use each month were monitored across the four audit cycles alongside the number of patients treated. As illustrated in **Figure 19**, total emissions decreased substantially after Cycle 1 but showed a partial rebound in Cycle 4. This fluctuation appears to reflect underlying variations in patient volume across cycles, which peaked again in Cycle 4 after a dip in Cycles 2 and 3. Notably, despite the increased number of patients in the final cycle, overall emissions remained lower than baseline, indicating improved efficiency in gas use per patient. These findings suggest that while total monthly emissions are sensitive to clinical

demand, the reduction in per-patient CO_2e is a more reliable marker of sustainable sedation practices.

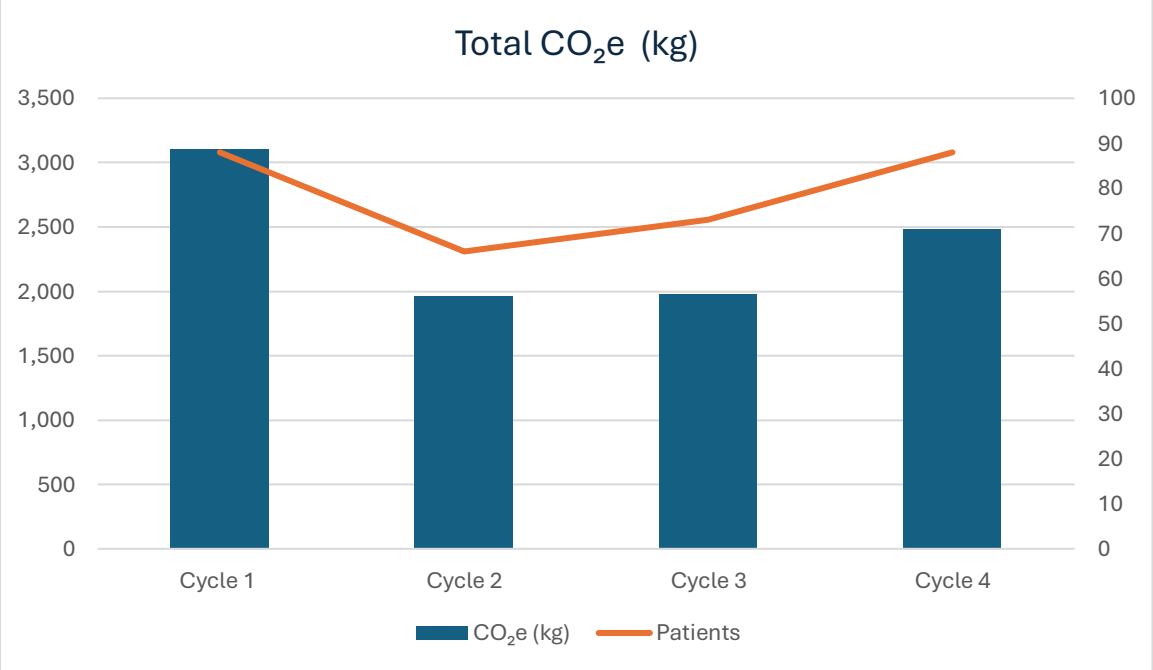


Figure 19: Total CO_2e (kg) & patients number receiving IHS across four Audit cycles.

4.5 Wastage

To assess the scale of potential N_2O wastage at Eastman Dental Hospital, institutional gas delivery data were compared with the clinical audit findings.

In the financial year 2022/2023, EDH recorded the delivery and collection of an average of six size G cylinders of N_2O per month, equivalent to an estimated 4,500 litres of N_2O supplied monthly. Based on the clinical audit data across three cycles, average monthly N_2O consumption was 4,463 litres per month. This indicates a minimal discrepancy, with implied wastage or leakage of less than 1% of total stock.

4.6 Summary of Results

This quality improvement project achieved its primary aim: to reduce the environmental impact of nitrous oxide (N_2O) use in clinical practice without compromising patient care. Across four audit cycles conducted between October 2022 and October 2023, total monthly CO_2e emissions fell from a baseline of 3101 kg in Cycle 1 to 2480 kg in Cycle 4 — representing an overall 20% reduction. This met the NHS Trust's Net Zero

Key Performance Indicator (KPI) for sedation, which set a target of 20% reduction in clinically administered N_2O over this period.

Importantly, patient numbers remained relatively stable throughout the audit period, particularly in Cycles 1 and 4, which had identical monthly patient volumes. In both cycles, the same number of patients were seen, yet with significantly lower gas usage in cycle 4, demonstrating a genuine improvement in the efficiency of N_2O delivery. This suggests that clinicians were able to better justify and tailor N_2O use, achieving the same clinical outcomes with reduced environmental cost. These patterns reflect a positive response to the clinical recommendations delivered after each audit cycle (Section 4.7) and reinforce the value of repeated, focused feedback to clinical teams. Furthermore, the proportion of cases where sedation was unsuccessful was minimal. In Cycle 4, for example, unsuccessful administrations represented just 2% of the overall carbon footprint, indicating that most sedation procedures were both clinically effective and environmentally responsible.

Further analysis highlighted that variations in CO_2e output were more closely associated with treatment duration rather than the concentration of N_2O administered. For example, restorative and endodontic procedures contributed disproportionately to total emissions despite similar average N_2O concentrations across all procedure types. This was largely attributed to their longer treatment times. These findings suggest that procedure duration — rather than gas concentration — is the primary driver of environmental burden and should be considered during clinical planning, especially where multiple visits or lengthy treatments are anticipated.

Finally, while variations were observed in total monthly CO_2e across audit cycles, this fluctuation appeared to reflect broader factors such as clinic closures or staff leave rather than changes in sedation policy or patient demand. Moreover, although the estimated wastage based on delivery versus usage data appeared negligible (less than 1%), even small inefficiencies may contribute cumulatively to environmental harm over time, particularly in high-activity departments. Passive leakage may also remain undetected without continuous monitoring or formal gas tracking protocols.

4.6.1 National QIP Comparison

To provide broader context for the findings of this local QIP, comparisons were drawn against the results of a recent national quality improvement project (QIP) on nitrous oxide (N_2O) use in dentistry, carried out and analysed by Dr Alexandra Lyne, one of the supervisors on this project. The methodology and successful outcomes from the local QIP directly informed the design and implementation of the national protocol, forming the basis for its wider rollout across the UK. Although the national QIP has not yet been published, the results were available to the research team and have informed the development of the accompanying mitigation toolkit (Chapter 5).

It is important to clarify that the national QIP was conducted independently of the present study. While its findings are referenced to aid comparison and support local recommendations, the author (SA) was not involved in collecting or analysing the national dataset.

In terms of clinical performance, the national QIP reported an overall inhalation sedation success rate of 92% (range 74–100%), closely aligning with local findings at EDH. The national dataset also explored access to alternative sedation pathways, finding that 19 services offered intravenous sedation (IVS), though this was often restricted to specific age groups or procedure types. Approximately 40% of the national cohort were considered eligible for IVS using standard age and ASA criteria.

Environmental outcomes were also evaluated nationally. The national QIP reported an average per-patient carbon footprint of 28.62 kg CO_2e (range: 10.74–40.67), comparable to the figures recorded in this local audit. Clinical variability was evident across both datasets. For example, the national average flow rate was 5.84 L/min (range: 1–13), with no apparent correlation between flow rate and patient age. Nitrous oxide concentrations ranged from 10% to 75% (average: 34.5%), and the average administration time was 28 minutes (range: 3–99). These trends mirrored those observed locally, reinforcing the need for regular clinical audit and continuing professional development.

The national audit also assessed documentation and justification, reporting that 80% of cases had a clearly documented rationale for using inhalation sedation over other behaviour management techniques. This benchmark figure was adopted within the toolkit accompanying this thesis, given the absence of other national standards.

In summary, the national QIP provides useful context for interpreting the findings of this local project. Its consistent trends in sedation outcomes, clinical variability, and environmental data highlights the need for ongoing audits, improved documentation, and continuous service-level optimisation.

4.7 Limitations

This quality improvement project was conducted in a real-world clinical setting, and as such, several limitations must be acknowledged. First, the calculation of carbon emissions (CO_2e) relied on data extracted from clinical records, which may not fully capture the fluctuations in nitrous oxide flow rates and titration increments during each procedure. This limitation reflects the current infrastructure of dental sedation machines, which lack automated flow meters capable of logging real-time gas volumes, unlike those used in general anaesthesia.

Second, the estimation of gas wastage was based on monthly supply-versus-use comparisons during the selected audit periods. This approach assumes that the chosen month was representative of typical departmental activity. However, fluctuations in patient attendance or case complexity during that time could have influenced both gas usage and emission patterns.

Additionally, this project was undertaken as a voluntary quality improvement initiative, without external funding or incentive, which may have influenced recruitment. While data collection at the Eastman Dental Hospital was thorough, the results may not fully reflect how sedation is used in other types of dental settings— such as general dental practices or private clinics—which were not part of this audit.

Finally, the sample was heavily weighted towards paediatric patients. This reflects both the population typically managed under inhalation sedation and the dissemination of the project through paediatric dental networks. However, as the

majority of patients were paediatric, the findings may not be fully applicable to adult services or other clinical care settings.

4.8 Recommendations and Implementation

Throughout the project, a series of targeted clinician recommendations and actions were introduced to support sustainable sedation practice across the department. These were informed by emerging audit findings, staff feedback, and observed variation in sedation techniques. Following each cycle, feedback was given to clinical teams through departmental meetings and training sessions, focusing on practical steps to reduce nitrous oxide usage without compromising clinical outcomes.

Key clinical recommendations included:

- Optimising sedation technique**:** Clinicians were advised to initiate inhalation sedation with 100% oxygen at 4 L/min, and to pay close attention to the reservoir bag, ensuring correct inflation before introducing nitrous oxide. To aid visual learning, clinical teams were also shown examples of incorrect reservoir bag inflation during feedback sessions (**Figure 20**) and (**Figure 21**).

