Original Article

Implementing nitrous oxide cracking technology in the labour ward to reduce occupational exposure and environmental emissions: a quality improvement study

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Summary

Nitrous oxide, a potent greenhouse gas, is a common labour analgesic. One method which may reduce its carbon footprint is to 'crack' the exhaled gas into nitrogen and oxygen using catalytic destruction. In this quality improvement project, based on environmental monitoring and staff feedback, we assessed the impact of nitrous oxide cracking technology in the maternity setting. Mean ambient nitrous oxide levels were recorded during the final 30 minutes of uncomplicated labour in 36 cases and plotted on a run chart. Interventions were implemented in four stages, comprising: stage 1, baseline (12 cases); stage 2, cracking with nitrous oxide delivered and scavenged via a mouthpiece (eight cases); stage 3, cracking with nitrous oxide via a facemask with an air-filled cushion (eight cases); stage 4, cracking with nitrous oxide via a low-profile facemask, and enhanced coaching on the use of the technology (eight cases). The median ambient nitrous oxide levels were 71% lower than baseline in stage 2 and 81% lower in stage 4. Staff feedback was generally positive, though some found the technology to be cumbersome; successful implementation relies on effective staff engagement. Our results indicate that cracking technology can reduce ambient nitrous oxide levels in the obstetric setting, with potential for reductions in environmental impacts and occupational exposure.

Introduction

The World Health Organization recognises climate change as "*the biggest health threat facing humanity*" [1]. The atmospheric release of greenhouse gases such as carbon dioxide and nitrous oxide (N_2O) is the principal cause of human-made global warming. The extent to which global surface temperatures are increased by the atmospheric release of a particular greenhouse gas relate to its global warming potential (GWP), which expresses the contribution of a substance to global warming over a specified timeframe (commonly 100 years; GWP_{100}), referenced to an equivalent mass of carbon dioxide [2]. This provides a basis for greenhouse gases to be described in terms of carbon dioxide equivalents (CO_2e). Many inhalational anaesthetic agents are potent greenhouse gases. For example, sevoflurane has a GWP_{100} of 144 [3], desflurane 2540 [2] and N_2O 265 [4]. Furthermore, N_2O depletes the ozone layer, further exacerbating the effects of climate change [2].

In 2020, the NHS in England committed to achieving net zero carbon by 2040, setting out these aims in *Delivering a Net Zero National Health Service* [5]. This document highlights the substantial contribution that anaesthetic gases make to the carbon footprint of the NHS, an estimated 2% of its overall carbon footprint or 8% of the carbon footprint of all medications [5]. Recent data from the Greener NHS Dashboard indicates that approximately 17,000 tonnes of CO_2e (tCO_2e) are accounted for by the release of volatile anaesthetic agents (based on rolling 12-month average data from January 2022), whereas N_2O accounts for approximately 250,000 tCO_2e (financial year 2020/2021 data) [6]. Of this, the majority (approximately 171,000 tCO_2e) was from 50:50 mixed oxygen and N_2O (O_2/N_2O) used for analgesia in the maternity setting.

Nitrous oxide is the most frequently used labour analgesic in the UK, and is available in all birth settings [7,8]. As such, healthcare staff who work in maternity services are frequently exposed to N_2O, with consequent occupational health risks including megaloblastic anaemia and pregnancy complications [9]. Occupational exposure limits (as a time weighted average) are 100 parts per million (ppm) in the UK [10], which is notably higher than in many other nations (e.g. 25 ppm the USA [11]). Previous work has noted high levels of N_2O exposure amongst midwives working on the labour ward [9]. Removal of N_2O manifolds and minimising its clinical use are the most important approaches, overall, to mitigating the atmospheric emission of healthcare-related N_2O [12]. Where N_2O is used, catalytic destruction, also known as 'cracking' has the potential to mitigate both occupational exposure and environmental impacts by breaking N_2O down into (non-greenhouse gas) N_2 and O_2 [4,13].

