

**Daith ear piercing, vagus nerve stimulation
and the
treatment of migraine headaches**

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Abstract

Following widespread reports on social media in 2015 of improvement in migraine after Daith ear piercing (DP), many thousands of migraine sufferers have visited lay piercing studios for migraine treatment in the hope of gaining improvement in their migraines. Despite this, no medical research by others has been performed. We report audits of two series of patients attending the London Migraine Clinic for DP.

In Series 1, 30 of 42 consecutive patients reported an improvement in headache 1-4 months after piercing, with a three-fold increase in average symptom-free days/month from 6.4 to 19.7. The improvement was retained in 9 of the 11 patients we were able to reach at 12 month follow-up. A reduction in headache and visual discomfort often occurred immediately following the DP, so we investigated the change in visual discomfort, before and after piercing, when viewing a series of gratings made up of parallel lines known to produce discomfort in migraineurs. The reduction in discomfort after piercing was significantly greater in the patients who subsequently reported improvement in migraines.

In Series 2, prior to piercing, as part of pre-treatment assessment, 115 patients received temporary stimulation with fine needles in the cartilage of the ear. Two points of stimulations were compared. The first was at the *antitragus* (innervated by the great auricular nerve, which is without vagal connections) and the second at the inferior surface of the *crus helix* at the inferior Daith point (an area innervated by the vagus nerve). Stimulation of the antitragus produced no effect, whereas stimulation of the Daith point measurably reduced visual discomfort and other symptoms, such as headache, within one minute. In about three-quarters of patients the symptoms returned over the same time scale when the needle was removed. There was a further significant reduction in both visual discomfort and other symptoms following therapeutic piercing.

The changes are strongly suggestive of vagal stimulation, though this requires confirmation. We conclude that DP is potentially a simple, inexpensive and effective treatment for a proportion of patients with severe migraine, and can be rapidly introduced through existing channels.

Glossary

ABVN Auricular branch of the vagus nerve

ATN Auriculo-temporal nerve (a branch of the trigeminal nerve)

CNxx xxth Cranial nerve

DP Daith ear piercing

GAN Great auricular nerve

LON Lesser occipital nerve

MEG Magnetoencephalography

VNS Vagus nerve stimulation

tVNS transcutaneous electrical VNS

sVNS sustained percutaneous VNS

Introduction

Soon after it came into vogue as a cosmetic ear decoration in 1992, Daith ear piercing (DP) patients began to report a serendipitous reduction in migraines. The reports of migraine improvement increased slowly at first, but in 2015 the practice of DP spread virally on social media after Dr Thomas Cohn, a pain physician in the USA, reported the reduction in headaches on his website. Since then many thousands of migraineurs have had a DP for migraines. In late 2016, when we first heard of the reports, any evidence of efficacy was limited to some amateur surveys. We analysed one of these surveys in detail and found that the relationship within the data suggested further professional surveys were justified. Since May 2017, we have conducted four in-depth web-based surveys of over 4500 migraineurs with a DP (over 850 with migraines >10 years and piercing >12 months) and all four have corroborated the reports of migraine reduction from the initial amateur survey (Blatchley *et al.* 2017)

To date, the only published work on Daith piercing is one case report of a single patient, advocating further research (Rizzo *et al.*, 2017). Nevertheless, there is a physiological rationale for supposing that DP might affect migraines. The DP passes through the *crus helix*, a fold of cartilage on the superior margin of the auditory meatus innervated by the auricular branch of the vagus nerve (ABVN) (see Figure 1b and 1c). Invasive vagus nerve stimulation (iVNS) is an established treatment for both migraines and epilepsy, and there has been considerable research in non-invasive transcutaneous electrical stimulation of the ABVN (tVNS) as an alternative (Gu *et al.*, 2018; Tassorelli *et al.*, 2018). Unlike the transcutaneous electrical devices, which are used intermittently, the piercing remains in situ permanently, so that any potential effect on the ABVN is likely to be sustained (sVNS), perhaps through irritation of terminations of the ABVN. This possibility, along with our own survey data, supported the need for a detailed audit of the effects of a DP on migraines.

We therefore started to offer DP to migraine patients who had sought treatment from searches on the internet. To our great surprise, it soon became apparent that most patients were reporting a marked and immediate improvement in symptoms such as “brain fog”, neck ache, jaw pain and visual comfort, and not just headache. Many reported complete disappearance of headache and symptoms, and this could often be witnessed in the patient’s reactions immediately after the piercing was performed.

It is well established that high contrast patterns of parallel lines (gratings) reliably cause visual discomfort in migraineurs, and that this discomfort is critically dependent on the characteristics of the pattern (Wilkins *et al.*, 1984; Marcus and Soso, 1989). From March 2018 we started to audit the changes in visual discomfort caused by gratings before and immediately after DP. The reduction in visual discomfort after piercing was often clear to observe during the treatment (described in Series 1 below) but we were concerned that this might simply be a placebo response potentially related to the distraction from the pain produced by the piercing process, though, it is worth noting that the pain response to piercing is very variable. We therefore audited the effects of temporary diagnostic stimulation with a fine needle that gave little or no pain. In many patients we found that needle stimulation of the Daith piercing point immediately reduced discomfort from gratings as well as symptoms (headache and “brain fog” etc) which returned when the needle was removed. As a check, we then added similar temporary stimulation to an area of the ear not innervated by the ABVN, which we hypothesised would be inactive (described in Series 2 below).

