Pattern of breathing during cigarette smoking

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Summary

1. Recordings were made of the pattern of breathing during and after smoking a cigarette in 14 smokers and nine non-smokers.
2. The most consistent effect was an increase in tidal volume during smoking which reverted to baseline over 1–2 min. Changes in breath times were smaller and less consistent. Similar effects were observed with intermittent inhalations of charcoal.
3. In four subjects the tidal volume response was significantly decreased by oropharyngeal and laryngeal anaesthesia with lignocaine.
4. Filtration of particulate matter from the cigarette smoke delayed the onset of changes in tidal volume.
5. The changes probably represent an irritant response with stimulation at laryngeal or oropharyngeal level.

Key words: breathing patterns, charcoal, cigarette smoke, irritant response.

Introduction

In animals the introduction of irritant substances into the respiratory tract produces both airway narrowing [1] and changes in the pattern of breathing characterized by a decrease in tidal volume and an increase in respiratory frequency [2]. Airway narrowing has also been demonstrated in man although the prevalence varies between different studies. Each inhalation of cigarette smoke appears to produce transient airway narrowing maximal within 15 s and usually lasting less than 1 min [3]. If cigarette smoke produces a reflex irritant effect in the airways at or below the larynx then a rapid shallow pattern of breathing would also be expected, as in the animal studies.

We have looked for evidence of an irritant effect of cigarette smoke in young male smokers and non-smokers by recording the pattern of breathing during and immediately after smoking a cigarette. The responses have been further investigated by filtering particulate matter from the cigarette smoke and assessing the response to a particulate irritant, activated charcoal [1]. In four subjects cigarette smoke was inhaled after local anaesthesia of the oropharynx to elucidate the site of stimulation for changes in the breathing pattern.

Methods

Subjects

Fourteen smokers and nine non-smokers were studied. All subjects were male and aged between 20 and 30 years. Smokers had consumed at least 15 cigarettes/day for more than 1 year, whereas non-smokers had never smoked as much as one cigarette/day for 1 year. Subjects were studied in a quiet room while relaxing in a chair with the backrest set at 45°; they were unaware of the purpose of the experiments.

Recordings

To avoid the effects of a mouthpiece and noseclip on breathing patterns [4] tidal volume and breath duration were measured by magnetometers [5]. In most studies a single central pair of coils was used which provides an adequate measurement of tidal volume and breath duration in the position in which the subjects were studied [6]. A volume calibration was performed against...
an integrated pneumotachograph signal at the beginning and end of each smoking period. Recordings were begun after the subject had been sitting in the chair for 5–10 min and the pattern of breathing had been observed to be regular. Baseline measurements were then made for 3 min followed by 3 min intermittent exposure to cigarette smoke or charcoal and 3 min after.

**Unlit cigarette**

The usual procedure of cigarette smoking involves drawing a volume of smoke from a cigarette (the 'puff'), holding this in the mouth for 1–2 s and then inhaling the smoke together with inspired air (the 'inhalation') [7]. In an attempt to assess the effect of these manoeuvres on the pattern of breathing, nine smokers and five non-smokers were studied with the cigarette unlit. They were asked to draw on the cigarette approximately every 30 s and inhale as they would if the cigarette were lit. Depth of inhalation was measured by the magnetometers to ensure that procedures with lit and unlit cigarette were comparable.

**Cigarette**

In 14 smokers and nine non-smokers the effects on breathing pattern of smoke from a filtered middle-tar cigarette (Embassy Filter) were assessed. After the baseline recordings subjects were given a lighted cigarette and asked to smoke in their normal manner, the only constraint being that they should take a 'puff' of smoke approximately every 30 s. At the end of 3 min the cigarette was taken from the subject.

**Filtration of particulate matter**

In three smokers and three non-smokers the effect on changes in pattern of breathing of removing particulate matter from the smoke was assessed. This was done with a Cambridge filter pad which removes more than 99% of particulate matter from cigarette smoke [8]. Each subject smoked a cigarette with and without a Cambridge filter, the order being randomized.

**Local anaesthetic**

In four subjects (three smokers, one non-smoker) the response to a cigarette was assessed after oropharyngeal lignocaine. In two subjects lignocaine anaesthesia consisted of gargling for 30 s with 5 ml of 2% (w/v) lignocaine on two occasions with an interval of 1 min. In the other two, in addition, a pledget of cotton wool soaked in 4% (w/v) lignocaine was held in each pyriform fossa for 1 min to block the superior laryngeal nerves which supply the laryngeal mucous membrane down to the vocal cords. The changes produced were compared with those produced in the same subjects on smoking a cigarette without local anaesthesia on a separate day at approximately the same time.