In a previous publication, we reported a bench experiment involving a N_2O cracking device (Mobile Destruction Unit (MDU), Medclair Invest AB, Stockholm, Sweden) and scavenging O_2/N_2O demand valve (Ultraflow, BPR Medical Ltd, Mansfield, UK) (Fig. 1), which demonstrated a substantial reduction in ambient N_2O concentrations under experimental conditions [13], consistent with the manufacturer's data that over 99% of N_2O is destroyed [14]. However, we noted that the effectiveness of the technology would depend on what proportion of the N_2O delivered to the patient was then exhaled into the scavenging system, thereby entering the device [12, 13]. Bearing in mind the potential challenges with achieving this in the setting of labour, we designed a quality improvement project based on environmental monitoring of N_2O levels and staff feedback to investigate whether using the MDU and Ultraflow demand valve could reduce N_2O release in practice.

Methods

Departmental approvals were granted for a quality improvement project with environmental monitoring of N_2O concentrations and the collection of staff feedback, based in three hospitals: St Mary's Hospital, Manchester (approximately 9000 deliveries per year, mixed midwifery- and consultant-led central delivery unit including tertiary services); Wythenshawe Hospital, Manchester (approximately 5000 deliveries per year, split between a midwifery-led birth centre and consultant-led delivery suite); and St John's Hospital, Livingston (approximately 3000 deliveries per year, mixed midwifery- and consultant-led labour ward).

Initially, we undertook a series of pilot measurements of ambient N_2O concentrations during labour in the central delivery unit at St Mary's Hospital, Manchester, with and without the cracking equipment, using an infrared N_2O detector (G200, Bedfont, Maidstone, UK) configured to log readings every 6 min. This pilot phase yielded no conclusive results (Table 1), prompting us to consider why the data were difficult to interpret. The challenges we identified included that different sized rooms might have different ambient dilution; use of delivery devices (i.e. mouthpiece and facemask) varied between parturients; ambient N_2O concentrations can change rapidly [13]; some parturients received additional analgesia (e.g. epidural); some parturients were transferred to the operating theatre for delivery; and parturients presented at different stages of labour.

We subsequently designed a measurement protocol to attempt to mitigate these challenges. We opted to use run chart methodology to record and analyse the data. Run charts are used in quality improvement to plot a quality indicator (in this case N_2O levels) in case or time order as a line chart.

Once a baseline median has been calculated (based on at least 12 data points [15]) and added to the chart, interventions aimed at improving the quality indicator are commenced and measurements continued. If the intervention has no effect, the developing line would be expected to cross the median at random (normal variation). Non-random patterns, known as special cause variation, indicate an effect – a concept analogous to statistical significance in research. According to the NHS Institute, special cause variation can be identified according to 'run chart rules', comprising: a shift (six or more consecutive data points above or below the baseline median); a trend (five or more data points increasing or decreasing in a row); too many or too few runs (based on data tables [16]); and astronomical data points [15]. Where special cause variation is identified, it is appropriate to recalculate the median, based on at least eight data points, so that further comparisons can be made [15].

The environmental monitoring phase of the project (November 2021–May 2022) was undertaken on the low-risk, midwifery-led Manchester Birth Centre at Wythenshawe Hospital, which has consistently-sized rooms (6.1 m x 5.6 m) with O_2/N_2O terminal units (Schrader valves) at either end of the room. As in our bench experiment, the infrared N_2O detector was positioned equidistant (3.1 m) from the piped O_2/N_2O terminal units at a height of 1.3 m (analogous to a member of staff sitting in the room) [13], and configured to log readings every 2 min. The equipment was set up as soon as possible following the admission of the parturient. To standardise data between cases, only the readings in the final 30 min of labour (i.e. the final 15 readings) were logged, and these were plotted as a mean value on the run chart. Readings obtained during the labours of parturients who did not deliver at the Birth Centre (i.e. transfer to the consultant-led delivery suite), who did not use N_2O for analgesia or whose admission before delivery was < 30 min duration, were not included. The N_2O detector was calibrated and maintained according to the manufacturer's schedule for the duration of the project.