We report the results of the two series of patients who attended the London Migraine Clinic seeking a DP for their migraines and who underwent the above examinations.

Series 1

Methods

In March 2018 we commenced collecting data from a series of 40 consecutive patients (39 women) with longstanding headache. Our patients had been seeking a DP as a result of their social media and internet searches. They completed a comprehensive headache questionnaire. After detailed explanation of the procedure they gave their signed consent.

Piercing

The DP passes through the cartilage of the *crus helix*, from the superior surface adjacent to the *cymba conchae* to the inferior surface adjacent to the roof of the auditory meatus, see Figure 1a and 1b.

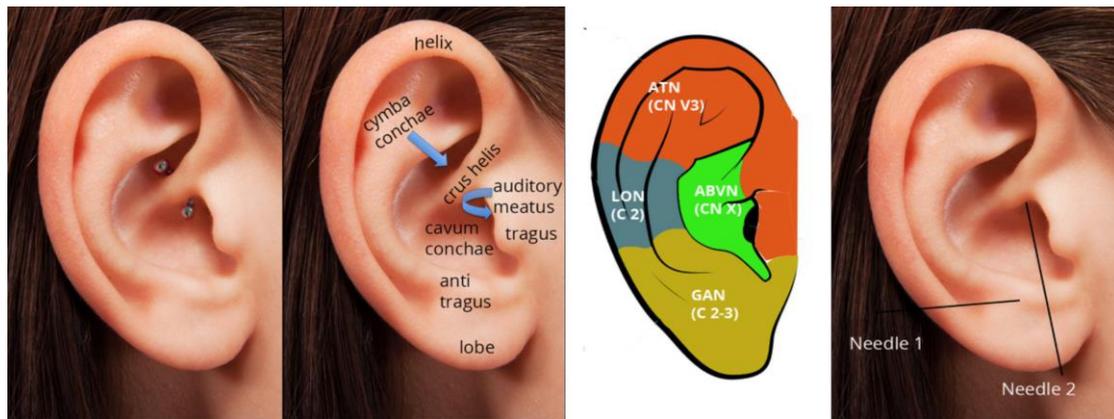


Figure 1 a. A Daith piercing with associated jewellery; b. Anatomy of the pinna. c. Innervation of the pinna (schematic). ABVN – auricular branch of the vagus nerve (CN10); ATN –auriculo-temporal nerve (from CN5); GAN – great auricular nerve (from cervical nerves) ; LON – lesser occipital nerve (from cervical nerves). d. Acupuncture needle positions in Series 2.

The skin was first cleaned with 70% alcohol. A sharp 18-gauge disposable needle (a “blade”) was used to puncture the epidermis on the superior surface of the *crus helix*. It then passed through the cartilage to emerge through the inferior surface. The needle was used to guide the jewellery that then remained *in situ* in the ear. Designs of jewellery included a closed ring, or a curved bar with metal retaining balls screwed top and bottom. We avoided surgical stainless steel because of its nickel content, and 100% titanium was used instead (this could be coated with 100% gold according to patient preference). All equipment and jewellery were vacuum autoclaved and the needle and guides were disposable single-use.

There is considerable technique in performing a Daith piercing well, and we worked with a piercer of many years’ experience. Surprisingly, the piercing was often painless. In patients who experienced pain, it was short-lasting.

Assessment of visual discomfort when viewing visual gratings.

Visual discomfort from gratings was assessed before and immediately after DP using a series of three gratings with different line spacing, followed by a series of 10 gratings with increasing contrast, each with the same line spacing. The line spacing in each grating is expressed as the spatial frequency, measured as cycles per degree (cpd). One cycle is one pair of black and white lines of equal width. It has previously been shown that a spatial frequency of approximately 3 cpd elicits the most discomfort (Wilkins *et al.*, 1984). The initial of three gratings had line widths that gave spatial frequencies of 0.5, 3 and 9 cpd at the viewing distance of 0.6m, as used in the Pattern Glare Test (Wilkins and Evans, 2001). The subsequent 10 gratings all had the same spatial frequency of 3 cpd, with

increasing contrast from 2.7% to 94%. All the patterns were circular in outline, and at 0.6m subtended 9 degrees at the eye. The room illuminance was 150 lux. Patients viewed each pattern for 1-2 seconds and reported any discomfort on a 6-point scale: "none", "aware", "slight", "moderate", "severe", "intolerable".

A comparison group of 130 patients without a medical history of headaches and not attending for a piercing (89 male, 41 female) was separately assessed for visual discomfort with the same gratings during a routine sight test under matched lighting conditions.

Follow Up Details

We followed up patients by email with a link to an online survey tool which included questions on frequency, severity, associated symptoms, medication use etc. The follow up was conducted from 31 May 18, 1-4 months after DP, and from 20 May 19, 12 or more months after DP.