**Charcoal**

In seven subjects (four smokers, three non-smokers) breathing patterns were recorded before, during and after intermittent inhalation of granular charcoal. The charcoal had a wide range of particle sizes with an average diameter of around 5 μm. A slow inhalation was taken approximately every 30 s from a flask containing the charcoal. Each subject performed a similar manoeuvre with an empty flask to assess the effect of the mouthpiece alone; the order of charcoal and empty flask was randomized.

**Analysis**

To assess the variation of the baseline tidal-volume measurements the coefficient of variation (SD divided by the mean) was calculated for each subject by using the mean values for each of the 3 min of baseline before smoking. Mean values of tidal volume, inspiratory time and expiratory time were calculated for each minute of baseline recording, each minute of exposure to smoke and for each of the following 3 min. These parameters in each period were found to approximate to a normal distribution and the mean values for each minute were compared with baseline values by Student's paired t-test. The depth of inhalation in control and exposure periods were similarly compared. In the local anaesthetic and Cambridge filter experiments changes in tidal volume with and without anaesthetic or filter were compared each minute by paired t-tests for the whole group of subjects used.

Augmented or sighing breaths, which we defined as greater than three times the mean tidal volume, were uncommon and not increased during or after smoking. Such augmented breaths were excluded from the analysis.

**Results**

**Unlit cigarette**

The mean changes in tidal volume, inspiratory time and expiratory time for 14 subjects during
Breathing pattern during smoking

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FIG. 1. Percentage changes in tidal volume and breath durations in 14 subjects (nine smokers, five non-smokers) during and after 3 min 'smoking' of an unlit cigarette. Each point represents the mean value for 1 min + S.E.M. (a) Tidal volume; (b) inspiratory time; (c) expiratory time. Baseline values are taken as the mean of 3 min before 'smoking'.

and after 'smoking' an unlit cigarette are shown in Fig. 1. Mean changes during the dummy smoking period were less than 8% from baseline in all three measurements. There were no significant changes from baseline in tidal volume or breath durations. Depth of inhalation was similar to that for subjects when the cigarette was lit (713 ml unlit, 718 ml lit).

The mean coefficient of variation of tidal volume for all subjects for the 3 min before smoking was 5.4% and the greatest coefficient of variation over these 3 min was 12.3%.

Cigarette

The most consistent change produced by smoking a cigarette was an increase in tidal volume, maximal during smoking and returning to baseline levels over the next 3 min. Mean changes in tidal volume and breath durations are shown in Fig. 2. Breath duration showed a tendency to increase, but the only significant change was an increase in expiratory time for the first minute of smoking in smokers ($t = 2.68$, $P < 0.025$). However, tidal volume increases were significant ($P < 0.05$) in smokers and non-smokers for all 3 min of smoking and for the first minute after in non-smokers.

FIG. 2. Percentage changes in tidal volume (a) and breath duration (b, c) from baseline in 14 smokers (○) and nine non-smokers (●) during and after cigarette smoking. During the smoking period subjects drew smoke from the cigarette approximately every 30 s. Each point represents the mean value for breaths in that 1 min + S.E.M.
Several non-smokers felt an irritant sensation during smoking which they localized to the back of the pharynx. Such sensations were not reported by smokers.

One smoker and one non-smoker performed this procedure with a lit cigarette on three occasions each. A similar pattern of changes was seen on each occasion and the coefficient of variation of the changes in total volume during the 3 min of smoking was 33% in the smoker and 31% in the non-smoker.

Filtration of particulate matter

With a Cambridge filter in position to remove particulate matter significant changes from baseline were seen only in tidal volume. The onset of these changes appeared to be slower (Fig. 3) and they were significantly less during the first minute of smoking ($t = 3.13, P < 0.05$). Changes in breath duration were, once again, smaller, more variable and insignificant.

Local anaesthesia

After pretreatment with lignocaine changes in tidal volume over the 3 min of smoking were significantly less than those in the same subjects without lignocaine (Fig. 4; $t = 2.60, P < 0.025$). Lignocaine decreased the sensation of irritation on smoking in the one non-smoker, but smokers reported no change in their usual sensations on smoking.

Charcoal

The changes found in five subjects after inhalation of activated charcoal were similar to those seen with cigarette smoke. There were only small changes in breath duration while tidal volume was significantly increased during first and third minutes of exposure and the first minute after (Fig. 5). Tidal volume changes with an empty flask were negligible (Fig. 5), although depth of inhalation was greater than that with charcoal in the flask (1069 and 709 ml respectively).
Discussion

When cigarette smoke is inhaled deeply it is possible to demonstrate airway narrowing several minutes later [9] lasting up to 1 h. When a cigarette is smoked in an unconstrained fashion there are a wide range of responses related, among other factors, to depth of inhalation [10]. However, each inhalation probably produces a transient bronchoconstriction [3] indicating that irritant effects of cigarette smoking are most likely to be detected immediately after inhalation of smoke.