Figure 21: Underinflated reservoir bag (Author's own)

Figure 20: Overinflated reservoir bag (Author's own)

- Reducing gas use during procedures**:** Teams were encouraged to reduce or discontinue N_2O during non-anxious phases of treatment (such as following local anaesthesia administration, or after caries removal is complete).
- Procedure planning**:** Efforts were made to care planning, particularly for patients requiring multiple visits. For example, combining procedures or using behavioural acclimatisation to reduce the need for sedation at subsequent appointments was recommended where appropriate.
- Alternative pathways**:** Greater emphasis was placed on referring suitable patients to the IV sedation service (only when IVS is a suitable alternative e.g. in older patients >12 years/ASA II/II requiring complex treatment).
- Documentation and data quality**:** Standardised phrases were incorporated into the sedation note template to capture accurate flow rates and timing increments, improving the quality of future audit data and enabling more meaningful comparisons. Also, reminding clinicians to accurately document these parameters (flow rates, separate increments of N_2O% with time).

These recommendations were accompanied by a clear and time-bound implementation plan (**Table 18**), which outlined specific institutional actions. These included changes to the sedation documentation template (completed December 2022), regular re-audit cycles (every three months), and formal integration of findings into sedation refresher training. Additionally, a gas usage analysis comparing delivered cylinder volume against clinical consumption was completed in May 2023, confirming minimal system leakage and helping to quantify departmental efficiency.

Action	Details	Timeline
Changes to sedation note template	Add in space to record flow rate and increment 'step downs'	**Completed:** Dec 2022
Share results and learning	Presentation at departmental meetings Included in annual sedation refresher training Present 3-cycle results in BSPD	**Completed:** Jan 2023 Jul 2023 September 2023
Re-audit every 3 months	To include Oral surgery who started using IHS in Jan 2023	**Completed:** Cycle 2 Feb 2023, Cycle 3 Jun 2023, Cycle 4 Oct 2023
Estimate wastage from our piped gas	Compare delivered cylinder volume to the volume used on patients	**Completed:** May 2023

Table 18: Action Plan after Cycle 1

The iterative nature of the QIP, combined with structured and well-communicated action plans, helped embed a culture of reflection and improvement within the clinical team. Notably, the fourth audit cycle—completed one year after baseline—showed both sustained reductions in carbon emissions and continued consistency in clinical outcomes. These findings strongly suggest that environmental sustainability can be improved through context-specific recommendations and departmental engagement, without compromising patient care.

Looking ahead, the department has committed to sustaining this progress through a formalised programme of re-audits every six months and annual estimations of nitrous oxide wastage (**Figure 22**). While the next audit cycle is planned for May 2024, this has not yet been completed at the time of writing. Nonetheless, the timeline reflects a clear intention to embed ongoing data collection and feedback mechanisms into routine practice. This approach of continuous improvement now forms the basis of the dedicated inhalation sedation toolkit described in the following chapter.

Figure 22: Timeline following 4 Audit cycles

Chapter 5

Development and Piloting of a Mitigation Toolkit for Sustainable Nitrous Oxide Use: A Qualitative Study

5.1 Introduction

The quality improvement project (QIP) outlined in Chapter 4 revealed substantial variation in the way nitrous oxide (N_2O) is used in paediatric dental services, with differences in clinical justification, delivery efficiency, and overall gas use. Given N_2O's high global warming potential, even small improvements in sedation behaviour can yield meaningful environmental benefits. Over four audit cycles, a structured audit and feedback approach resulted in a 20% reduction in carbon emissions, underscoring the value of measurable, service-level change.

These findings supported the next phase of the project: developing a practical resource to help dental teams embed more sustainable practices into routine care. While national organisations such as the Scottish Dental Clinical Effectiveness Programme (SDCEP, 2024) have produced useful tools for N_2O mitigation, early informal feedback from clinicians suggested that awareness and day-to-day use of these resources remains limited. This highlighted a gap between existing guidance and real-world implementation, particularly in general dental settings.

In response, I created a simplified mitigation toolkit, aimed at promoting efficient N_2O use in a way that is accessible, actionable, and relevant to clinical practice. Rather than replicating national tools, the focus was on enhancing usability, encouraging team engagement, and supporting routine quality improvement processes.

This chapter presents the development and piloting of that toolkit. It begins by outlining the toolkit's aim and design process, followed by a qualitative evaluation exploring how dental professionals perceived its clarity, relevance, and potential impact. The findings offer insight into how environmental sustainability can be better integrated into routine sedation care.

5.2 Toolkit Aim and Development

5.2.1 Aim

The aim of this phase of the project was to explore how general dental practitioners (GDPs) perceived a newly developed toolkit designed to support the environmentally sustainable use of nitrous oxide in paediatric dentistry. Specifically, it examined whether such a resource could feasibly be integrated into everyday practice and whether it might support dental teams in undertaking audit and quality improvement (QI) activities that reduce avoidable clinical emissions.

5.2.2 Toolkit Design Process

5.2.2.1 Rationale and Background

The development of the nitrous oxide mitigation toolkit was directly informed by the findings of the quality improvement project outlined in Chapter 4. Across four audit cycles, the QIP demonstrated that modest procedural changes—such as improving clinical justification and conducting regular audits—led to a measurable reduction in N_2O-related carbon emissions. These results emphasised the need for a resource that could translate data-driven improvements into sustainable, long-term behavioural change.

Recognising that successful mitigation efforts require more than awareness alone, the team aimed to develop a toolkit that would be practical, easy to implement, and aligned with real-world workflows in general dental settings. Rather than replicate existing national guidance, the focus was on improving accessibility, prompting clinical reflection, and embedding sustainability into routine care.

5.2.2.2 Structure and Content

The toolkit was designed as a visual, stepwise guide for general dental services, designed to support dental teams in reflecting on their nitrous oxide (N_2O) use and identifying opportunities for improvement. The toolkit was subsequently peerreviewed by my supervisory team to ensure clinical accuracy, relevance, and alignment with current guidance.

The toolkit consists of two main components:

- A full-length guidance document containing instructions, templates, national benchmarking data, and suggested mitigation strategies.
- A summary flowchart designed for quick reference and display in staff areas.

The stepwise guide of the toolkit is presented in **Figure 23.** This was developed to mirror the cyclical quality improvement (QI) approach used in Chapter 4 of this project and to offer a simplified, repeatable framework for general dental teams.

1. *Identify N_2O Supply and Storage*

Services are first prompted to assess how N_2O is delivered within their setting (e.g., piped or via cylinders) and who manages stock control. This step establishes the scope of stakeholders and operational systems involved in sedation delivery.

2. *Identify Stakeholders*

The toolkit encourages multidisciplinary involvement, prompting teams to identify everyone involved in the delivery, ordering, storage, or use of nitrous oxide. This may include clinicians, nurses, managers, procurement staff, porters, and estates teams. Engagement at this stage is critical to ensuring shared understanding and accountability for sustainable practice.

3. *Evaluate Clinical Use*

Teams are guided to collect one week of sedation data using audit templates provided in the toolkit. Services are supported to calculate justification and success rates, estimate CO_2e emissions per patient, and identify sources of waste. Benchmark figures are provided to allow comparison with national data. This stage also introduces suggested clinical improvements, such as adjusting gas flow rates and checking for mask leakage.

4. *Reassess and Maintain*

Based on the audit findings, teams are supported to develop local action plans and agree on next steps. Recommendations are included for both clinical and operational changes. Teams are encouraged to repeat the QI cycle periodically to monitor progress, adjust

strategies, and maintain gains. This aligns with broader NHS targets on sustainability and continuous service improvement.

A condensed version of this process is presented in **Figure 24**, which provides a summary flowchart designed for quick reference. The full toolkit, including editable data collection sheets, audit templates, and guidance examples, is provided in **Appendix 3**.

Figure 23: Stepwise Guide

Reducing the nitrous oxide footprint: A toolkit for dental services

Step 1. Identify your supply

Piped

Cylinders

Step 4.Re-assess & Maintain

Identify areas of the service that contribute the most to the carbon footprint and make an action plan accordingly.

Step 2. Who is involved?

Engage all stakeholders in supply, storage, clinical use, and disposal. Ensure they are aware of the sustainability issues related to N_2O sedation.

Step 3. How is it used?

Track usage: Record how N_2O is used in your service

Clinically Administered Gas	Wasted Gas
Measured from sedation log: • N_2O (%) • Flow rate (L/min) • Time of N_2O exposure (min) • CO_2e per patient	Gas not clinically administered to a patient: • Leakages • Theft • Stock control

Recommendations

Clinical Management	Waste Management
• Use lowest effective flow rate and N_2O % • Reduce sedation time where possible without compromising patient care	• Repair leaks and faulty equipment e.g., connections, seals • Fully utilise cylinders before replacing • Use a stock control system to track waste

Produced by Sarah Ahmad, Alexandra Lyne, Paul Ashley, [TO BE ADDED]
Version 1.1 DRAFT February 2025

UCL eastman DENTAL INSTITUTE

Figure 24: Summary Flowchart

5.3 Qualitative Study Methodology

5.3.1 Rationale for Qualitative Approach

A qualitative approach was chosen for this stage of the project to explore general dentists' perspectives on the practicality, usability, and clinical relevance of the nitrous oxide mitigation toolkit. This method was selected because it supports open-ended enquiry, enabling a deeper understanding of how and why clinicians may engage with environmental sustainability measures in practice—rather than quantifying outcomes numerically (Green and Thorogood, 2018). The aim was not to produce generalisable findings, but to explore the lived experiences and views of those who regularly deliver inhalation sedation using nitrous oxide.

Qualitative methods are particularly well suited for both evaluative and generative research (Ahmed *et al.*, 2025). In this context, the approach allowed for critical reflection on current awareness of national mitigation resources (e.g., SDCEP, 2024), assessment of how the toolkit aligned with day-to-day clinical workflows, and exploration of its potential to influence behaviour, promote discussion, or drive local action.

Focus groups were selected as the data collection method. This format provides a structured yet flexible space for discussion, guided by a topic framework but enriched by interaction between participants. It enabled participants to share reflections, challenge assumptions, and co-construct ideas around sustainability in sedation delivery. Unlike structured surveys, focus groups are well-suited to surfacing practical barriers, contextual concerns, and real-world uncertainties—all of which were crucial to understanding the toolkit's acceptability and impact. This method also aligned with project timelines and allowed for real-time feedback on the toolkit materials.