Assessment of headaches

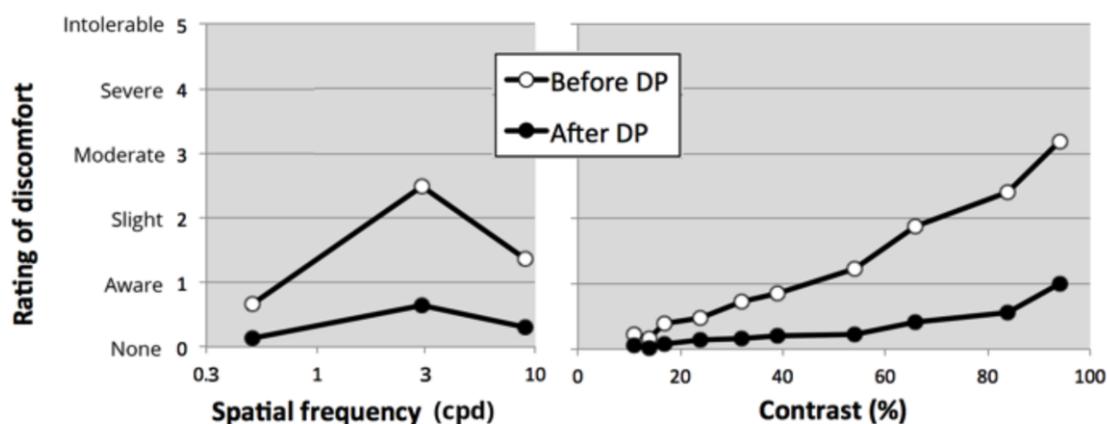
Headaches and other symptoms associated with migraine were assessed in detail. Patients were asked about the frequency of migraines/severe headaches, other non-migraine headaches and completely symptom-free days, both initially and at follow-up. At follow-up they were also asked: "Overall, how has your Daith Piercing altered your migraines/severe headaches?", with the options of "a lot worse", "a little worse", "no obvious change", "a little improved", "greatly improved" and "I no longer have them".

Results of Series 1

At 1-4 months we were able to follow up 42/57 patients (73%). We report on these 42 patients, who had received a DP between March and May 2018. They had longstanding headaches for an average of 16 years (minimum 1 year, maximum more than 20 years). Their headaches were frequent (with an average of less than seven symptom-free days per month) and they were severe (preventing work in 80% of cases). 36% patients experienced aura.

Immediate response to gratings

Figure 2 shows the average rating of the 42 migraine patients before and immediately after DP for the three gratings that varied in spatial frequency (left panel), and subsequently for the ten gratings that increased in contrast (right panel). The average rated discomfort from all patterns was significantly greater before the DP than it was immediately afterwards ($t(41)=10.1, p<.0001$).



The standard error of all points was less than 0.23

Figure 2. The ratings of visual discomfort from the gratings before and after DP. Left panel: high contrast gratings with spatial frequencies 0.5, 3 and 9 cpd. Right panel: variable contrast gratings with spatial frequency 3 cpd. Separate curves show the ratings before and after DP.

In the comparison group of 130 patients (89 male 41 female) without a medical history of migraines, 125/130 reported no discomfort from the gratings. The discomfort was "slight" in 4 patients (3 female) and "moderate" in only one male.

Clinical changes in symptoms at 1-4m follow-up

For the group as a whole, there was a highly significant reduction in migraine days and increase in symptom-free days (Wilcoxon tests, $z>4.19, p<.0001$, two-tail, both measures). There was also an associated and highly significant reduction in migraine severity ($t(36)=7.05, p<.0001$).

This improvement was further illustrated when the entire group was sub-divided according to the response to the question at follow-up: "Overall, how has your Daith Piercing altered your migraines/severe headaches?". The choice of answers is shown in the first column of Table 1, and tabulated against the mean number of migraine days and symptom-free days per month, at consultation before DP and at follow-up. Patients' subjective assessment of the change in their migraines is consistent with the change in their reported migraine and symptom-free days.

Table 1. Average migraine days and symptom-free days in the month before DP and at follow-up, grouped according to reported overall improvement at follow-up.

Reported Improvement at 1-4m follow-up	Migraine days			Symptom-free days	
	N	Before	At	Before	At
		DP	follow-up	DP	follow-up
A lot worse	0				
A little worse	2	3.5	7.3	14.0	3.5
No obvious change	10	12.5	17.4	7.4	9.2
A little improved	14	9.9	7.9	5.1	11.6
Greatly improved	13	9.4	1.5	7.5	26.3
No longer have them	3	2.2	1.5	8.5	29.0

As can be seen from Table 1, individuals who reported their headaches were “greatly improved” showed a substantial reduction in migraine days and a substantial increase in symptom-free days. The corresponding figures were less pronounced in those who reported “little improvement”, and those who reported “No obvious change” showed little difference between before DP and follow-up.

