ORIGINAL ARTICLE

Computed tomography versus bronchography in the diagnosis and management of tracheobronchomalacia in ventilator dependent infants

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Aim: To assess the relative accuracy of dynamic spiral computed tomography (CT) compared with tracheobronchography, in a population of ventilator dependent infants with suspected tracheobronchomalacia (TBM).
Setting: Paediatric intensive care unit in a tertiary teaching hospital.
Patients and methods: Infants referred for investigation and management of ventilator dependence and suspected of having TBM were recruited into the study. Tracheobronchography and CT were performed during the same admission by different investigators who were blinded to the results of the other investigation. The study was approved by the hospital research ethics committee, and signed parental consent was obtained.
Results: Sixteen infants were recruited into the study. Fifteen had been born prematurely, and five had cardiovascular malformations. In 10 patients there was good or partial correlation between the two investigations, but in six patients there was poor or no correlation. Bronchography consistently showed more dynamic abnormalities, although CT picked up an unsuspected double aortic arch. Radiation doses were 0.27–2.47 mSv with bronchography and 0.86–10.67 mSv with CT.
Conclusions: Bronchography was a better investigation for diagnosing TBM and in determining opening pressures. Spiral CT is unreliable in the assessment of TBM in ventilator dependent infants. In addition, radiation doses were considerably higher with CT.

Neonatal and paediatric intensive care units often encounter infants who are difficult to wean from ventilatory support. A combination of factors may be responsible, such as neuromuscular weakness, cardiac failure, or chronic lung disease. However, in preterm infants with chronic lung disease, tracheobronchomalacia (TBM) may cause an important additional problem, often presenting with sudden cyanotic episodes, wheezing, and poor chest wall expansion (bronchopulmonary dysplasia or BPD "spells").[1 2] These episodes are often managed by an increase in ventilatory support and the need for muscle relaxants.

The diagnosis of TBM requires dynamic assessment of the trachea and bronchi, with demonstration of collapse of the airway in expiration.[3] Bronchoscopy has been used widely to investigate airway pathology in all age groups. However, bronchoscopy is particularly difficult in this group of patients with borderline lung reserve and small airway diameter, and potential limitations, such as splinting of the lesion by the bronchoscope or positive pressure, have been identified.[3 4] Bronchography has therefore been recommended for the investigation of TBM and congenital abnormalities of the airways.

At our institution bronchography is considered to be the optimum imaging method for infants with suspected TBM. Quantification of the degree of TBM by this method has been shown to be important in management and also to be closely correlated with morbidity.[5 6] Bronchography in small babies, however, requires some expertise and is time consuming. It is also potentially hazardous in this population with poor lung function and a tendency towards apnoeic episodes, and therefore not widely practised.

In recent years, dynamic computed tomography (CT) has emerged as a promising imaging modality for upper airway pathology in all age groups.[7–10] It is a time efficient imaging method and it is non-invasive as there is no requirement for endobronchial contrast. Many of these patients require chest CT as part of the investigation of their ventilator dependence, and we were interested in the advantage of obtaining adequate information from one investigative procedure. With the widespread availability of spiral and newer generation CT scanners in many hospitals, the advantage would be that the investigation could be performed locally without the need to transfer the child, with all the attendant risks. Spiral CT scanners are gradually being replaced by faster multidetector CT scanners, which will be capable of shorter data acquisition time (faster scans), longer scan ranges (allowing more of the body to be scanned), and smaller sections (thinner scans).[11] We wanted to assess the relative accuracies of dynamic CT and bronchography, and in addition work out the radiation dose implications of the two procedures.

PATIENTS AND METHODS

Sixteen infants who were referred to the intensive care unit for investigation and management of their ventilator dependence and who were suspected of having TBM were recruited into the study. The suspicion of TBM was raised by an inability to wean from ventilatory support and frequent occurrences of cyanotic spells when agitated. They were

Abbreviations: CPAP, continuous positive airway pressure; CT, computed tomography; PEEP, positive end expiratory pressure; TBM, tracheobronchomalacia