5.3.2 Ethical Approval

Ethical approval for this qualitative study was granted by the University College London (UCL) Research Ethics Committee on 25 March 2025 (Project ID: 0789).

The study was also registered with UCL's Data Protection Office (Reference: Z6364106/2025/03/31). A copy of the project's ethical approval is provided in **Appendix 4**.

5.3.3 Researcher Training and Reflexivity

The qualitative component of the project was led by the main researcher (S.A.), who undertook formal training through the *Introduction to Qualitative Research* course delivered by the Social Research Association (SRA) in October 2023 (Social Research Association, 2023). The course, hosted via UCL, provided structured learning in study design, sampling, ethics, focus group facilitation, and thematic analysis. This training directly informed the development of the topic guide, facilitation strategy, and overall analytical framework for the study. A certificate of course completion is provided in **Appendix 5**.

It is acknowledged that the researcher's dual role as both toolkit developer and focus group facilitator may have influenced aspects of data collection and interpretation. However, this "insider" perspective also supported informed discussion, provided contextual clarity, and allowed for deeper engagement with participant feedback. Reflexivity was maintained throughout the study, and the analysis was grounded in a transparent coding and theme development process.

5.4 Participant Recruitment

Participants were recruited via email invitation, which included the participant information sheet, consent form, and a digital copy of the draft version of the nitrous oxide mitigation toolkit. The recruitment strategy focused specifically on general dental practitioners (GDPs) with clinical experience in delivering nitrous oxide inhalation sedation to children. This was aligned with the toolkit's intended user group—general dental teams rather than specialist paediatric services.

While none of the participants were paediatric dental specialists, all had direct experience with inhalation sedation in either primary or secondary care settings. Their perspectives were therefore highly relevant to the evaluation of the toolkit's content, format, and feasibility within general practice environments. A copy of the

participant information sheet and consent form is provided in **Appendix 6** and **Appendix 7**, respectively.

5.4.1 Inclusion Criteria

Participants were eligible for inclusion if they met all the following criteria:

- Qualified dentists currently practising in the United Kingdom.
- Clinically involved in the delivery of nitrous oxide inhalation sedation in primary or secondary care.

5.4.2 Exclusion Criteria

Participants were excluded if they:

- Had no prior or current experience with the clinical use of nitrous oxide.
- Were specialists or consultants in paediatric dentistry, as the focus of the study was on the views of general dental practitioners.

5.5 Focus Group Discussion

The focus group guide was developed by the main researcher (SA) in consultation with academic supervisors. The guide ensured consistency while still allowing for spontaneous discussion and elaboration. It was shaped around the core aims of the project, with specific reference to the themes emerging from the literature, QIP findings, and toolkit content. The focus was on assessing the toolkit's acceptability, usability, and potential to drive quality improvement and sustainable behaviour change in general dental practice.

A semi-structured approach was adopted to encourage open-ended discussion, while ensuring coverage of the following domains: current sedation practices, awareness of nitrous oxide's environmental impact, familiarity with existing sustainability guidance, and practical impressions of the toolkit's layout, relevance, and feasibility. Participants were also invited to reflect on the audit and data collection tools, and to suggest improvements based on their clinical experience.

The guide was used consistently across both focus groups and served as a flexible framework to support participant-led discussion. A copy of the guide is included in **Appendix 8.**

5.6 Data Collection

Two online focus groups were conducted in May 2025 using Microsoft Teams (Microsoft Corporation, 2025). The use of a virtual format was chosen to accommodate participants' clinical commitments. This approach also enabled flexible scheduling and improved accessibility, especially for general dental practitioners (GDPs) working across different care settings.

Each focus group lasted approximately 20–30 minutes and was facilitated by the main researcher (SA). The discussions were carried out using the semi-structured approach shown in **Section 5.5.**

In addition to the participants providing written consent in advance, verbal consent was also confirmed at the beginning of each session. At the start of each focus group, SA provided a brief introduction outlining the purpose of the study and invited participants to share their reflections on the toolkit.

During the discussions, the screen was shared to display relevant sections of the toolkit and visual aids, facilitating deeper engagement and clarification where needed. Participants were asked to reflect on their sedation practices, toolkit usability, and any perceived barriers to implementation. They were encouraged to elaborate on their responses and share contextual examples from their clinical experience.

All sessions were audio-recorded with participants' consent and subsequently transcribed verbatim. Transcripts were anonymised using participant codes and securely stored on the UCL-protected N-drive for analysis. Identifiable data were removed during transcription, and participants were informed of their right to withdraw at any time. The data formed the basis for the thematic analysis presented in the following sections.

5.7 Data Analysis

Thematic analysis was undertaken following the six-phase framework described by Braun and Clarke (2006), which provides a structured yet flexible approach to exploring qualitative data. This method was considered appropriate for addressing the present study's aim of examining perceptions, barriers, and practical considerations related to the integration of the nitrous oxide mitigation toolkit into clinical practice.

The focus group discussions were automatically transcribed using Microsoft Teams and reviewed several times by the primary researcher (SA) to gain a thorough understanding of the discussions. A hybrid coding approach was used, combining deductive codes based on the study's objectives and topic guide with inductive codes that developed naturally from participants' comments, helping to capture unexpected but relevant insights.

Manual coding was carried out in Microsoft Excel (Microsoft Corporation, 2025), which allowed responses to be organised clearly, row by row. Each piece of data was given a descriptive code, which was refined as patterns began to emerge. These codes were then reviewed, grouped together, and developed into overarching themes and subthemes. The coding process is shown in **Appendix 9**, which includes a colour-coded extract of the transcripts illustrating how codes were applied and connected to their respective themes.

To provide additional transparency and depth, **Appendix 10** presents a snapshot of the theme and subtheme analysis, detailing how individual participant quotes were categorised within each subtheme. Themes were cross-checked for consistency across both focus groups and aligned with the study's key domains of interest—namely, sustainability awareness, toolkit usability, clinical impact, and audit feasibility.

5.8 Results

5.8.1 Theme Development

A total of six participants took part in two online focus groups held via Microsoft Teams. From the two focus group discussions, five main themes were identified. These covered a broad range of feedback, starting with participants' own backgrounds and experience with sedation, moving through their awareness of environmental sustainability, and exploring their views on the toolkit's design and practical use. The themes also captured how the toolkit might influence day-to-day clinical decisions and confidence, as well as reflections on carrying out the audit and quality improvement process.

Within each theme, several subthemes highlighted more specific points, such as understanding of nitrous oxide's environmental impact, opinions on the toolkit's layout and clarity, and practical challenges to putting it into use. **Table 19** summarises these themes and subthemes with their key areas of focus. **Figure 25** illustrates the conceptual model developed from the thematic analysis (Braun and Clarke, 2006), outlining the interrelationship between participant demographics, perceptions, and the practical application of the toolkit. Participant demographics—such as level of training, clinical setting, and prior exposure to sustainability principles—were found to influence both awareness and attitudes towards environmental sustainability in dentistry, as well as perceptions of the toolkit's content and usability. These factors, in turn, shaped the extent to which the toolkit facilitated clinical impact and behavioural change, particularly in terms of nitrous oxide use and audit engagement. The resulting clinical outcomes and reflections on the audit and quality improvement process (QIP) then fed directly into feedback. Overall, the themes form a cycle where the toolkit, its use in practice, and feedback from users continually inform one another. These themes are explored in detail in the following sections.

Theme 1: Participant Demographics	
Sub-theme	**Focus**
1.1 Role, Experience, Clinical Environment	Level of training, years qualified, clinical environment
1.2 Sedation Exposure	Access to sedation, frequency of N_2O use, access to alternative sedation options (IVS)
Theme 2: Awareness and Attitudes toward Sustainability	
2.1 Understanding of N_2O impact	Awareness of environmental effects and carbon footprint
2.2 Motivation for change	Willingness to engage in QIPs or mitigation efforts
2.3 Knowledge of existing toolkits	Experience using, format, accessibility
Theme 3: Toolkit Content and Usability	
3.1 Clarity & Design	Visual layout, simplicity, length
3.2 Relevance to clinical practice	How well it reflects real-world sedation practice
3.3 Ease of implementation	Practicality, barriers to using, suitability to be added into local protocols/teaching
3.4 Visual aids and summary tools	Usefulness of flowchart, visual prompts
Theme 4: Clinical Impact and Behavioural Change	
4.1 Impact on sedation decisions	Whether toolkit affects when or how they use N_2O
4.2 Clinical confidence and change	If toolkit increases confidence to make a change
Theme 5: Feedback on Audit and QIP Process	
5.1 Feasibility of data collection	Challenges with completing logs or data collection
5.2 Suggestions for improvement	Recommended changes to toolkit/audit forms

Table 19: Themes and Sub-themes

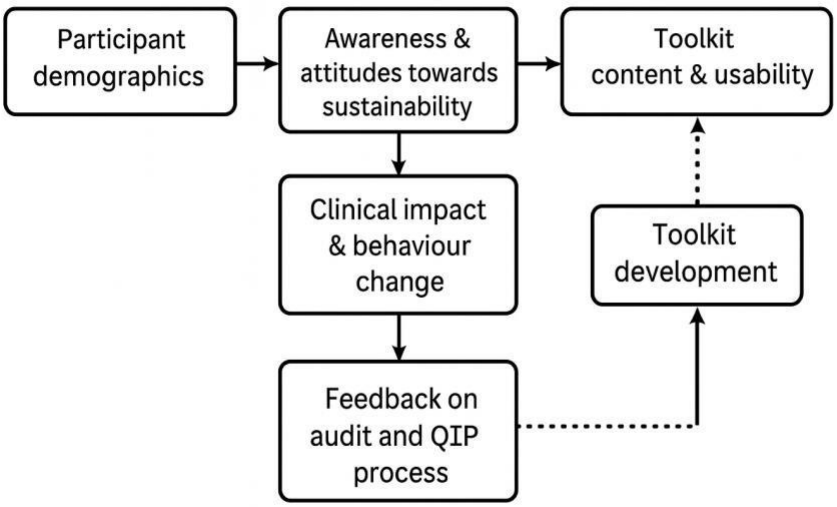


Figure 25: Conceptual model for toolkit pilot focus groups

Theme 1: Participant Demographics

Sub-theme 1.1: Role, Experience and Clinical Environment

The six participants had between four and eight years of post-qualification experience. Two were general dental practitioners working across both community dental services and a dental hospital, while the remaining four were full-time postgraduate trainees in paediatric dentistry based at a dental hospital. All participants were practising in the United Kingdom, meaning their work was shaped by the same national regulations on sedation in children. A summary of participant characteristics is provided in **Table 20**.