Relationship between immediate response to gratings at DP and later clinical outcome

For the group as a whole there was also a correlation between the reduction in rated visual discomfort from gratings at DP and the subsequent change at 1-4m in migraine days ($\rho=0.31$, $p<.05$) and symptom-free days ($\rho=0.32$, $p<.05$). This improvement is similarly illustrated by subdividing the entire group according to reported overall improvement at 1-4 months, see Table 2.

Table 2. Mean rated discomfort before and after DP, grouped according to overall improvement

Reported Improvement at 1-4m follow-up	N	Mean Before DP	Mean After DP	Mean difference
A lot worse	0			
A little worse	2	4.00	3.00	1.00
No obvious change	10	2.08	1.00	0.92
A little improved	14	2.73	0.55	2.09
Greatly improved	13	2.77	0.46	2.31
No longer have them	3	2.00	0.33	1.67

Long-term effects of DP

At 12 months post DP we were able to reach only 11 of the 30 patients who had reported overall improvement at 1-4 months (we did not follow up the 12 patients who had reported no improvement). 5 of the 11 also reported that the effect “had not begun to wear off”. See Figure 3 for the averaged data.

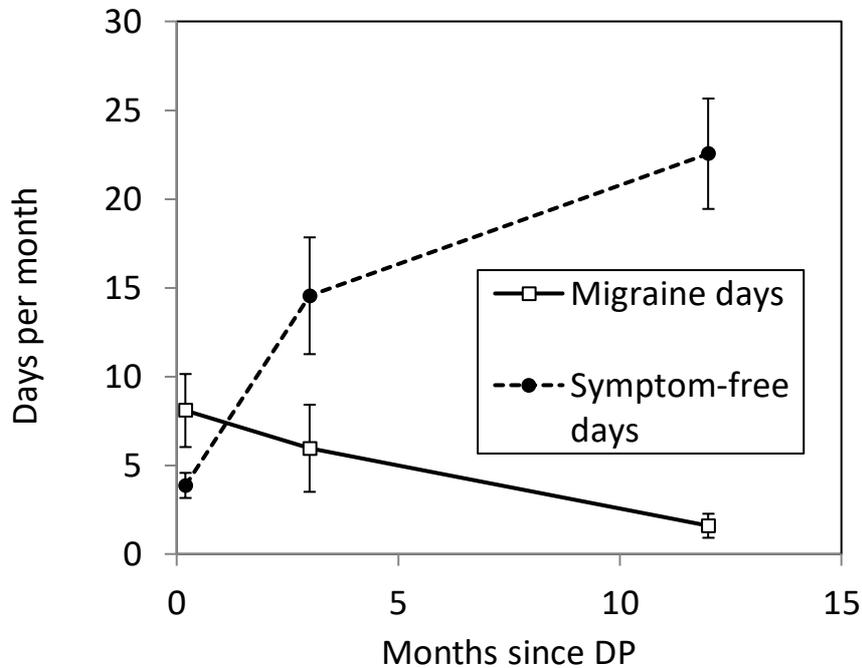


Figure 3. Data from the 11/30 patients previously reporting improvement when followed up at 1-4 months (8/11 had reported little improvement and 3/11 great improvement). At 12 months 1 reported migraine stopped, 9 great improvement, 1 little improvement and 1 no obvious change. Note that the reported migraine days did not include mild “other headache” days.

Interim Discussion: Series 1

Patients in Series 1 had headaches that were frequent and debilitating. At first follow-up more than half the patients reported an improvement, and the improvement was marked in 38% patients. In the small sample we were able to follow up at one year, 9/11 continued to report great improvement. Visual discomfort from patterns occurred in most patients with migraine, and the average reduction from DP predicted the improvement in headache not only at 1-4m follow-up, but also at 12month.

Series 2

To explore the contribution from placebo response in the results observed in Series 1, we added temporary diagnostic stimulation with fine needles prior to piercing, for a consecutive series of 115 patients (treated between March and December 2019). We were then able to compare the immediate effects of DP with stimulation of both the Daith point and an inactive point.

Methods

The general procedures for initial questionnaire, consent and method of piercing remained the same as in Series 1. For Series 2 we added temporary stimulation with fine 31G solid needles 0.25mm in diameter, consecutively at the two points shown in Figure 1d, Needle 1 into the *antitragus*, an area not innervated by the ABVN, and Needle 2 in the future lower Daith piercing point on lower surface of the *crus helix*, an area that is innervated by the ABVN. We explained that we would be inserting two diagnostic needles in sequence in separate places to measure the response, and obtained consent. We were careful not to explain the specific significance of each needle. In all cases the fine needles were inserted through the epidermis into the cartilage. In all patients, insertion of the needle produced little or no discomfort. Prior to insertion we cleaned the area with 70% alcohol.

Patients were asked to observe the patterns and rate discomfort four times: at the outset, whilst each needle was inserted, and again after the DP. They were also asked to report any change in symptoms after insertion of each needle and again after its withdrawal.

Results of Series 2

At initial assessment the patients reported an average of 8.2 migraine days per month and 7.5 symptom-free days. The migraine headaches were severe enough to interfere with work in 75% of cases. 59 (51%) patients reported aura.