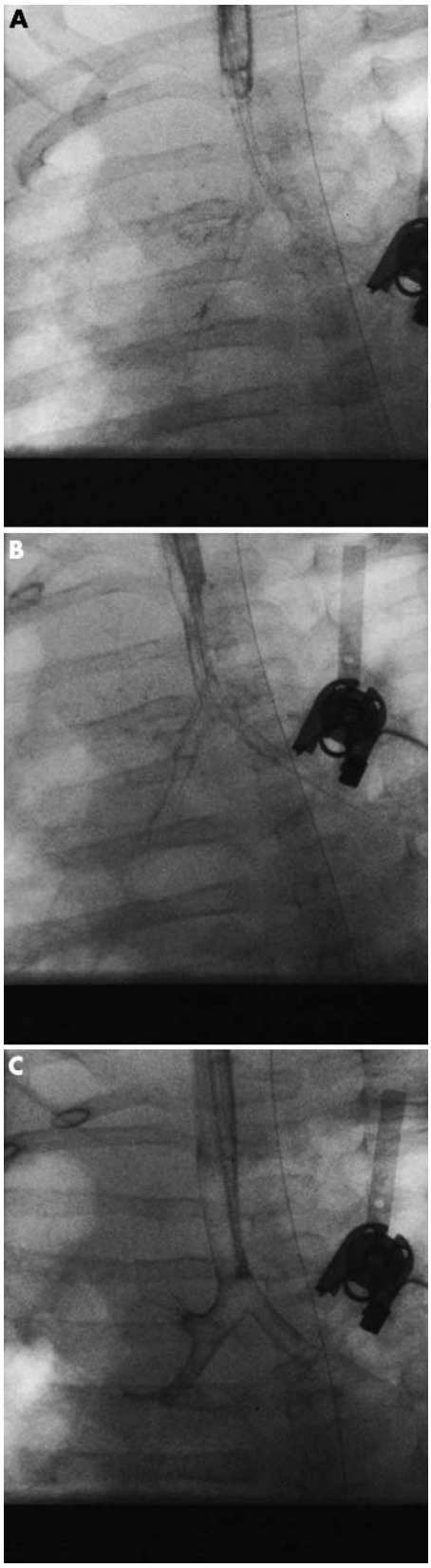

Figure 1 Tracheobronchogram showing tracheobronchomalacia, and the effect of different levels of positive end expiratory pressure (PEEP). (A) PEEP = 0; (B) PEEP = 5 cm H_2O; (C) PEEP = 15 cm H_2O.

typically ex-preterm infants who were on minimal ventilatory support for their lung disease, but requiring continuous positive airway pressure (CPAP) or reinstitution of ventilation with a high positive end expiratory pressure (PEEP). The study was approved by the hospital ethics committee, and signed parental consent was obtained. Spiral CT and bronchographic images were obtained during the same admission for each infant according to the protocols detailed below. They were performed in no particular order of preference by different investigators who were blinded to the results of the other investigation. A series of two to five different CPAP settings were used to quantify the TBM seen. The measured pressure required to overcome the malacia (opening pressure) is defined as the pressure support needed to open the airways to 75% patency, as we considered collapse in expiration of up to 25% acceptable. Bronchography was assumed to be the yardstick.

Bronchography protocol

The investigations were performed by one of two authors (CM, DR) in a digital angiography suite, with the patient positioned supine. The contrast used was iotrolan (Isovist; Schering, Burgess Hill, Sussex, UK) at an iodine concentration of 240 mg/ml. This was injected into the endotracheal tube through a 4-French nasogastric tube inserted through an airtight connector. Aliquots of approximately 0.2 ml were used, to a maximum of about 1.0 ml, as previously described.[3] The endotracheal tube was withdrawn into the upper trachea, using fluoroscopic guidance. Images were obtained with different levels of CPAP, with the patient breathing spontaneously above this level of CPAP throughout the study (fig 1). The images were acquired at 6–7.5 frames per second for about three to five seconds in posteroanterior and lateral projections.

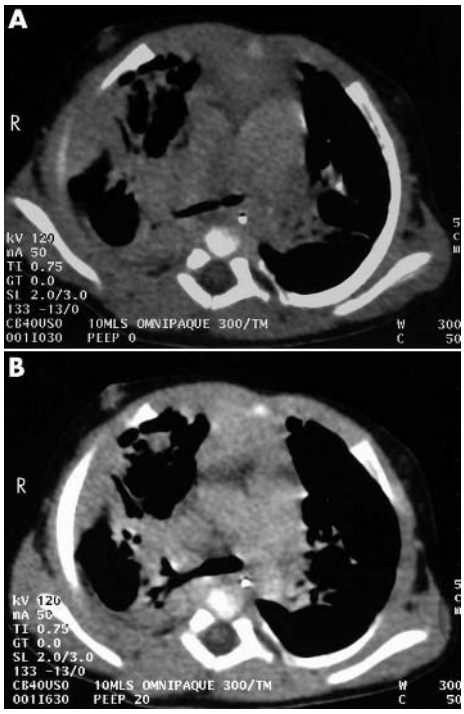

Figure 2 Computed tomography of the same patient as in fig 1 showing bronchomalacia at (A) positive end expiratory pressure (PEEP) of 0, which was overcome by (B) PEEP of 20 cm H_2O.