Sub-theme 1.2: Sedation Exposure

Postgraduate trainees reported a similar caseload, delivering nitrous oxide inhalation sedation to between two and four patients each week. The two practitioners working across community dental services (CDS) and hospital settings described a higher total exposure — up to four patients per week in hospital plus a further four in CDS. All participants noted that intravenous sedation was available within their hospital setting for use in children, although none had the required training to deliver it. No one

reported access to oral sedation for paediatric patients, reflecting the limited alternative routes available under current UK legislation.

	Job role	Years qualified	Clinical Environment
Participant 1	Post-graduate student in Paediatric Dentistry	8	Dental Hospital
Participant 2	Post-graduate student in Paediatric Dentistry	6	Dental Hospital
Participant 3	General Dental Practitioner	6	Community Dental Service & Dental Hospital
Participant 4	General Dental Practitioner	6	Community Dental Service & Dental Hospital
Participant 5	Post-graduate student in Paediatric Dentistry	5	Dental Hospital
Participant 6	Post-graduate student in Paediatric Dentistry	4	Dental Hospital

Table 20: Participant Demographics

Theme 2: Awareness and attitudes towards sustainability

Sub-theme 2.1: Understanding of Nitrous Oxide's Environmental Impact

All participants recognised that nitrous oxide is a greenhouse gas with global warming potential, though none were confident about the exact magnitude of its environmental effect.

"I know it's bad for the environment" (Participant 3)
"I'm not sure what the exact global warming potential is but I know it's similar to carbon dioxide" (P6)

Sub-theme 2.2: Motivation for Change

All participants expressed a willingness to engage in quality improvement projects and mitigation strategies aimed at reducing environmental harm from sedation practices.

Sub-theme 2.3: Knowledge of Existing Toolkits

No participants were aware of the 2024 SDCEP guidance on nitrous oxide mitigation prior to the study.

"I didn't know they have a toolkit!" (P4)

"I didn't know either, the first time I heard about a nitrous oxide mitigation audit was when you carried out the nitrous audit at the Eastman." (P1)

Theme 3: Toolkit Content & Usability

Sub-theme 3.1: Clarity and Design

Participants found the toolkit's layout clear, simple, and appropriately concise.

"Very clear and easy to understand. That was my first impression" (P3)

"I really liked the step-by-step guide with the pictures; it was very easy to follow" (P5)

Sub-theme 3.2: Ease of Implementation

Several participants highlighted time constraints and lack of financial incentives as potential barriers, suggesting the need for a motivated audit lead or trainee to take ownership. Others felt confident they could integrate the toolkit into their own settings, particularly if embedded in local protocols.

Sub-theme 3.3: Visual Aids & Summary Tools

All participants valued the inclusion of photographs, diagrams, and the flowchart, noting that they made the process easier to understand and remember.

*"The pictures and diagrams were very helpful" (*P2)

"I really like the flowchart; it simplifies the whole toolkit nicely" (P4)

Theme 4: Clinical Impact Behaviour Change

Sub-theme 4.1: Impact on Sedation Decisions

Participants reported that the toolkit encouraged them to reflect more critically on whether nitrous oxide was always necessary and how to deliver it more efficiently without compromising patient care.

Sub-theme 4.2: Clinical Confidence and Change

There was a consensus that the toolkit increased confidence in applying the QIP within their own workplace and in following its steps consistently.

Theme 5: Feedback on Audit and QIP process

Sub-theme 5.1: Feasibility of Data Collection

While most participants were open to contributing to future audits, time demands were a concern. Suggestions included embedding data collection into routine documentation and using pre-prepared templates.

Sub-theme 5.2: Suggestions for Improvement

Practical recommendations included adjusting font colours for clarity, repositioning explanatory text under images, and separating certain clinical recommendations into distinct bullet points. Some also proposed producing a poster version of the flowchart or adding a QR code in clinics to allow quick access to the guidance.

5.9 Discussion

This qualitative study aimed to explore the perspectives of dentists on the use of nitrous oxide (N_2O) in dental settings and to evaluate the design, usability, and potential clinical impact of a newly developed toolkit intended to support environmentally sustainable sedation practices. Through thematic analysis of the interview transcripts, five major themes were identified. These themes provide insights into the contextual factors influencing toolkit engagement, highlight areas of strength and suggested improvements, and offer a basis for future toolkit refinement

and implementation across wider clinical settings. Each theme is discussed in relation to relevant literature and the aims of the toolkit.

Theme 1: Participant Demographics

Sub-theme 1.1: Role, Experience and Clinical Environment

Participants included four postgraduate paediatric dentistry trainees and two general dental practitioners**,** all based in the United Kingdom and working across both hospital and community settings. They had between four and eight years of post-qualification experience**,** providing a balance between early-career and mid-career perspectives**.** This mix was valuable for capturing differences in clinical confidence, familiarity with quality improvement (QI) processes, and priorities across service contexts. Participants with experience in both hospital and community environments reported greater exposure to sedation cases and a broader understanding of service delivery models, potentially increasing their readiness to implement practice-wide interventions such as the N_2O toolkit (Rogers ***et al.***, 2021).

Sub-theme 1.2: Sedation Exposure

All participants routinely used nitrous oxide inhalation sedation, with case volumes typically ranging from two to four patients per week. Those working in community services reported higher volumes due to increased clinical demand. None of the participants were trained in or actively using oral sedation, and although IV sedation was available within their hospitals, it was not used for paediatric patients by these participants.

This pattern reflects the structure of paediatric sedation services in the UK, where nitrous oxide is considered the default technique, particularly in children under the age of 12 (SDCEP, 2017; IACSD, 2020). The participants' limited exposure to alternative sedation routes is consistent with regulatory requirements—oral and intravenous sedation require additional training, enhanced monitoring protocols, and specialist facilities, all of which present practical barriers to routine use in most general dental or hospital settings. These constraints support the rationale for a toolkit focused on optimising N_2O use rather than replacing it, ensuring that the most accessible modality is delivered in an efficient and environmentally responsible way.

Theme 2: Awareness and Attitudes Towards Sustainability

Sub-theme 2.1: Understanding N_2O Environmental Impact

All participants were aware that nitrous oxide is a greenhouse gas with significant global warming potential. However, none were familiar with specific environmental data, such as the global warming potential (GWP) value or its relative contribution to healthcare emissions. This finding mirrors previous national audit data, which suggest that while dental professionals are broadly aware of sustainability concerns, they often lack access to quantified, context-specific environmental data (Duane *et al.*, 2020). The inclusion of national benchmark figures and CO_2e calculations within the toolkit was therefore particularly valuable for raising awareness and providing concrete targets for emission reduction.

Sub-theme 2.2: Motivation for Change

All participants expressed a willingness to engage with sustainability-focused quality improvement and recognised the importance of reducing unnecessary N_2O use. This motivation appeared natural rather than policy-driven, aligning with previous findings that clinicians are more likely to engage in sustainable behaviour when they perceive personal or professional (Duane *et al.*, 2019). The toolkit's step-by-step audit guide and visual summaries appear to offer a meaningful entry point for clinicians motivated to act but uncertain about how to begin.

Sub-theme 2.3: Knowledge of Existing Toolkits

Participants were unaware of the existing SDCEP (2024) guidance on N_2O mitigation, highlighting a gap in the dissemination of national-level sustainability tools. This knowledge gap suggests that even when guidelines exist, uptake and visibility remain challenges. Participants noted that they first encountered the concept of N_2O-related quality improvement projects through the current project's pilot, underscoring the value of embedding guidance into local practice with actionable, user-friendly resources rather than relying on abstract policy statements alone.

Theme 3: Toolkit Content and Usability

Sub-theme 3.1: Clarity and Design

The toolkit was positively received for its clear, simple layout and appropriate length. Participants found the document easy to read, concise, and unintimidating, with one participant describing the step-by-step structure as “very easy to follow.” This clarity is essential in quality improvement resources, which must be immediately usable in busy clinical environments (Buljac-Samardzic *et al.,* 2020). Participants also appreciated the use of simple language and well-labelled headings, and visual flow, suggesting that the toolkit successfully achieved a balance between professional tone and usability.

Sub-theme 3.2: Ease of Implementation

While participants felt the toolkit was feasible to implement, time pressures and competing clinical priorities were identified as potential barriers. One participant suggested that assigning the project to a dental foundation trainee could improve feasibility, especially as audits are a common requirement for trainees and newly qualified clinicians. This aligns with NHS QI policies in the UK, where dentists are expected to undertake regular quality improvement activities as part of their contractual obligations and CPD portfolios. For example, NHS Scotland requires a minimum of 15 hours of QI activity in each 3-year cycle under its Terms of Service for Dentists, with defined criteria for what constitutes a QI project (NHS, 2017). Such initiatives can also be supported by NHS Education for Scotland (NES), which offers funding for approved QI projects in primary care (SDCEP, 2025). Embedding the toolkit into routine sedation protocols or linking it to these QI requirements could enhance uptake, particularly in settings where sustainability and audit are increasingly prioritised. This also echoes findings by (Riley *et al.*, 2018), who highlighted the importance of administrative simplicity and role clarity in reducing audit fatigue and ensuring QIP sustainability.

Sub-theme 3.3: Visual Aids and Summary Tools

The inclusion of visual guides, such as the flowchart and images of sedation equipment, was consistently highlighted as a strength. Participants felt the visuals improved

comprehension and helped translate the written guidance into practical action. Visual tools also offer the potential for integration into posters, clinics, or quick-reference sheets; one participant even suggested a poster version to be displayed near sedation equipment. This type of embedded visual reminder has been shown to support habit formation and protocol adherence in healthcare settings (Grol and Grimshaw, 2003).