Changes in Visual Discomfort

The visual discomfort ratings before, during Needle 1, during Needle 2 and after the DP are shown as separate curves in Figure 4. Needle 1 (in the antitragus, see Figures 1b and 1d) had no effect on ratings. The overall mean ratings before and after Needle 1 were 1.34 and 1.35, respectively; $t(114)=1.06$, $p=.29$. By contrast, Needle 2 in the Daith point significantly reduced ratings of discomfort (mean rating 1.00, $t(112)=8.04$, $p<.0001$). A further significant reduction resulted from the DP (mean rating 0.54, $t(113)=11.61$, $p<.0001$).

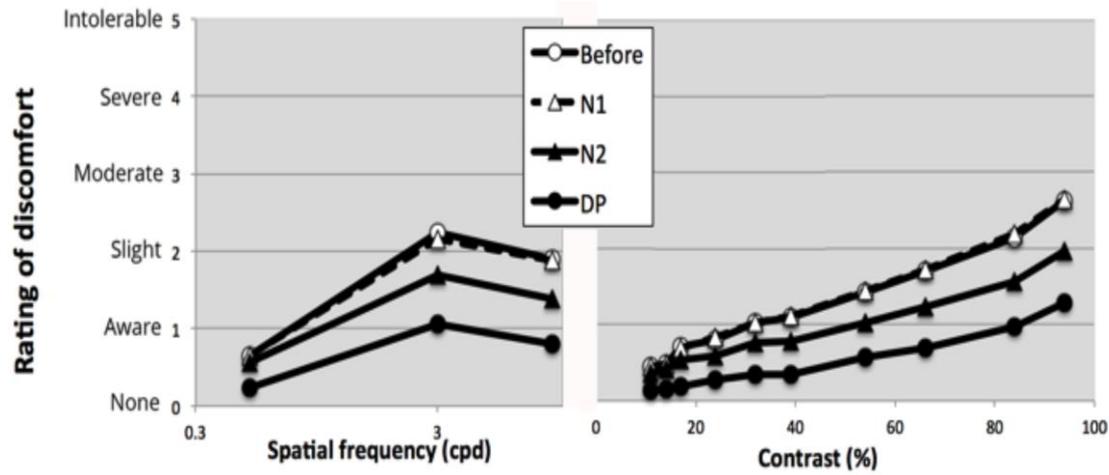


Figure 4. The ratings of visual discomfort from the gratings. Left panel: high contrast gratings with spatial frequencies 0.5, 3 and 9 cpd. Right panel: variable contrast gratings with spatial frequency 3 cpd. For all points the standard error was less than 0.23. Separate curves show the ratings before needle stimulation, during stimulation with Needle 1 (N1), during stimulation with Needle 2 (N2) and after DP. (The curves "before" and "N1" are nearly superimposed.)

For all points the standard error was less than 0.17

Changes in Symptoms

Patients were questioned concerning the effects of the needle stimulation on symptoms, and whether the symptoms returned when the needle was removed.

Table 3 shows the symptoms reported and the number of patients reporting them before DP. It also shows the change in symptoms when the needles were removed.

Table 3. Symptoms reported prior to DP, and the effect on these symptoms after insertion and removal of Needle 1 (antitragus) and Needle 2 (lower Daith point) , and after DP.

Symptoms	Number with symptom	Symptom reduction with Needle 1	Return of symptoms on withdrawal of Needle 1	Symptom reduction with Needle 2	Return of symptoms on withdrawal of Needle 2	Symptom reduction with DP
Headache	61 (53%)	2 (3%)	2 (3%)	47 (77%)	37 (61%)	58 (95%)
Photophobia	19 (17%)	1 (5%)	0 (0%)	14 (74%)	14 (74%)	18 (95%)
Neck/shoulder	78 (68%)	3 (4%)	1 (1%)	63 (81%)	50 (64%)	73 (94%)
Jaw tension	29 (25%)	0 (0%)	0 (0%)	24 (83%)	18 (62%)	29 (100%)
Brain fog	52 (45%)	1 (2%)	1 (2%)	34 (65%)	26 (50%)	42 (81%)
Vision clarity	31 (27%)	2 (6%)	1 (3%)	24 (77%)	18 (58%)	30 (97%)
Vision comfort	34 (30%)	2 (6%)	1 (3%)	22 (65%)	15 (44%)	30 (88%)

As can be seen from Table 3, Needle 1 had little effect on any symptom, whereas Needle 2 reduced most symptoms and did so usually only whilst it was in place. The DP reduced nearly all symptoms.

Discussion

Currently, published medical research on Daith Piercing (DP) for migraines is limited to one case report, even though many thousands of migraineurs have visited lay piercing studios for 20 years to self-treat their migraines. Two initial questions need addressing:- 1. Is there a central effect of DP beyond that of placebo? 2. If there is, then how effective is it in reducing migraines and how long does the effect last?

Our research is an audit of treatment with a DP, and not a placebo-controlled trial. A DP is a visible procedure in a group of patients who are both knowledgeable and motivated, and it would be clear to them whether they had an active or placebo treatment. Effective trial design requires initial data. Presently there are none, so we decided on an incremental research path to discover whether the reported responses were likely to be entirely placebo, and whether further research was justified.