The environmental monitoring phase was undertaken in four stages. Stage 1 provided baseline environmental monitoring (12 cases), with no scavenging or cracking equipment used. Parturients used our standard O_2/N_2O delivery system comprising a demand valve (Pain Relief Unit, Oxylitre, Manchester, UK) and a mouthpiece with viral filter (Mouthpiece Filter Kit, Intersurgical, Wokingham, UK). In stage 2 the MDU and Ultraflow scavenging demand valve were used with a mouthpiece (eight cases). The midwives and parturients were educated (including written information) on the use of the MDU and associated equipment (Fig. 2). Midwives were encouraged to provide feedback to parturients on their technique. In stage 3, the mouthpiece was exchanged for an anaesthetic facemask with an air-filled cushion (Economy Mask, Intersurgical, Wokingham, UK), and the written information was amended accordingly (eight cases). In stage 4, in response to feedback from the midwives working at the Birth Centre, the Economy Mask was exchanged for a low-profile anaesthetic facemask (Clear Lite Mask, Intersurgical, Wokingham, UK), and a member of staff familiar with the MDU was asked to provide the parturient some brief coaching on the use of the equipment (eight cases). Verbal consent was sought for the use of the equipment and the presence of the N_2O monitor, but as only environmental data were recorded, written consent was not obtained from parturients.

We invited staff at all three sites to anonymously provide feedback on the use of the cracking equipment via an online survey platform (Google Forms, Google LLC, Mountain View, CA, USA; online Supporting Information Appendix S1). In addition, members of the authorship team who were involved in the implementation of the cracking equipment at different sites (BL, KM and AF) authored reflective vignettes on their experiences (Box 1).

Results

The run chart for the environmental monitoring stage of the project is shown in Figure 3. In stage 1, the baseline median of ambient N_2O levels in the 30 min before delivery from the initial 12 cases was 45.4 ppm (range 1.4–172.4 ppm). In stage 2, the median levels of ambient N_2O were 13.05 ppm (range 0–64.9 ppm), with a shift of seven consecutive data points below the baseline median, meeting the criteria for special cause variation [15]. In stage 3 median ambient N_2O levels were 7.5 ppm (range 0–234.2 ppm); however, the results did not meet the criteria for special cause variation as N_2O levels fluctuated above and below the baseline median, consistent with normal variation [15]. In two cases (seen on the run chart as cases 26 and 27), parturients did not tolerate the use of the facemask and switched to using a mouthpiece part-way through their labour. These results were included in the run chart as this was a real-world clinical situation. Finally, in stage 4, median ambient N_2O levels were 8.7 ppm (range 0–27.3 ppm), with all eight data points below the baseline median, again meeting the criteria for special cause variation [15]. The low-profile mask appeared to be associated with greater parturient satisfaction than the mask with the air-filled cushion, with none of the cohort requesting to switch to an alternative delivery device.

Of 41 staff members who responded to the survey, 12 work at the Manchester Birth Centre, 12 at St Mary's Central Delivery Unit and 17 at St John's Labour Ward. Twenty-two of the respondents had used the cracking equipment in practice. The quantitative results from these 22 respondents are summarised in Table 2. In general, staff feedback was positive, although all but one respondent found that the additional tubing 'got in the way' to some degree. Free text feedback was sought about the size of the machine relative to the size of the room. Of the 22 respondents with experience of using the equipment, 19 commented that the machine was larger than they would wish ("*Could be smaller due to everything else that needs to be in the room especially if the [neonatal resuscitation unit] is needed*"). Of eight staff who reported encountering problems/faults with the machine, five referred to the illumination of the 'overheat' light – a self-limiting issue caused by high levels of N_2O being (exothermically) cracked. Three referred to a 'malfunction' light which required intervention by the manufacturer in the form of a configuration update. A similar malfunction was encountered at all three sites, and we are informed by the manufacturer that the MDUs had initially been configured to shut down if even a small concentration of N_2O was detected by the device in the exhaust gas (i.e. when the cracking capacity of the MDU is exceeded), making it too sensitive for the large amounts of N_2O exhaled by some parturients. This appears to have been corrected by configuration update, which allows a slightly greater concentration of exhaust N_2O before a malfunction code is triggered.