CT protocol

A Somatom Plus4 (Siemens, Erlangen, Germany) spiral scanner was used. For the first dynamic contiguous CT acquisition, iohexol (Omnipaque 300; Nycomed Imaging, Oslo, Norway) was injected intravenously at a dose of 2 ml/kg, and scanning was started 10 seconds after completion of the injection. Images were acquired from just above the tip of the endotracheal tube to the level of the lower lobe bronchi, using 2 mm collimation, a pitch of 1.5, and a scan time of 0.75 second per rotation. The patient was breathing spontaneously above a level of CPAP, and the study started at the level of PEEP or CPAP on which the patient had been maintained in the intensive care unit. If there was evidence of narrowed airway on CT, the CPAP was increased by 10 cm H_2O, and the scan was repeated without contrast, limiting the CT scanning slices to suspected areas of abnormality from the first acquisition. If airway narrowing persisted, the CPAP was increased in 10 cm H_2O increments (to a maximum of 30 cm H_2O), and images were acquired at each level (fig 2). If the trachea and major bronchi were normal at the initial study, images were acquired at zero PEEP to determine if there was airway malacia without pressure support. Two or three acquisitions were usually adequate, with a maximum of four. All CT studies were performed with contiguous sections (continuous volume acquisition with no intersection gaps), and not with non-contiguous high resolution sections normally used to study detail in the lung parenchyma, in which typically 1 mm sections are taken with gaps between slices of 9 mm or more. All the studies were performed at the lowest tube current (50 mA) possible on our CT scanner.

Statistical analysis was performed using the sign test, which assumes equal sensitivity between the two tests.

Radiation dose parameters were analysed by an independent physicist, from data collected at the time of the investigations. Effective dose was calculated for the CT studies using standard assumptions of patient weight and both lateral and posteroanterior dimensions, by the method of Huda *et al*.[12] Effective dose for bronchography was calculated using the PCXMC software.[13]

RESULTS

Sixteen infants were recruited into the study. Fifteen were born prematurely, with gestational ages of 24–35 weeks (median 31 weeks). Five had cardiopulmonary malformations, although the cardiac defects had been previously surgically corrected. The infants were aged 1–10 months (median 3.5 months) at the time of the study. The two investigations were performed within two days of each other in 12 infants, but imaging occurred within four days in three infants and delayed up to 16 days apart in one infant because of intercurrent illness. In nine patients, the bronchogram was performed before the CT; the sequence was reversed in the remainder. The order of, and time interval between, the tests had no influence on the results.

We analysed whether there was agreement in the diagnosis of malacia in the trachea and bronchi and also in the opening pressure between CT and bronchography (table 1). Agreement was considered partial when malacia was detected but the opening pressure was underestimated by more than half. Agreement was partial or good in two thirds of the studies performed overall, although the opening pressures tended to be underestimated with CT. However, when the results were analysed by location of malacia, the agreement between the two procedures was better for tracheomalacia and poorer for bronchomalacia, where at least half of the cases showed no agreement between the tests. Bronchography showed more dynamic abnormalities, particularly of the left main bronchus. There was good agreement between bronchography and CT in two cases of focal tracheal stenosis. CT identified a previously unsuspected double aortic arch in one patient.

Statistical analysis was performed using the sign test, assuming equal sensitivity between the two tests. The p value was 0.03, which shows that there is significant evidence that the two tests were not equally sensitive ($p>0.05$ for equal sensitivity).

The effective radiation dose was 0.27–2.47 mSv for bronchography and 0.86–10.67 mSv for CT. The higher CT doses occurred in the studies with acquisitions at more levels of CPAP.

DISCUSSION

In patients with chronic lung disease or cardiac anomalies, TBM may be an important additional reason for difficulty in weaning from ventilatory support.[1 2] The diagnosis is important, as the management can be tailored to minimise frequent respiratory collapses and the need for reventilation, with concomitant complications.[3]

TBM may be focal or diffuse, and results from softening of the tracheal and/or bronchial cartilages with development of flaccid airways with abnormal compliance. The exact pathophysiology for this is unclear. In some patients, TBM may be primary, and is due to a congenital abnormality of the tracheobronchial cartilages. In the group of patients we have studied, TBM is more likely to be secondary to associated cardiorespiratory pathology. Degeneration of previously normal cartilage may occur after a long period of ventilation in premature infants with respiratory distress syndrome. Secondary TBM may also occur in patients with cardiovascular anomalies as a result of external compression by structures such as vascular rings.