Our research supports the hypothesis that there is a marked and long-lasting central effect on migraine in some patients, possibly mediated via stimulation of the vagus nerve. While it does not exclude placebo, it is difficult to explain the findings as entirely placebo for the following consecutive reasons:-

1. Migraineurs are known to find visual patterns of black and white parallel lines uncomfortable. Prior to a DP, patients' responses were entirely as expected when both the spatial frequency and the contrast of the patterns were varied. After DP the rated discomfort consistently followed a similar but reduced pattern of response. Other subjective symptoms were also reduced, and the patients' experience was obvious to witness in the treatment room. The consistency of the change after DP was remarkable and statistically highly significant. While these changes might be explained by the pain/distraction of piercing, it is more difficult to explain them in terms of patients' expectations. Patients might possibly have expected the discomfort to increase with increasing pattern contrast, but they would not have known of the effects of changes in spatial frequency.
2. An acupuncture needle (Needle 2) inserted into the point later to be pierced with the DP produced an equally consistent (though less marked) reduction in rated discomfort and other symptoms, even though the needle produced minimal or no discomfort when inserted. These changes support at least an element of non-placebo response, but the distraction of piercing or patient expectations have not been excluded as possible explanations.

3. After removal of Needle 2, the symptoms returned in many patients. The increase and decrease in effect occurred within 60s of insertion/removal.
4. An acupuncture needle (Needle 1) inserted into the cartilage of the antitragus, a structure not innervated by the ABVN, produced no change whatever in symptoms or ratings of discomfort. The difference between the effects of the two needles was profound. One would reasonably anticipate some effect of the antitragus needle if distraction were to affect discomfort when viewing the gratings. The dissociation is similar to that already seen in studies with auricular transcutaneous electrical stimulation (Gu et al., 2018) which have used the same inert area as a comparison point.
5. Further knowledge is still required before design of a placebo-controlled study can be attempted. fMRI and MEG imaging studies may be useful in assessing immediate central response.

In summary, patients rated visual discomfort from the series of visual gratings. Plots of the rated discomfort were consistent with those expected from the literature for each of the stimulation methods (piercing or needles). At every stage we have sought to explore any effect of DP as placebo. With each element of our research it has become progressively more difficult to explain the effects as entirely placebo.

Popularity of Daith piercing

DP is generally only available in non-medical piercing studios, so it is difficult to assess the numbers performed. It was a rare piercing until news that it had an effect on migraines started spreading virally on the internet from March 2015. Blue Banana piercing studios have informed us (personal communication) that they have performed more than 32,000 DPs since May 2015, an average of 10 per week per clinic in each of their 13 UK clinics. Informal discussions with other clinics suggest that this is not atypical. Evidently large numbers of patients are seeking a DP from non-medical clinics.

Patients with migraine appear to be seeking a DP because routine medical treatments have not succeeded. Our online surveys of those with a DP record that 90% had previously seen their family doctor and 50% a neurologist before seeking a DP. Patients with a positive response are unlikely to seek the further advice of a neurologist, which may explain why neurologists rarely report successful outcomes, despite the large numbers of DPs being performed without medical supervision.

Placebo response.

Randomised placebo-controlled studies are the gold standard for assessing the effects of treatment, but are difficult to apply to an obviously visible intervention such as a DP, so other evidence must also be sought.

Quantifying a placebo response can be a challenge, especially in headache. In a 2002 meta-analysis (Van Der Kuy and Lohman, 2002) of 22 placebo controlled studies of 19 different prophylactic treatments for migraine it was concluded that no placebo response ever resulted in a reduction in mean attack frequency >40%, at least in the studies reviewed.

The decay of the placebo effect over time has also been explored (Sun *et al.*, 2013). The DP is given as a single procedure. If the response to DP were entirely placebo, we would suggest it reasonable to expect a decay in efficacy within a few months, and that there would be little or no placebo response from a single intervention remaining after a year.

Researchers of transcutaneous electrical stimulation of the ear have compared stimulation of the *cymba conchae* (innervated by the ABVN) with a control area (innervated by the non-vagal GAN). fMRI imaging showed that stimulation of the *cymba conchae* activated known vagal projections (including the solitary tract and the spinal trigeminal nucleus), but this did not occur with stimulation of the control area (Frangos, Ellrich and Komisaruk, 2015). Although there are no imaging studies of the effects of a DP, this study supports our choice of the antitragus as an inactive comparison (with Needle 1).

Our clinic patients attended with the specific intention of obtaining a piercing, having researched the topic on the internet. It is prudent to assume that their hopes of success were influenced by positive reports. However, online chat forums express mixed views - from great success, through temporary or no effect, to *a priori* statements that "it can't possibly work". Our patients generally saw it as "worth a try" because no other treatments had worked adequately, but did not generally expect success. During the consultation we made it clear that the DP is not effective for everybody, and patients were given the chance to either refuse treatment or delay it pending further thought.