Theme 4: Clinical Impact and Behaviour Change

Sub-theme 4.1: Impact on Sedation Decisions

Several participants noted that the toolkit prompted them to think more critically about their sedation choices. While nitrous oxide is routinely used in their settings, the toolkit encouraged a shift away from defaulting to sedation, prompting reflection on whether behavioural techniques or acclimatisation could be tried first. This was particularly influenced by the audit prompts and justification criteria, which highlighted the importance of planning sedation more deliberately. Rather than introducing new techniques, the toolkit reframed existing practice through a sustainability lens, helping clinicians reflect on how and when nitrous oxide is used in the best interest of both the patient and the environment (Michie *et al.,* 2011).

Sub-theme 4.2: Clinical Confidence and Change

The toolkit was seen as a practical structure for initiating and sustaining QI projects on N_2O use. Participants felt it increased their confidence to lead or contribute to such initiatives, especially those less familiar with audit methodology. This is an important finding, as confidence in initiating audit cycles is often a barrier for junior clinicians or those new to sustainability initiatives (Gillam and Siriwardena, 2013). The toolkit's simplicity and integration of templates appear to address this barrier effectively.

Theme 5: Feedback on Audit and QIP Process

Sub-theme 5.1: Feasibility of Data Collection

Participants were generally positive about the feasibility of data collection using the toolkit's pre-structured forms. While some acknowledged that audits can feel time consuming—especially in busy departments—they appreciated that the toolkit's clear

instructions and ready-to-use data sheets removed much of the administrative burden. Several participants felt that integrating the logbook into the clinical notes template or digitising the process would further streamline implementation. This feedback reflects the recurring theme across healthcare quality improvement literature: tools must be practical, intuitive, and easy to embed within existing workflows to succeed. The preference for simplicity reinforces the value of the toolkit's visual and procedural clarity and highlights the potential benefit of future digital adaptation.

Sub-theme 5.2: Suggestions for Improvement

Participants offered constructive and thoughtful suggestions to refine the toolkit, demonstrating genuine engagement with its content and format. Minor design improvements were proposed, such as adjusting the font contrast in the flowchart and repositioning explanatory labels in the bag inflation diagram to enhance readability. There was strong support for creating a poster or QR-code version of the toolkit for quick reference in clinical settings—suggestions that reflect a desire for convenient, point-of-care access. Importantly, participants also asked for greater clarity around national benchmarking data, which was subsequently addressed through the inclusion of explanatory context. These refinements reflect the value of involving end users in shaping clinical tools through an iterative, collaborative process. By listening to feedback and adapting the toolkit accordingly, the final version feels more relevant and practical—an approach aligned with co-creation principles in healthcare improvement (Greenhalgh *et al.*, 2016).

5.10 Summary of Findings

This study explored dental professionals' perspectives on a newly developed nitrous oxide (N_2O) mitigation toolkit, aiming to assess its relevance, usability, and feasibility in clinical settings. Five themes emerged from the focus group discussions: participant demographics; awareness and attitudes towards sustainability; toolkit content and usability; clinical impact and behaviour change; and feedback on the audit and quality improvement process.

Overall, participants valued the toolkit's clear, step-by-step format, the inclusion of visual aids, and its ability to simplify audit processes. The resource was considered

practical and adaptable, though some refinements were suggested—such as improved visual contrast, integration into clinical protocols, and digital or quick reference formats.

Importantly, the toolkit prompted clinicians to reflect more critically on their sedation practices and consider sustainability alongside patient care. Barriers to adoption included time constraints, reliance on a motivated audit lead, and limited awareness of existing national guidance. These insights directly informed revisions to the toolkit and highlight key considerations for its future dissemination.

5.11 Limitations

The findings should be interpreted considering certain limitations. The sample size was small and limited to UK-based hospital and community dental practitioners, which may affect generalisability to other settings, such as general dental practice or international contexts. The focus group method may have encouraged consensus, potentially limiting the range of views expressed. Additionally, participants self-selected into the study, which may have introduced bias towards those already interested in sustainability or quality improvement.

5.12 Conclusion

This study demonstrated that dental professionals are willing to engage with sustainability-focused QIPs when provided with clear, practical, and visually accessible tools**.** While baseline awareness of N_2O's environmental impact was limited, participants expressed strong motivation to act and reported that the toolkit helped structure their efforts and build confidence in initiating audits.

The evaluation findings build directly on the outcomes of the Quality Improvement Project (Chapter 4), which demonstrated that targeted audit interventions can measurably reduce N_2O-related carbon emissions in clinical practice. Whereas the QIP focused on measuring change within a single service, this toolkit extends the approach by providing a standardised, adaptable resource that can be applied across varied clinical settings to replicate and sustain those gains. The toolkit was widely regarded as relevant and implementable, though barriers such as time constraints and

low visibility of national guidance remain. Addressing these challenges—through simplified data collection methods, embedding the toolkit into sedation protocols, and enhancing accessibility via posters, QR codes, or digital formats—may support wider adoption.

Although this evaluation was limited to a small, context-specific sample, the results provide valuable guidance for refining the toolkit and for informing a broader rollout. Future research should assess its impact across a wider range of dental settings and include other members of the sedation team to ensure the resource remains inclusive, adaptable, and sustainable in routine practice.

Chapter 6
Summary of Results, Strengths, Limitations and Recommendations

6.1 Summary of Results

This thesis explored the role of nitrous oxide (N_2O) in paediatric dentistry, the environmental implications of its use, and practical strategies to optimise efficiency without compromising clinical care. Across its three interconnected parts, the work progressed from evaluating alternatives to N_2O, to testing targeted interventions for reducing waste, and finally to developing and piloting a national toolkit to support sustainable sedation practice.

- **Chapter 1** set out the broader context of paediatric behaviour management, sedation techniques, and the climate change agenda in dentistry, identifying a clear gap in targeted interventions for reducing N_2O emissions.
- **Chapter 2** reviewed N_2O's clinical properties, benefits, limitations, and environmental profile, while critically assessing its position relative to alternative sedation options. Evidence confirmed that N_2O remains the most widely available, accessible, and safe pharmacological sedation modality for children in the UK, reinforcing the need to focus on efficiency rather than elimination.
- **Chapter 3** presented a scoping review of emerging sedative agents and delivery systems. While some alternatives (e.g., remimazolam, ADV6209) showed promise, none offered a fully equivalent, immediately scalable replacement for N_2O in paediatric dentistry.
- **Chapter 4** reported a multi-cycle Quality Improvement Project (QIP) which achieved a 20% reduction in N_2O-related CO_2e emissions by targeting justification rates, streamlining delivery, and reducing waste. This confirmed that measurable environmental gains are achievable through structured audit and behaviour change.
- **Chapter 5** described the development and piloting of the N_2O mitigation toolkit, designed to allow dental teams to replicate the QIP process locally.

Thematic analysis of focus group feedback demonstrated strong professional motivation to engage with sustainability initiatives, with the toolkit valued for its clarity, practicality, and potential to integrate into existing workflows. Suggestions for minor refinements were incorporated into the final version.

Together, these findings provide a coherent evidence base and practical framework for reducing the environmental footprint of paediatric dental sedation while maintaining high-quality patient care.

6.2 Strengths

This thesis brings together multiple strands of research and practical application to address a clear gap in sustainable paediatric sedation practice. Its key strengths include:

- **Integrated, multi-phase design:** This thesis uniquely combines a literature and scoping review, real-world quality improvement project data, and qualitative evaluation. Together, these phases provide both academic depth and a clear pathway to practical implementation.
- **National relevance:** The toolkit is directly aligned with NHS sustainability targets and national sedation guidelines, making it readily applicable across a wide range of UK dental settings.
- **Stakeholder engagement:** Feedback from clinicians shaped its final design, increasing its usability and the likelihood of sustained adoption.
- **Measured environmental benefit:** The QIP recorded measurable reductions in N_2O-related CO_2e emissions, offering tangible evidence that small, targeted changes can deliver real-world environmental benefits and providing a strong case for the toolkit's effectiveness.

6.3 Limitations

This thesis has several limitations that should be considered when interpreting its findings.

- **Scoping review evidence base:** While the review identified emerging sedatives and delivery systems, the available literature was limited in scope and quality, with small sample sizes, heterogeneous study designs, and a lack of paediatric-specific data. This restricts the ability to draw firm conclusions about clinical equivalence or sustainability benefits of alternatives to N_2O.
- **Generalisability of QIP and toolkit findings:** The quality improvement project and toolkit pilot involved a small sample of UK-based clinicians, mainly from hospital and community settings, which may not reflect practice patterns in general dental practice or internationally.
- **Environmental measurement scope:** The QIP measured carbon emissions at the point of use but did not account for life cycle impacts such as gas production, transportation, or equipment disposal.
- **Behavioural sustainability:** The toolkit was tested over a short period. Long-term uptake and its ability to sustain behaviour change have not yet been evaluated.
- **Clinical outcome measures:** The focus of this work was on environmental efficiency rather than patient-reported outcomes or sedation efficacy when alternatives were used.

6.4 Recommendations for Future Research

Building on the work presented in this thesis, the following areas require further exploration to advance safe, effective, and environmentally responsible paediatric dental sedation:

- **Evaluate emerging sedation alternatives:** High-quality clinical studies are needed to assess the safety, efficacy, acceptability, and environmental impact of newer sedatives such as remimazolam, ADV6209, and Penthrox, alongside existing oral and intravenous options. This would help establish whether any

alternative could realistically complement or replace N_2O in routine paediatric dental care.

- **Refine environmental impact assessment:** Future studies should incorporate full life cycle analyses to capture the true environmental footprint of sedation, from gas production through to disposal, enabling more accurate carbon accounting for sedation services.