Discussion

Overall, our environmental monitoring data indicates that N_2O cracking equipment achieves a reduction in median ambient nitrous oxide levels by 71% when used with a mouthpiece, and by 81% with a low-profile facemask, accompanied by a brief period of coaching. This is consistent with system-level research from Sweden which indicates that double-masks (a mask type not available from our suppliers) can collect 75–85% of exhaled N_2O [17]. It also illustrates that different delivery devices may yield different results, based on parturient cooperation with exhaling reliably into the device.

The introduction of cracking technology to maternity units may be an invaluable method of reducing the carbon footprint of N_2O. Whilst analgesic alternatives such as epidurals and remifentanil may have a lower carbon footprint as well as higher analgesic efficacy [18], these techniques may not be desirable or acceptable to many parturients. Furthermore, the risks and burdens inherent to these techniques mean they cannot be delivered in the midwifery-led setting without medical involvement and continuous fetal monitoring [7].

The NHS Net Zero plan advocates for the introduction of N_2O cracking technology, suggesting that implementation may reduce the carbon footprint of N_2O by 75% [5]. Whilst this figure is supported by system level observations in Scandinavia [19], to our knowledge this technology has not previously been evaluated in 'real-world' clinical settings. Our previous bench experiment, completed under ideal conditions, demonstrated the MDU is effective at destroying N_2O that passes directly into the unit [13], and supports the manufacturer's data that the MDU can crack more than 99% of N_2O [14]. However, labour is often far from a controlled situation. It is unpredictable, may last a long time, and parturient co-operation is not guaranteed. As such, the effectiveness of the MDU in real life scenarios was not assured.

We initially opted to use a mouthpiece as the N_2O delivery device in stage 2 of the project because the staff working on the Birth Centre were most familiar with this method for delivering N_2O in labour. This showed very promising results, which was somewhat surprising considering the manufacturer recommendation to use a facemask to maximise capture of exhaled gas. We speculate that the mouthpieces were effective because the midwives at the Manchester Birth Centre routinely advise parturients to both inhale and exhale via the mouthpiece, even without any scavenging in place, as a strategy to help control breathing during labour.

The facemask with the air-filled cushion was used in stage 3 as these were supplied by the manufacturer with the demand valve disposables in addition to the mouthpieces. However, this did not prove to be consistently effective. It is possible that patients simply did not like using the mask and felt it was uncomfortable or claustrophobic. The midwives noted that some patients who wore spectacles found it difficult to obtain a good seal around the mask and also found their view was obstructed (Fig. 4a), leading to requests to change delivery device. It may also be that the usual practice (in our unit) of exhaling through the delivery device was lost with this intervention, as parturients may have removed the facemask to breathe out, resulting in exhaled N_2O not passing into the MDU.

Considering the challenges encountered by parturients who wear spectacles, in stage 4 we swapped to a low-profile facemask (Fig. 4b), and added a short period of coaching by an experienced staff member to increase parturient and (if necessary) midwife understanding of the optimal approach to using the cracking equipment. This was primarily to ensure the parturient understood how to exhale into the mask whilst using N_2O, and also to account for a small number of new midwifery staff rotating through the Birth Centre.

Though staff feedback was mostly positive, some concerns about the size of the equipment were raised. Space considerations could be mitigated by the development of smaller versions of the units, considering this equipment in future room size specifications or installation of a 'central' (i.e. plumbed-in) version of the technology. However, this may be disruptive and costly to install as it would require an anaesthetic gas scavenging system. The scavenging tubing was noted to get in the way to some extent by most respondents. Again, this could potentially be mitigated by considering room layout and using central, rather than mobile units. A substantial minority of respondents reported encountering problems with the technology, though these were mostly self-limiting. Although the MDU is quiet (< 35 decibels [20], which according to the American Academy of Audiology is between the volume of a whisper and a quiet library [21]), some found the noise intrusive. These challenges do not seem insurmountable, but as noted in our reflective statements (Box 1), at a time of extraordinary healthcare workload (currently the case in the NHS) even small additional burdens can be off-putting for staff, particularly when they are perceived as non-essential. The successful implementation of this technology therefore relies not only on evidence of effectiveness (to which this work adds), but on a collaborative approach to implementation and making the time to allow staff to become proficient with using the equipment. It is notable that experiences seemed to be somewhat more positive in the Manchester Birth Centre, which may indicate that it is easier to reach a 'critical mass' of engaged individuals amongst a smaller group [22]. This is also the centre in which the environmental monitoring phase of the quality improvement project took place, and staff may have found it motivating to be involved in this process [23].