Migraines and visual discomfort from gratings

The relationship between migraines and visual symptoms (including discomfort from patterns and flicker, as well as photophobia) is well established. The immediate reduction in discomfort from visual gratings following DP was unexpected and is difficult to attribute simply to the distraction/discomfort of

piercing. Stimulation with fine needles causes minimal pain and yet has a marked effect on visual discomfort, while needle stimulation of a non-vagal area had no effect at all. The modulation of visual discomfort is unlikely to be by direct action on the visual pathways, and instead points to other more general central mechanisms that are also associated with migraine.

The visual gratings used in this study were “strong” patterns in the following respects:-

1. They elicit visual distortions and discomfort, particularly in individuals with migraine (Marcus and Soso, 1989) or photosensitive epilepsy (Kasteleijn-Nolst Trenité and Parisi, 2012)
2. They are epileptogenic in patients with photosensitive epilepsy (Wilkins, Darby and Binnie, 1979)
3. They have the spatial frequency (2-4 cycles/degree) that produces the greatest cortical excitation in normal controls (Wilkins *et al.*, 1984).
4. They elicit high-amplitude evoked potentials and gamma activity in EEG and MEG studies (Adjamian *et al.*, 2004) and strong cortical haemodynamic responses in BOLD fMRI studies (Huang *et al.*, 2003)
5. Sleep deprivation (a recognised pro-convulsant) produces increased distortions in and discomfort from visual gratings (Wilkins *et al.*, 1984)-

All the above observations are consistent with other evidence that the visual cortex is hyper-excitabile in migraine (Aurora and Wilkinson, 2007). The reduction in pattern-induced discomfort by Daith piercing is consistent with a reduction in the hyper-excitability of the cortex, as occurs when vagal stimulation is used to treat epilepsy (Uthman, 2000).

Anatomy, embryology and neurophysiology of the innervation of the external ear, including the CNS connections

The sensory innervation of the external ear is supplied by four separate nerves, see Figure 1c and Figure 5a. The ABVN is particularly relevant because it innervates the superior and inferior surfaces of the *crus helix*, a fold of cartilage that the Daith piercing passes through. The origins and distribution of the ABVN and auriculo-temporal nerve (ATN), a branch of the trigeminal nerve (TGN), are both relevant and complicated.

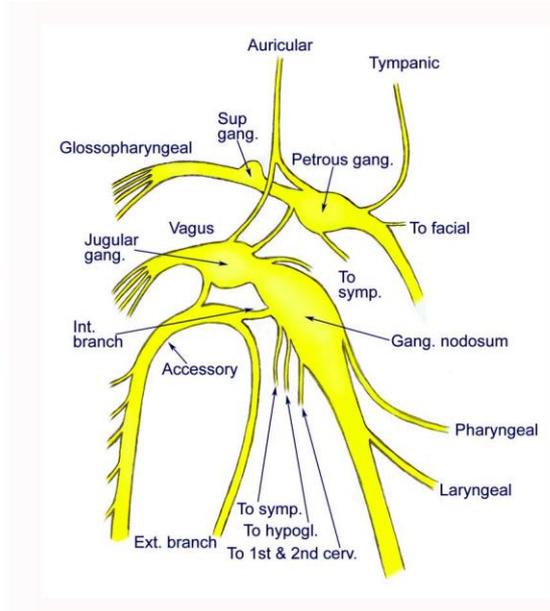
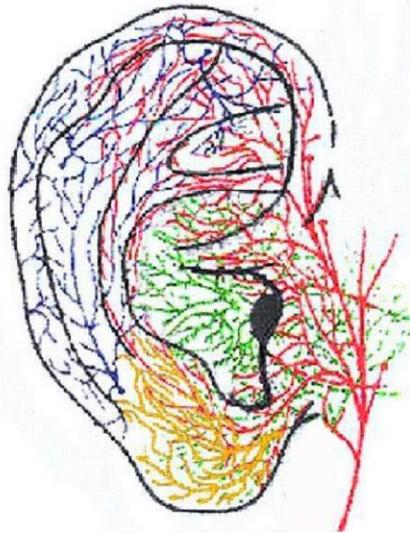


Figure 5a. Schematic innervation of external auricle the auricular branch of the vagus nerve showing the ABVN in green (CN X), the auriculotemporal nerve (ATN) in red (CN V3), the lesser occipital nerve (LON) in blue (C2), and the great auricular nerve (GAN) in yellow (C2-3). b From Gray's Anatomy Adapted from reference (He *et al.*, 2012).

Embryology of peripheral innervation of the external ear

The detailed sensory innervation of the external ear has been described by several authors (Peuker and Filler, 2002; He *et al.*, 2012; Bermejo *et al.*, 2017) each with small differences. Embryologically, both the sensory neurons and the auricular cartilage originate from neural crest cells. The upper antero-superior parts of the auricular cartilage (including the *tragus*, *crus helix* and *cymba conchae*) originate from the neural crest cells that migrated into the 1st arch, whereas the lower postero-inferior parts below the *crus helix* (including the *cavum conchae* and *antitragus*) arise from the 2nd arch neural crest cells (Anthwal and Thompson, 2016). The auditory meatus originates from the ectodermal 1st cleft between the two arches, and the eustachian tube/middle ear from the endodermal 1st pouch.