- **Replicate QIP interventions in varied settings:** The carbon reduction strategies trialled here should be tested in general dental practice, dental schools, and community clinics, to confirm feasibility and identify setting specific adaptations.
- **Advance toolkit design and delivery:** Further work is needed to explore the impact of long-term toolkit use on behaviour change and to test digital delivery methods, such as integrated e-logbooks, CO_2e calculators, and point-of-care QR code access which could improve accuracy in monitoring gas use.
- **Evaluate long-term impact:** Longitudinal follow-up is needed to determine whether the toolkit leads to sustained changes in N_2O use and measurable reductions in emissions over time.
- **Embed sustainability in training:** Collaboration with national dental bodies and education providers could ensure sustainability principles are included in sedation training curricula and clinical governance frameworks.
- **Investigate capture and destruction technologies:** Research into N_2O capture devices in dental settings is urgently needed. Machines must be tested for their ability to handle dental flow rates and be evaluated for both environmental and financial cost-effectiveness. At present, there is no robust evidence supporting their benefit in dentistry, and cost remains a significant barrier.
- **Reassess scavenging flow rate guidelines:** Current recommendations of 45 L/min lack strong evidence and may be unnecessarily high. Investigating optimal scavenging levels—taking into account patient breathing rate and sedation flow rate—could inform updated, more efficient guidance.
- **Encourage industry innovation:** There is scope for collaboration with manufacturers to design dental sedation machines that allow full cylinder

depletion before auto-switching, incorporate accurate usage gauges to support wastage audits, and offer more practical cylinder expiry dates to minimise avoidable waste.

7. Conclusion

This thesis demonstrates that sustainable paediatric sedation is both achievable and deliverable without compromising patient safety or treatment outcomes. By combining evidence review, real-world audit, and co-designed tools, it delivers a practical, scalable pathway to reduce nitrous oxide emissions while maintaining the highest standards of clinical care. The final toolkit equips clinicians to act now—turning sustainability from an abstract goal into a routine part of dental practice. This work turns the challenge of nitrous oxide sustainability into a practical, evidence-based solution for every dental team to protect both patient wellbeing and the planet.

8. Appendices

Appendix 1: Data Extraction Sheet Used in Scoping Review

Result —	
Title	
Authors	
Year of publication	
Country/Region	
Setting (dental, medical, hospital etc.)	
Aim	
Study design/methodology	
Sedative/Intervention studied	
Participant age group	
Route of administration	
Outcome measures (e.g. anxiety reduction, success rate)	
Key findings	
Reported side effects or complications	
Conclusion	

Appendix 2: Audit Registration Form

Royal National ENT and Eastman Dental Hospital

Clinical Audit - Project Registration Form

Project Title: The environmental harm of nitrous oxide inhalation sedation at the Eastman Dental Hospital		
Start Date: October 2022	**Expected End Date:**	**Department:** Paediatric, Oral Surgery, Special Needs
Project Lead: Sarah Ahmad	**E-mail:** sarah.ahmad11@nhs.net	**Phone:**
☐ **Approved by Departmental Audit Lead**	☐ **Approved by Departmental Clinical Lead**	

Other Personnel Involved

Ms Alexandra Lyne, audit supervisor. Email: alexandra.lyne@nhs.net.

Reasons for audit:

N2O is a greenhouse gas and is nearly 300 times more damaging than CO2. UCLH have pledged to achieve net zero carbon emissions by 2031.

Aims and objectives with an overview of the project:

Aim: To reduce the environmental impact of nitrous oxide use in RNENTED.

Objectives:

1. Quantify the climate change impact of nitrous oxide use in the Eastman building, using carbon footprinting (CO2e).
2. Identify areas of waste nitrous oxide (e.g. nitrous oxide that is administered without patient benefit)
3. Identify what alternatives might be available for the patient
4. Consider whether capture technology might mitigate the environmental harm of nitrous admissions

Standards:

This is a QIP and therefore standards are not relevant to all parts of this project. However, one objective is to audit of patient selection for nitrous oxide sedation and potential alternatives), the standard, based on IASCD and SDCEP guidelines, is that all patients treated under IS should have a clear justification for the use of nitrous oxide sedation for the planned dental procedure over alternative treatment modalities. These justifications include Mild to moderate anxiety, Moderately complex or long procedure, Gag reflex, To aid cannulation before IV sedation, Patient of age/level of understanding to be able to breathe through nose with mouth open, No contraindications for IS – e.g. blocked nose, lacking co-operative ability with clinical technique, etc.

A local 'standard' was agreed for patients that may have been suitable for an alternative type of sedation, e.g. IVS, include: 12 years or over, BMI under 30, ASA 1 or 2, Suitable veins for cannulation, No contraindications for IVS – psychological disorders, needle phobia, etc

Materials and method for measuring against standards (include sample size & timescale):
The below methodology is to achieve objectives 1-3. Objective 4 is a long-term goal and is being considered through the UCLH Nitrous oxide delivery group.

1. Retrospective examination of case notes to quantify current global warming potential

   Sample: 1 months' worth of sedation clinics in Paediatric Dentistry and Special Care Dentistry (in addition to Oral Surgery in cycle 2 & 3) – to include any type of conscious sedation where nitrous oxide was used (i.e. including IV sedation where nitrous oxide was used for cannulation).

   Data collection: through examination of case notes.

   Data analysis: on Microsoft teams.

   Timeline: to re-audit every 3 months.

   Carbon footprint Using the same sample and data collection above, calculate carbon footprint (CO2e) from the nitrous oxide gas used. The calculation will use the following assumptions: - 1kg N2O = 265kg CO2e - 1L N2O = 0.001875kg N2O - From sedation narrator, the maximum N2O titration is recorded, along with the time N2O was administered for. Therefore, the volume of N2O delivered will be assumed as 6L/min x (mins with N2O administration) x (maximum of % N2O titrated). This will result in an over-estimation, as the clinical technique incrementally increases the N2O concentration. 6L/min is chosen as an average flow rate, although this will also differ between patients.

2. Identify ways clinicians can reduce unnecessary N2O administration.
3. Wastage Audit- compare amount ordered vs amount delivered to patients.
4. Mitigate the damage with N2O capture technology.

APAT SCORE: This gives an indication of the quality of the proposed audit. If there is a low score, then a redesign may be required.

Double Click the Icon for the APAT calculator APAT SCORE CALCULATOR

SCORE **25** / 25

Interdepartmental audit: More than one department involved	☐ **No**	√ **Yes,** specify departments**: Paediatric, Oral Surgery, Special Needs**	
Multi-professional audit: E.g. Dentists/ Dental Nurses/ Admin team/ Medics	☐ **No**	√ **Yes,** specify professions**: Dentists, Dental nurses in PZ in cycle 1**	
Type of audit project:	☐ **Structure**	☐ **Process**	√ **Outcome**
Scope of audit project: (tick one or more)	☐ **National**	☐ **Regional**	√**Local**
Does this project link with research?	☐ **No**	√ **Yes,** give details**:**	
Does this project link with the clinical audit priorities in the annual report?	☐ **No** If No, please give good reason for audit:	√ **Yes**, please specify:	
Audit Office support required: (*e.g.* project design, database creation, Formic)	√ **No**	☐ **Yes,** please specify**:**	

Appendix 3: Full Version of the Nitrous Oxide Mitigation Toolkit

○ Toolkit Cover Page

Nitrous Oxide Mitigation in Dentistry

A toolkit for dental services in the UK

Intended as a supporting document for V2 of: Anaesthetic nitrous oxide system loss mitigation and management technical update

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Introduction & Aim

Introduction

Nitrous Oxide (N_2O) is a potent greenhouse gas and has a global warming potential 298 times greater than carbon dioxide. Nitrous Oxide contributes to 2% of the total NHS England carbon footprint, and 75% of the total anaesthetic gas footprint. Nitrous Oxide is commonly used in dentistry for paediatric dental sedation. To ensure that we can continue to use it, it is important to demonstrate that as a profession we are taking steps to reduce usage where possible.

Aim

To support dental services to reduce the environmental impact of nitrous oxide (N_2O) sedation.

It is recommended that services providing inhalation sedation undertake ongoing this quality improvement activity to assess and reduce the environmental impact of their gas. This should include assessing and improving:

- Clinical benefit of nitrous oxide
- Access to alternative forms of conscious sedation
- Clinically administered volumes of nitrous oxide
- Wastage of nitrous oxide

All members of the team should be involved in this process, not just those who provide the treatment. This includes individuals involved in the supply and stock control. Depending on the setting, this may include dental clinicians and nurses, sedationists, procurement team, management and administrative staff, pharmacy or medical gases colleagues, porters, and estates teams.

This is the first edition of this toolkit, based on current understanding of nitrous oxide mitigation and dental guidelines. It is expected that exact recommendations and approaches will change in future editions.

- Stepwise Guide

Reducing the environmental impact of nitrous oxide in dentistry

To mitigate the environmental impact of N_2O, its usage can be broken up into 4 different areas (**Figure 1**).

1. Identify N_2O supply & storage
2. Identify all stakeholders
3. Evaluate the clinical use of N_2O
4. Reassess and Maintain

Figure 1. Nitrous Oxide (N_2O) usage

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- Steps 1, 2, and 3

Step 1. Identify Nitrous Oxide (N_2O) supply & storage

- Identify nitrous oxide supply to your service (piped supply or cylinders).

* Staff identification & stock record sheet attached in Appendix 1.

Step 2. Identify Stakeholders

- Identify the stakeholders in the service who need to be involved in the quality improvement process.
- All involved staff should be aware of the sustainability issues associated with N_2O sedation and be engaged in the measures that are taken to reduce the environmental impact of it.

Step 3. Evaluate Your Current Service

The goal of Step 3 is to determine how N_2O is currently being used in the service. This data will be the foundation for identifying areas of improvement in the next step!

3.1 Collect data on clinical usage

Choose a specific period (e.g. 1 week) and use either data collection sheet 1 or 2 (Appendix 1) to record:

- Each patient who received N_2O - include all departments using N_2O sedation including theatres.
- Justification for N_2O use - ensure a clear justification for using inhalation sedation over other behaviour management options, e.g., no sedation, intravenous sedation, or general anaesthesia.
- Success or failure of treatment- success defined as completed treatment with nitrous oxide administered.
- N_2O log- Flow rate (LPM), N_2O concentration (%), time of administration.