The diagnosis of TBM requires a dynamic assessment of the trachea and bronchi throughout the respiratory cycle, with demonstration of collapse of the airway in expiration. Because of their invasive nature, investigations for structural and dynamic abnormalities of the airways tend to be among the last tests performed when the infant fails to progress off ventilatory support. However, it is important for management to confirm the diagnosis and to determine accurately the level

Table 1 Number of patients in whom malacia was detected by tracheobronchogram (TBG) and computed tomography (CT)

	Trachea	Right main bronchus	Left main bronchus
Malacia detected by TBG	16	14	14
Malacia detected by CT; pressure concordant	8	6	5
Malacia detected by CT; pressure discordant	2	1	2
Malacia missed by CT	6	7	7
Malacia absent on TBG	0	2	2
Malacia absent on CT	0	2	2

of pressure support required to overcome the airway collapse. Quantification of the degree of TBM using bronchograms has been shown to be correlated closely with morbidity and mortality and aid in subsequent management of children in intensive care.[5 6]

Bronchoscopy has been used widely to investigate airway pathology in all age groups, but several investigators have highlighted limitations such as splinting of the lesion by the bronchoscope or the generation of positive pressure, resulting in false negative results.[3 4] Even with the newer generation of smaller flexible bronchoscopes, it is likely that this will remain a problem. The poor respiratory reserve in these infants makes it a difficult technique to perform, especially when the airway is almost entirely obliterated by the bronchoscope. Bronchography can be performed safely in intubated patients with minimal respiratory compromise. It is capable of showing both structural abnormalities and segments of airway malacia, as well as making an assessment of the airway dynamics, to determine the pressure required to maintain airway patency.[3] Non-ionic contrast agents are used, which have not been reported to cause complications such as atelectasis and pneumonitis. In this difficult group of patients with borderline lung reserve and small airways, we generally recommend bronchography for the investigation of TBM.

Dynamic CT can also be used to obtain this information, but the sensitivity of this imaging modality in this particular population was unknown. As most of these patients will have chest CT at some stage, we performed the investigation with the hope that it would be possible to obtain all the information from one study, reducing radiation exposure and the need to transfer the patient to fluoroscopy for additional bronchography. We found, however, that dynamic CT is less useful for showing distal airway malacia, and often underestimated the opening pressure required for management of the patient, although it is superior at revealing pulmonary and vascular pathology. The radiation doses were also significantly higher with CT than bronchography, despite a low dose (low mA) CT technique. Even in this limited study, spiral CT appears to be an insufficiently sensitive method for the investigation of TBM in ventilator dependent infants. This is probably because a CT tube rotation time of 0.75 second is too long for truly dynamic evaluation of the airways. Multidetector CT scanners are now becoming widely available. They are likely to provide superior images in this context, possibly with a lower radiation burden because of dose modulation, but this remains to be proven. Electron beam CT scanners are not widely available in paediatric centres.

It is unlikely that the general lack of agreement between the two studies was because they were performed on different days, as TBM takes months to resolve. An alternative explanation for the higher number of abnormalities seen with bronchography may be the invasive nature of the test. It is possible that instillation of contrast into the airway may provoke increased respiratory effort, which would lead to an appearance of collapse in airways that were susceptible to malacia, whereas CT poses no challenge to the tracheobronchial tree. This is unlikely to be the entire explanation as numerous bronchographic studies have now been performed by our team, and normal results with no evidence of TBM are seen in children who do not have malacic airways. This also would not explain the poorer agreement between the two modalities for diagnosing bronchomalacia than for diagnosing tracheomalacia. It is likely that the bronchi are so small that differences in diameter are less evident on CT than on bronchography.

On the other hand, we found that bronchography is capable of showing both structural abnormalities and malacic segments. It permits an assessment of the airway dynamics and determination of the pressure required to maintain airway patency. In addition, bronchography requires a lower effective dose of radiation. No complications of bronchography occurred during the study. It is possible that the good results and safety profile in our study are due to the experience of our radiology department with the technique of bronchography. The bronchograms were performed by a radiographer (CM) who had recently been trained in the technique. In the past five years we have performed over 500 bronchograms without major complications.[14] We believe that the technique can be taught and used in other paediatric radiology departments with similar results.

In conclusion, we continue to favour bronchography with varying CPAP when investigating small, ventilator dependent infants for TBM.

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