Our study has several limitations. The design was a quality improvement project based on environmental monitoring in the clinical setting. As such, strict research protocols were not applied to the staff or parturients involved (with no limitations being placed on door or window opening, for example). As illustrated by the wide variability of our baseline data, the amount of N_2O used varies widely between parturients, some of whom may elect to use pharmacological analgesia sparingly. A further limitation was that parturient inclusion was based on investigator and equipment availability and thus was not truly consecutive; there was also a break in data collection due to the project lead self-isolating due to SARS-CoV-2 infection (late March/early April 2022), and the malfunction code displayed on the MDU awaiting correction (late April 2022). Furthermore, N_2O is denser than air (1.9 $g.l^{-1}$ vs. 1.2 $g.l^{-1}$ at 15°C) and exists as a vapour below its critical temperature of 36.5°C [24-26], so may not mix uniformly with room air. We therefore advise caution in drawing direct links between the findings of our study and the absolute proportion of N_2O broken down by cracking technology in practice. Finally, parturient feedback was not directly sought as this was felt to be potentially burdensome in the low-risk maternity setting.

Given that a similar magnitude of reduction in N_2O levels was seen with mouthpieces and low-profile facemasks, we suggest that parturients should be offered the option of either device when cracking is used. Parturient education and choice in use is vital given the high degree of co-operation required, and this is consistent with guidelines for choice and personalised care in maternity services [27]. Future research to better characterise the optimal use of this technology could focus on investigating other delivery device types, and considering the optimal timing and method of education (e.g. antenatal vs. intrapartum).

Our real-world data are consistent with Greener NHS estimate that cracking may reduce the 'scope 1' (direct) greenhouse gas emissions associated with N_2O by 75% [5]. However, even with 75% destruction, N_2O would still have a higher carbon footprint than other methods of labour analgesia [12]. Based on the calculations of Pearson et al., a 75% N_2O capture rate over a 4-h period of labour would reduce N_2O related emissions from 237.33 $kgCO_2e$ to 59.33 $kgCO_2e$ (remifentanil patient-controlled analgesia 0.75 $kgCO_2e$; epidural bupivacaine 1.2 $kgCO_2e$; intramuscular morphine 0.08 $kgCO_2e$) [18]. The extent to which these comparisons should be discussed with patients as part of the consent process remains a matter of some controversy [28], and should be investigated in future study. Of note, we attempted to avoid burdening parturients with 'climate guilt' during their labour; for example, by taking care to describe this project as an attempt to reduce our carbon footprint, as opposed to that of the parturient (Fig. 2).

In conclusion, our study finds that introduction of N_2O cracking technology has the potential to reduce ambient N_2O levels by 71–81% in the obstetric setting, with positive implications for environmental impacts and occupational exposure. We believe that the results of this exploratory project will be useful to those who may be considering commissioning this technology.

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Table 1 Mean ambient N_2O levels measured at the St Mary's Hospital central delivery unit during the pilot phase, with and without the use of N_2O cracking equipment

Case	Total time monitored; min	Mean N_2O levels; ppm	Cracking/scavenging technology
1	158	24	No
2	294	138	
3	564	205	
4	204	297	
5	330	49	
6	132	32	
7	540	106	MDU, Ultraflow demand valve, facemask or mouthpiece.
8	338	130	
9	143	50	
10	557	127	

ppm, parts per million; MDU, Mobile Destruction Unit.