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After collecting the data, calculate the following:

- **Justification Rate:** (Number of justified cases / Total cases) x 100%
  Recommendation:
  - National results show an average justification rate of 80%.
  - If justification rate is <80%, investigate further:

- **Success Rate:** (Number of successful cases / Total cases) x 100%
  Recommendation:
  - National results show an average success rate of 92%.
  - If success rate is <90%, investigate reasons for failure, such as:
    - Inadequate pre-assessment.
    - Equipment issues.
    - Patient-related factors.

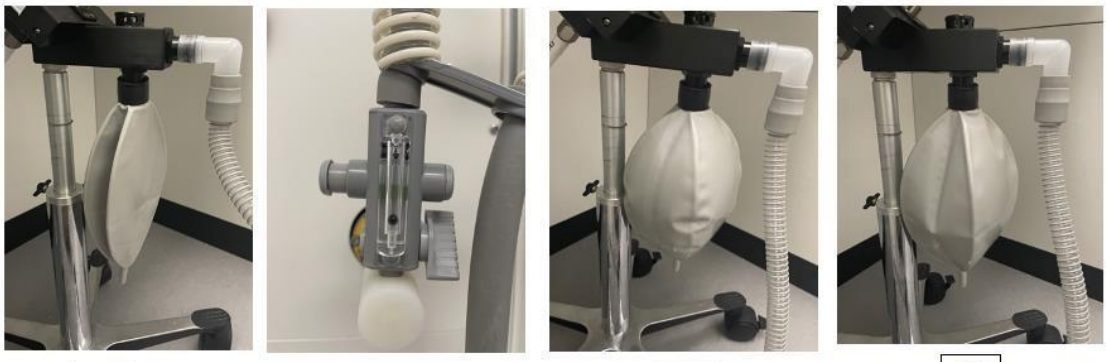
- **Total CO_2e and CO_2e per patient:** ([%] x [mins] x [Flow rate LPM] x [conversion of N_2O volume to weight] x [265]
  Recommendation:
  - National results show an average of 28.62kg CO_2e per patient for a 1-week IHS audit period.
  - Services should aim for a 5-10% reduction in CO_2e per patient across each QIP cycle. **For reference: Some improvement projects have successfully reduced CO_2e per patient by 20% over four cycles (audit cycles were 4 months apart).*
  - Once this reduction is achieved, services should aim to maintain that to ensure N_2O is used appropriately.

This reduction can be achieved by:

- Lowering flow rates.
- Reducing sedation time e.g. During root canal treatment: reduce after local anaesthesia, consider turning off after working length instrumented.
- Improving clinical administration of N_2O e.g. leaks from nasal mask.

Lower administered flow rates to patients reduces the volume of nitrous oxide delivered to patients without compromising their patient care. However, the scavenging volume still needs to be high enough to provide protection against occupational exposure.

- Start at 4L/min on 100% of O_2
  - If under-inflated' **(A)**, see if turning scavenging **(B)** down helps
  - If still under-inflated **(C)**, try 5LPM then 6LPM
  - Do not over-inflate, aim is last pic**(D)**



(A) (B) (C) (D)

Figure 2. Lowering flow rates and scavenging.

3.2 Identify and Address Wastage

Wastage refers to any gas not clinically administered to patients.

- **Estimate Wastage:** Compare the total N_2O supplied to the service versus the total volume clinically administered.
- **Recommendation:**
  - Ideally, wastage should be 0% or as close to 0% as possible, meaning that all the nitrous oxide ordered by the dental service is used on patient care.
  - National results suggest that wastage figures outside the range of 0-25% require further investigation.

Investigate Causes of High Wastage:

- Validate or recalculate wastage estimations by checking:
  - Cylinder numbers directly with suppliers.
  - Clinically administered volumes over a longer audit period.
- Check for equipment issues such as:
  - Leaks, poor connections, or faulty gauges.
- Ensure staff are educated on proper cylinder use:
  - Avoid replacing cylinders before they are empty.
- Implement a stock control system to identify:
  - Lost cylinders.
  - Expired cylinders.
- Consider equipment upgrades:
  - Use digital gauges.
  - Use machines with auto-switch mechanisms for cylinders.
  - For piped services with high wastage, consider moving to a cylinder-based system.

○ Step 4 with Example Action Plan

Step 4. Reassess and Maintain

- After evaluating your service and analysing the data collected, create a clear plan to optimise the use of nitrous oxide and reduce its environmental impact. This step focuses on implementing targeted interventions based on the findings from Step 3. See Table 1 for an example action plan following the first cycle.
- Involve all stakeholders in the decision-making process to ensure a practical and collaborative approach.
- Repeat QIP annually to measure improvement

Action	Details	Timeline
Share results and learning	Discuss with involved team in staff meeting	Date of staff meeting
Optimise clinical administration	Implement strategies to reduce CO_2e (e.g., reducing flow rates)	Before the next scheduled audit cycle
Re-audit every 3-6 months	Measure improvements in comparison to previous cycle and adjust recommendations as needed	Next planned audit period
Estimate wastage	Compare delivered cylinder volume to the volume used on patients	Annually or bi-annually

Table 1. Example of an action plan following cycle 1 of QIP

Appendix 1: Data Collection Sheets

Staff Identification & Stock Record Data

Date	N_2O supply type Piped/Cylinders	Cylinder size (if applicable) E / F / G / N/A	Starting stock (Litres or No. of cylinders)	Remaining stock (Litres or No. of cylinders)	Stock checked by (Initials)

Data Collection Form 1- Retrospective Data Collection Sheet

If your service routinely records flow rate, % N_2O, and time of administration, then you may be able to complete this retrospectively from patient notes / IS logs. If this information is not routinely recorded, you will need to collect the data using form 2.

- Only patients who have received N_2O during their visit should be included.
- Patients who were unable to tolerate wearing the mask etc or ended up not having N_2O for any other reason, should be excluded, as no N_2O would have been administered.
- If the patient has had more than 1 appointment using N_2O during the week period, please include each appointment separately.

Link to data collection spreadsheet here

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Results											
2	Name of department/ unit / service:	Total CO2e for 1 month:		kg CO2e									
3	Period audited:	Average per patient:		kg CO2e					kg of N2O is equivalent to 1L of N2O				
4	Does this service use cylinders or piped gases?	Average flow rate:		L/Min					is the GWP of 1kg N2O (IPCC AR5 data)				
5	Audit lead / contact:	Average max dose (% N2O):		% N2O									
6		Average mins with N2O:		Mins									
7		Anonymous patient identifier		Alternatives & justification					CO2e calculator				
8	Specialty	Date	Clinician / clinic code	Age	ASA	Could your service have offered an alternative to IS? (e.g. IVS)	Was IS justified over other forms of sedation?	Was procedure successful? (Y/N)	Flow rate (LPM)	Max N2O %	Total time of N2O administration (minutes)	CO2e	Additional comments (if felt relevant)
9													
10													

Data Collection Form 2 – Per Inhalation Sedation Visit

If you are collecting data retrospectively from patient notes, you will not need this form and can enter data directly into the data collection spreadsheet. If you are collecting data prospectively, please ask the treating clinician and/or nurse to fill out the form below for each inhalation sedation clinic in your chosen week. You will then need to review the patient notes to complete data collection on the spreadsheet.

- **Please complete the following form for all patients who had any amount of nitrous oxide (N_2O) delivered during their visit.**
- **Return the completed form to the audit lead.**

Date/Time of appointment	Age	ASA grade	Flow rate (LPM)	Maximum N_2O % given	Length of N_2O administration time

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Appendix 4: Ethical Approval

London's Global University

UCL

25/03/2025

Eastman Dental Institute

Dear Miss Sarah Ahmad, Professor Paul Ashley, and Ms Alexandra Lyne

Notification of Ethical Approval

Project ID: 0789

Study Title: Nitrous Oxide Mitigation in Dentistry: A toolkit for dental services in the UK

Approval end date: 25.03.2030

I am pleased to inform you that your application has been approved by the Life and Medical Sciences REC.

Ethical approval is subject to the following responsibilities after approval https://www.ucl.ac.uk/research-ethics/responsibilities-after-approval:

Notification of Amendments

Please seek approval for any proposed amendments (to include extensions to duration) to this approved study. You will be able to submit amendments for this application through the ethics@ucl system. Further details on how to submit an amendment can be found here: Responsibilities after ethical approval | UCL Research Ethics - UCL – University College London

Adverse Event Reporting – Serious and Non-Serious

You must report to the Research Ethics Committee any unanticipated problems or adverse events involving risks to participants or others. The REC should be notified via email (ethics@ucl.ac.uk) of all serious adverse events immediately after the incident occurs and non-serious events within ten working days of the incident occurring. Please provide details of any related amendments to the protocol or participant documentation.

Where the adverse incident is unexpected and serious, the Chair will decide whether the study should be terminated and may seek the opinion of an independent expert.

For non-serious adverse events, the Chair will confirm that the incident is non-serious and report to the REC at the next meeting. The final view of the REC will be communicated to you.

In addition, please:

1. ensure that you follow all relevant guidance as laid out in UCL's Code of Conduct for Research;
2. note that you are required to adhere to all research data/records management and storage procedures agreed as part of your application. This will be expected even after completion of the study.

We may, for the purposes of audit, contact you to ascertain the status of your research.

If you have any query about any aspect of this ethical approval, please email ethics@ucl.ac.uk

We wish you every success with this research.

Yours sincerely,

Lola Alaska

Research Ethics Service
On behalf of the Chair of the Life and Medical Sciences REC

Appendix 5: Certificate of Attendance

SOCIAL RESEARCH ASSOCIATION

Certificate
of attendance

The Social Research Association is pleased to award this certificate to

Sarah Ahmad

For attendance at

Introduction to Qualitative Research - Online

26 & 27 October 2023

Tina Haux
Chief Executive

Appendix 6: Participant Information Sheet

Participant Information Sheet

UCL Research Ethics Committee Approval ID Number: **0789**

YOU CAN SAVE A COPY OF THIS INFORMATION SHEET

Title of Study: Nitrous Oxide Mitigation in Dentistry: A toolkit for dental services in the UK

Department: Paediatric Dentistry, Eastman Dental Institute

Name and Contact Details of the Principal Researcher:

Professor Paul F. Ashley (p.ashley@ucl.ac.uk)

Name and Contact Details of the Researcher(s):

Sarah Ahmad (Rmhvsa7@ucl.ac.uk)
Ms Alexandra Lyne (Alexandra.lyne@nhs.net)

1. Invitation Paragraph

You are being invited to take part in a research project. Before you decide to take part, it is important that you understand why the research is being done and what your participation will involve. Please read the following information and please ask us if there is anything that is unclear or if you would like further information. Thank you for your time, it is much appreciated.