The name ABVN suggests vagus root origins but it is a complex mixture of fibres related to the facial nerve (CN 7) - 2nd arch, the glossopharyngeal nerve (CN 9) - 3rd arch, and the vagus nerve - 3rd & 4th arches. The complexity is illustrated schematically in Figure 5b. The TGN (CN 5) develops entirely from the 1st arch.

The ABVN has fibres originating from both the glossopharyngeal nerve (CN 9) and the vagus nerve (CN 10). It then passes around or through the mastoid process, where a small branch joins from the facial nerve (CN 7). After reaching

the posterior surface of the external ear (which it innervates), it passes through the auricular cartilage in line with the division between embryological origins of the upper and lower parts to reach the anterior surface in the *cavum conchae*. Fibres which are applied closely to the cartilage then spread out to innervate the *cymba conchae* above the *crus helix*, and the *cavum conchae* below. Fibres also extend to innervate the posterior wall of the auditory canal, and some reach the posterior surface of the *tragus*. The boundaries of the areas supplied by the ABVN and ATN are particularly indistinct, with extended overlapping in poorly defined watershed areas. There is considerable individual variation between the boundaries of the areas innervated by these nerves.

The distinction is clearer for the area innervated by cervical root nerves (supplying the LON and GAN) in the lower ear (see Figure 5a). We chose the *antitragus* as an inert reference comparison point because it is both cartilaginous and innervated solely by the GAN originating from spinal roots C2-3 (Peucker and Filler, 2002). The ear lobe itself has no cartilage.

Central neuronal connections to the brainstem - The ABVN and ATN both contain a mixture of large diameter myelinated and small diameter minimally myelinated or un-myelinated fibres, with the ABVN fibres passing the brainstem. Nomura has confirmed histologically that the ABVN projects to both the solitary and trigeminocervical tracts and other areas in the brainstem (Nomura and Mizuno, 1984). Henssen has written an extensive review of these dense interconnections (Henssen *et al.*, 2019). Using fMRI, Frangos confirmed in humans that transcutaneous electrical stimulation of the area of the ear innervated by the ABVN produced changes in activity in mid-brain and brainstem, whereas similar stimulation of the antitragus/earlobe (innervated from C2-3) had no such effect (Frangos, Ellrich and Komisaruk, 2015). Bermejo discusses the evidence that the effects of electrical stimulation are via the large myelinated and not the unmyelinated fibres (Bermejo *et al.*, 2017). It is possible but as yet unconfirmed that unmyelinated fibres are directly stimulated by irritation from a DP.

Potential mechanism of action

Invasive electrical stimulation of the vagus nerve reduces cortical excitability in epilepsy and is used to treat both epilepsy (Uthman, 2000) and intractable migraine. Transcutaneous electrical stimulation of the auricular branch of the vagus nerve is used to treat migraines (Gu *et al.*, 2018) and has also been shown to have an effect on epilepsy (Yuan and Silberstein, 2016). Visual discomfort from grating patterns is thought to reflect cortical excitability in migraine (Huang *et al.*, 2003). The location of the piercing is important. No other ear piercing

(including tragus piercing) has been associated with migraine reduction, in line with the reduced or absent innervation by the ABVN.

The immediate reduction in symptoms and visual discomfort after needle stimulation or DP is therefore consistent with vagus nerve stimulation from sensory nerve irritation, and an associated reduction in cortical excitability. Cosmetic ear piercings through cartilage (of which DP is only one), are routinely performed in piercing studios. It is uniformly recognised that they are slow to heal because blood supply to cartilage is low and epithelialisation along the track of the piercing is slow. Low-grade inflammation can continue for several months and is routinely managed by piercing studios.

Problems/side effects/infection rate

A DP is not easy to perform and requires experience and technical expertise.

Piercing studios have been piercing ear cartilage for many years and are generally well versed in offering aftercare regimes:-

1. Immediate effects – Unlike cervical VNS (invasive or transcutaneous) the DP stimulates afferent fibres only, so no direct effect on the heart from stimulation of vagal efferents would be expected, and none are reported. Perhaps surprisingly, most report little or no pain during piercing.
2. Short term effects - primarily related to discomfort and care with sleeping.
3. Longer term effects – It is common to experience irritation and crusting around the piercing for 1-3 months and occasionally longer. Nevertheless infection requiring medical intervention is largely avoidable by cleanliness regimes. Infection necessitating piercing removal is uncommon, but the risk of potentially serious infection requiring antibiotics must not be ignored, and must be taken into account in aftercare.

Conclusion

DP is potentially an inexpensive, safe and effective migraine treatment that can be rapidly introduced. Further research on a larger cohort of migraine patients is required.

We are currently collaborating on a 12 month observational follow-up of customers who have chosen to have a Daith piercing for their migraines, with Blue Banana, a national chain of piercing studios in the UK who perform up to 200 Daith piercings a week, many of them in migraine sufferers.

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