The most consistent change found in this study was an increase in tidal volume after inhalation of cigarette smoke and charcoal. Although tidal volume is subject to a degree of spontaneous variability the changes seen during smoking were considerably greater than the variation in tidal volume during the 3 min of baseline recording before smoking. Changes in duration of inspiration and expiration were small, usually a slight increase. All effects disappeared over 1 or 2 min after 3 min of intermittent exposure. The pattern was similar in smokers and non-smokers with greater changes in non-smokers although their depth of inhalation was smaller. Although subjects were encouraged to relax as much as possible the manner of smoking in a laboratory is likely to be different from a social situation [11]. However, depth of inhalations was similar to that found in previous studies [7]. The results of Gupta & Tandon [12] also suggested a slight increase in tidal volume after smoking in 40 non-smokers.

Airway narrowing in man can be produced in response to both particulate and gaseous phases of cigarette smoke [13]. Charcoal is an inert particulate substance with a larger range of particle sizes than cigarette smoke. A similar pattern of changes in tidal volume was produced by inhalation of charcoal, indicating the possibility that the immediate responses may be produced by the particulate element of the smoke. However, removal of particulate matter by a Cambridge filter only seemed to delay the onset of the changes, suggesting that the gaseous phase produces similar effects, but that the response is slower.

In experimental animals mechanical or chemical irritation of the respiratory tract results in a decrease in tidal volume with an increase in respiratory rate [2, 14]. Similar changes have been seen with dust exposure in man [15]. The effects of laryngeal irritation depend on the strength of the stimulus: strong stimuli producing a decrease in tidal volume and respiratory rate while weaker stimuli produce an increase [16]. The intensity of the stimulus needed to change the breathing pattern is less for the larynx than for lower airways [17].

If the changes in tidal volume which we have found are an irritant response then they may well originate at an oropharyngeal or laryngeal level. The concentration of irritant substances reaching the airways may be too low to induce the rapid shallow breathing observed in animals. Volumes of inhalation in smokers were approximately twice the tidal volume. In conscious man lung inflation usually produces an increase in tidal volume ([18]; P. J. Rees & T. J. H. Clark, unpublished work). It was for this reason and to avoid the effects of a mouthpiece [4] that we included a control period with an unlit cigarette and mouthpiece alone. Changes seen in this control period were small and the inhalation procedure itself is, therefore, unlikely to contribute significantly to the changes seen with cigarette smoke and charcoal (Fig. 1).

The possibility that the changes observed were a result of conscious influence is unlikely in view of the blocking effects of lignocaine. A sensation of irritation during smoking was only reported by non-smokers. Although smokers appear to have lost the conscious sensation of irritation produced by cigarette smoke they are still susceptible to the airway narrowing [3] and to changes in the breathing pattern demonstrated here.

In asthmatic patients it has been suggested that oropharyngeal anaesthesia may attenuate exercise-induced bronchoconstriction [19]. This is thought to act by decreasing the stimulus of cold air in the pharynx. In two subjects we deliberately attempted to anaesthetize down to the level of the larynx. In the other two who gargled lignocaine this may well have reached the larynx and so oropharyngeal and laryngeal anaesthesia could not have been differentiated. The decrease in response in four subjects after lignocaine suggests that part of the stimulus of the irritant substances originates at oropharyngeal or laryngeal level.

The physiological significance of an increase in tidal volume in response to irritants is not clear. The increased tidal volume would draw an irritant substance further into the lungs although the increased inspiratory flow rate would tend to deposit particulate matter high in the bronchial tree especially if it were associated with airway narrowing. There might be similarities to the aspiration reflex elicited from the epipharynx which is probably designed to clear the upper airways [20]. In cigarette smoking the changes will have little direct effect on smoke exposure,
which is dependent on the characteristics of puff and inhalation. However, the presence of an irritant effect during smoking might influence the way in which the cigarette is smoked and might potentially be adjusted to moderate exposure to other harmful elements of the cigarette smoke.

We believe that these results confirm the presence of an irritant effect of cigarette smoke and charcoal dust which is manifest during and immediately after exposure and disappears over 3 min from the time of exposure. Similar effects may explain the slower deeper breathing found on exposure to orthochlorobenzylidene malonitrile (CS) gas [21]. The nature of the change in breathing pattern and blockade by local anaesthetic make it likely that the stimulation is from the oropharynx or larynx. These sites are exposed to the maximum intensity of stimulus and changes from the larynx are initiated at a much lower irritant dose than from the lower airways.

References