2. What is the project's purpose?

This project aims to pilot and evaluate a newly developed nitrous oxide (N_2O) mitigation toolkit for dental services in the UK. The toolkit is designed to help clinicians optimise the use of nitrous oxide during inhalation sedation and reduce environmental impact. The aim of this research is to gather feedback from dental professionals to assess the clarity, usability, and feasibility of the toolkit before wider implementation. The project will consist of a focus group discussion with dentists who have experience with inhalation sedation. Their insights will be used to refine the toolkit and improve its effectiveness. This study is expected to take place May 2025 and June 2025.

3. Why have I been chosen?

You have been invited to participate because you are a general dentist with experience in inhalation sedation, practising in the UK. Your insights will be valuable in assessing the practicality and usability of the toolkit in real-world clinical settings. Participation is voluntary, and you may choose to withdraw before the end of the focus group discussion.

- Exclusion criteria: Had no prior or current experience with the clinical use of nitrous oxide.
- Were specialists or consultants in paediatric dentistry, as the focus of the study was on the views of general dental practitioners.

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4. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form attached to this email. You can withdraw at any time before the focus group proposed date without giving a reason. If you decide to withdraw you will be asked what you wish to happen to the data you have provided up that point. Please note data cannot be withdrawn after the focus group has taken place.

5. What will happen to me if I take part?

You will be asked to review the toolkit attached to this email, and participate in an online focus group with the research team. You will be asked a couple of questions on the clarity and feasibility of the toolkit to help refine it before it's available for the public use. The online meeting will roughly take 30 mins of your time.

6. Will I be recorded and how will the recorded media be used?

The focus group discussion will be audio-recorded (with your consent) to ensure that all feedback is accurately captured. No video recording will take place. The recordings will be used for analysis only and will be deleted once the data analysis is completed

7. What are the possible benefits of taking part?

Although there is no direct benefit to you, your feedback will contribute to improving a toolkit aimed at supporting dental services in mitigating the environmental impact of nitrous oxide. The toolkit may be considered for wider use in the future.

8. What if something goes wrong?

It is unlikely anything will go wrong in this study. However, should you wish to raise any concerns or complaints, you can contact Sarah Ahmad, the lead researcher, at Rmhvsa7@ucl.ac.uk. Alternatively, you may contact Professor Paul Ashley, the project's supervisor at p.ashley@ucl.ac.uk.

If you feel that your concern or complaint has not been handled to your satisfaction, you can contact the Chair of the UCL Research Ethics Committee (ethics@ucl.ac.uk).

9. Will my taking part in this project be kept confidential?

While every effort will be made to maintain confidentiality, please note that confidentiality cannot be guaranteed in a focus group setting, as other participants will also hear the discussion. Your anonymised responses will be used to refine and improve the toolkit. However, all personal identifiers (e.g., email, name) will be deleted after recruitment. The audio recordings will only be used for analysis. All data will be securely stored on UCL N-Drive and password-protected university computers. Data will be retained until September 2025, when the DDent thesis is submitted, after which all recordings will be securely deleted.

10. What will happen to the results of the research project?

The results will be used to refine the toolkit and may be included in a DDent thesis, academic publications, or conference presentations. Participants will not be identified in any reports. A summary of the findings can be provided upon request.

11. Local Data Protection Privacy Notice

Notice:
The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our 'general' privacy notice:

For participants in health and care research studies, click here

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices.

For this study, only minimal personal data will be collected:

- Basic identifiers (e.g., first name, email address) for recruitment purposes.
- Audio recordings of the focus group discussion.
- Transcripts from the discussion, which will be fully anonymised.

The lawful basis that would be used to process your personal data will be performance of a task in the public interest.

- Your name and contact details will only be used for recruitment and will not be linked to any data collected in the study.
- The focus group discussion will be audio-recorded (with your consent), but no visual recordings will be taken.
- The recording will be transcribed and anonymised, ensuring that no identifying information is retained.
- Data will be securely stored on UCL N-Drive and password-protected university computers.
- Only the research team will have access to the data.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

12. Contact for further information

Should you have any further questions about this project or should you wish to receive an abstract of the final results, please contact Sarah Ahmad *(Rmhvsa7@ucl.ac.uk) or Professor Paul Ashley* p.ashley@ucl.ac.uk) *or Ms Alexandra Lyne (Alexandra.lyne@nhs.net)*

Thank you for reading this information sheet and for considering to take part in this research study.

Appendix 7: Consent Sheet

Consent form

Please complete this form after you have read the Information Sheet
Title of Study: Evaluating a Nitrous Oxide (N_2O) Mitigation Toolkit for Dental Services
Department: UCL Eastman Dental Institute
Researcher Contact Details: Sarah Ahmad rmhvsa7@ucl.ac.uk
Principal Researcher Contact: Prof. Paul Ashley p.ashley@ucl.ac.uk
Name and Contact Details of the UCL Data Protection Officer: Alexandra Potts dataprotection@ucl.ac.uk
This study has been approved by the UCL Research Ethics Committee Project ID number: 0789

Thank you for considering taking part in this research. Please read the information below and **tick each box** to confirm your consent.

- I confirm that I have read and understood the Participant Information Sheet and have had the opportunity to ask questions. ☐
- I agree to participate in the focus group discussion. ☐
- I understand that participation is voluntary, and I can withdraw at any time before the discussion begins without giving a reason. ☐
- I understand that the focus group discussion will be audio recorded (not video) for research purposes and securely stored. ☐
- I understand that confidentiality cannot be fully guaranteed in a focus group setting, as other participants will also hear my responses. ☐
- I understand that the audio transcriptions are anonymised and no identifiable information will be included in any reports or publications. ☐
- I understand that my data will be stored securely on UCL N-Drive and used solely for this research only. ☐
- I understand that my anonymised data may be used to refine the toolkit and will be retained until the submission of the researcher's DDent thesis in September 2025. After this, all audio recordings will be permanently deleted. ☐
- I understand that the lawful basis for processing my personal data is "performance of a task in the public interest" under UK GDPR. My personal data will be handled in line with UCL's Data Protection Policy. ☐

Participant's Name:
Date:
Signature:

Researcher's Name:
Date:
Signature:

Appendix 8: Focus Group Discussion

Focus Group Questions

1. Clinical Background and Sedation Exposure

- Can you briefly describe your role and typical clinical setting?
- How frequently do you use nitrous oxide in your current practice?
- What alternative sedation options (e.g. IVS) are available to you?

2. Awareness and Attitudes toward Sustainability

- Before receiving this toolkit, were you aware of the environmental impact of nitrous oxide?
- Are you familiar with any existing sustainability guidance or toolkits (e.g. SDCEP, NHSE)?
- How motivated do you feel, in general, to reduce the environmental impact of dental sedation?

3. Toolkit Content and Usability

- What were your first impressions of the toolkit's layout and design?
- Did the content feel relevant to your day-to-day practice?
- What parts (if any) did you find difficult to understand or less applicable?
- How useful did you find the visual aids and summary flowchart?

4. Clinical Impact and Behavioural Change

- Do you think this toolkit could influence your clinical decisions around when and how nitrous oxide is used?
- Has it changed your confidence in initiating a quality improvement project on this topic?

5. Feedback on Audit and QIP Process

- What are your thoughts on the audit templates and data collection process?
- Do you think these tools are practical to use in your clinical setting?
- Are there any specific suggestions you'd make to improve the toolkit?

Appendix 9: A Snapshot of the Coded Transcript Excerpts from the Focus Group Discussions in Chapter Five

Transcript	Code	Theme
SA: Do you know how N_2O affects the environment? Are you aware of its exact global warming potential?		
P: I know it's bad for the environment	Environmental awareness	Understanding N_2O impact
P: I'm not sure what the exact global warming potential is but I know it's similar to carbon dioxide	Environmental awareness	Visual aids & summary tools
SA: Did you come across any other N_2O toolkits? Like the SDCEP one?		
P: I didn't know they have a toolkit!	Awareness of existing toolkits	Knowledge of existing toolkits
P: I didn't know either, the first time I heard about a nitrous oxide mitigation audit was when you carried out the nitrous audit at the Eastman	Awareness of existing toolkits	Knowledge of existing toolkits
SA: What do you think of the layout of the toolkit? Do you think it's clear enough?		
P: Very clear and easy to understand. That was my first impression	Clear layout	Clarity and design
P: I thought it was very easy to read. It's simple and not complicated	Clear layout	Clarity and design
P: I really liked the step-by-step guide with the pictures it was very easy to follow	Visual aids	Clarity and design
P: The pictures and diagrams were very helpful	Visual aids	Visual aids & summary tools
P: I really like the flowchart; it simplifies the whole toolkit nicely	Visual aids	Visual aids & summary tools

Appendix 10: A Snapshot of the Theme and Sub-theme Analysis from the Focus Groups in Chapter Five

Participant	Clarity and design	Ease of implementation	Visual aids and summary tools
Participant 2	Very clear and easy to understand. That was my first impression	I think it should definitely be included into the local protocols at hospitals, and practices using sedation as long as there's a clear guide like this toolkit	The pictures and diagrams were very helpful
Participant 3	I thought it was very easy to read. It's simple and not complicated	I feel like time would be a barrier and people won't be getting paid extra to do this so it will have to be a good audit lead who's willing to take this on and maybe a dental foundation trainee who needs to do an audit	It's very useful you added pictures of the equipment, and I liked the diagram of the different flow rates and how it looks if under/over inflated
Participant 4			I really like the flowchart, it simplifies the whole toolkit nicely
Participant 5	I really liked the step-by-step guide with the pictures it was very easy to follow	I feel like this is something I can easily bring to my practice because I have all the steps I need here as a guide	I really liked the step-by-step guide and the pictures you included

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