Table 2: Summary of staff feedback on the nitrous oxide cracking equipment (n = 22)

How would you rate setting the machine up for use? (1 = very difficult; 5 = very easy)				
1	**2**	**3**	**4**	**5**
2	1	3	8	8
How would you rate the level of difficulty explaining to patients how to use it? (1 = very difficult; 5 = very easy)				
1	**2**	**3**	**4**	**5**
0	1	2	5	14
How would you rate the level of difficulty changing the disposable components between patients? e.g. masks/filters (1 = very difficult; 5 = very easy)				
1	**2**	**3**	**4**	**5**
0	0	3	6	13
Did the machine tubing get in the way when you were doing work? (1 = not at all; 5 = very much so)				
1	**2**	**3**	**4**	**5**
1	6	7	4	4
How satisfied overall were you with the machine? (1 = not satisfied; 5 = very satisfied)				
1	**2**	**3**	**4**	**5**
2	0	8	4	8

The level of noise of the machine was…	
Acceptable	**Unacceptable**
18	4
Did you encounter any problems/faults with the machine?	
Yes	**No**
8	14

Box 1: Reflective vignettes on the introduction of N_2O cracking at three institutions.

St John's Hospital, Lothian (RL, Specialty Doctor in Anaesthesia)
The principal challenge that we encountered was that using the equipment seemed overwhelming for some colleagues. When introducing a new technology adds even a small additional burden to an already demanding workload, reverting to usual practice can be tempting. Though colleagues appreciated the potential benefits of the technology, barriers to use included the size of the machine, the humming nose that it makes, and the prolonged start-up period. This was mitigated in part by keeping the equipment 'on standby' in the largest room, but implementation still required encouragement.

St Mary's Hospital, Manchester (KM, Consultant Anaesthetist)
We found that utilising the cracking equipment required constant presence and prompting. Barriers to use included: the diversity of analgesic approaches used; rapid staff turnover; clinical workload and staff pressures; lack of enthusiasm for work perceived as non-essential; and limited prior knowledge about the environmental and occupational health effects of N_2O. Initiatives to promote use included: storing the equipment on the corridor where it was easily visible; discussing suitable cases at handovers; and clearly identifying which room the equipment was being used in.

Manchester Birth Centre, Wythenshawe (AF, Midwife and Ward Manager)
There were some initial reservations about using the cracking technology, which seemed at odds with the aesthetic of our calm and homely Birth Centre. However, this was something we got used to. A demonstration video helped our small team (12 midwives and five maternity support workers) feel confident in using the equipment. Overall, N_2O cracking was well received by colleagues, as well as the women and families that participated. The Birth Centre team were invested in the success of the project; they were enthusiastic about the potential environmental and occupational exposure benefits, and interested in the findings of the ongoing quality improvement work.

Figure legends

Figure 1: Mobile Destruction Unit (Medclair Invest AB, Stockholm, Sweden) and Ultraflow demand valve (BPR Medical Ltd, Mansfield, UK), with a low-profile facemask (size 4 Clear Lite Facemask, Intersurgical, Wokingham, UK).

Figure 2: Sample written information for patients, displayed as an A4-sized poster attached to the Mobile Destruction Unit; an equivalent poster was produced for when using the facemask.

Figure 3: Run chart displaying mean ambient N_2O concentrations in the 30 min before delivery. Stage 1, N_2O used for labour analgesia without scavenging or cracking equipment; stage 2, Mobile Destruction Unit (MDU) and scavenging demand valve, N_2O delivered via mouthpiece; stage 3, MDU and scavenging demand valve, N_2O delivered via facemask with air-filled cushion; stage 4, MDU and scavenging demand valve, N_2O delivered via low-profile facemask, brief period of coaching from experienced staff member. Solid line, stage median; dashed lines, medians of prior stages; green data points indicate shifts below the baseline median consistent with special cause variation.

Figure 4: A staff volunteer wearing spectacles, using (a) a facemask with an air-filled cushion (size 4 Economy Facemask, Intersurgical, Wokingham, UK) and (b) a low-profile facemask (size 4 Clear Lite Facemask, Intersurgical, Wokingham, UK).

Online Supporting Information

Appendix S1 Blank staff survey.