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Review

Chest Drains: Does Size Matter?

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Hippocrates first advocated pleural drainage 2400 years ago when he described the use of incision, cautery and metal tubes to treat empyema [1]. The technique became widely used during the influenza epidemic of 1917 to drain post-pneumonic empyema [2]. In recent years, large-bore drains have been the mainstay of treatment for percutaneous drainage of pleural collections and they remain in use for post-surgical thoracic drainage. Indications for tube placement within the chest include pneumothorax, benign and malignant pleural effusion, parapneumonic effusion and empyema, and haemothorax. Traditional surgical teaching dictates that viscous fluid collections require large tubes for successful drainage [3,4]. Recent publications suggest that a variety of pleural collections can be adequately drained using small-bore catheters, often inserted under imaging guidance, avoiding the complications associated with the 'blind' insertion of large-bore chest tubes. It is likely that the evidence supporting the use of small-bore drains within the abdomen and pelvis may be applicable in the chest. It is also possible, but perhaps less likely, that dissemination of this evidence may end the not infrequent assertion by clinicians that patients 'would have been better treated with a bigger drain'.

FACTORS INFLUENCING SUCCESSFUL DRAINAGE

For a fluid or air collection to be drained successfully the draining catheter needs to be of sufficient bore to allow adequate flow, to remain patent and for all or the majority of the collection being drained to be in communication with the catheter. It is also desirable to use the catheter that is the safest and most comfortable for the patient. A large-bore catheter would appear to fulfil the first two criteria best. However, review of the published evidence suggests that small-bore catheters are at least as effective as large-bore tubes, implying that other factors need to be considered. The distinction between a small and large-bore catheter is entirely arbitrary; for the purposes of this discussion we regard drains of up to and including 14-French (F) as small-bore, and above 14 F as large-bore.

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Tube Size

According to Poiseuille's law, the flow of a liquid through a tube depends on the internal diameter (D) and length (L) of the tube, the viscosity of the liquid (η) and the pressure difference between its ends (ΔP).

$$\text{Flow rate} = \frac{\pi}{128}\frac{D^4 \Delta P}{\eta L}$$

It follows that if the diameter of a tube is doubled, flow will increase by a factor of 16, implying that small increases in the size of drainage tubes will result in substantial improvements in flow rates. In an *in vitro* study Park *et al*. measured flow rates of different viscosity fluids (serous fluid, blood and pus) through catheters of different diameters, ranging from 6 to 18 F and found that flow rates increased for larger catheters as predicted by Poiseuille's law [5]. However, at catheter sizes above 7 F the differences were small. The addition of urokinase significantly decreased fluid viscosity and thus decreased drainage times.

Reports on drainage techniques suggest that, before drainage of a collection, diagnostic needle aspiration should be performed, initially via a 22G needle and, if this is unsuccessful, via a 20 or 18G cannula [6]. This has the dual purpose of determining the contents of the collection and guiding subsequent drain insertion. It has been postulated that if pus can be aspirated by such a needle it should be drainable through a catheter twice the size i.e. 6 F or above [7]. As such, if drain patency can be maintained (for instance by flushing or the use of suction) the maximum flow rate of the catheter is unlikely to be the limiting factor for most pleural collections. Although no comparative studies for pleural collections have been performed to date, two series have compared the effectiveness of different sized catheters for draining intra-abdominal abscesses [8,9]. Gobien *et al*. drained 51 abdominal abscesses with a variety of catheters ranging from 5 to 18 F [8]. Five patients initially had 5 or 6 F catheters inserted but these repeatedly blocked and had to be exchanged for larger catheters. Above 8.3 F, increasing catheter size did not improve outcome as defined by length of post-procedure fever, duration of drainage or overall technical success. Rothlin *et al*. retrospectively reviewed 64 patients with abdominal abscesses drained with either a 7 F pigtail catheter or a 14 F sump drain [9]. No

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significant difference was found in drainage success rates or drainage times. In a review of the literature, Park *et al*. assessed the effect of catheter diameter on abscess drainage from 25 studies and found that duration of drainage was shorter for smaller diameter catheters [5]. Although this appears counter-intuitive, it may reflect bias introduced by the operator's choice of smaller catheters for thinner pus, identified on initial diagnostic aspiration.

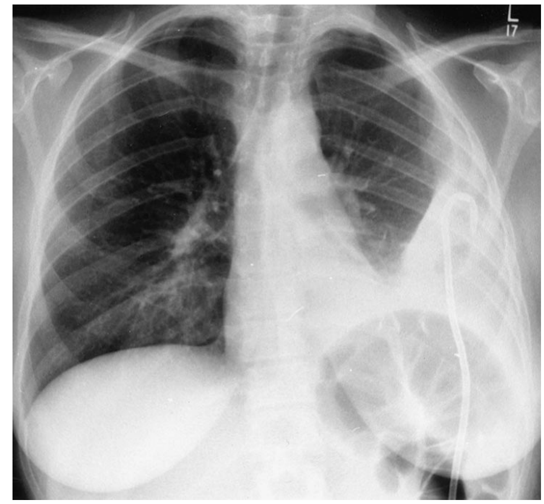
Further support for the use of small-bore chest drains is found in the extensive body of work using small-bore catheters to drain abdomino-pelvic abscesses, both as a primary treatment and as a temporizing measure prior to definitive surgery. Success rates compare well with surgical series, even in difficult areas such as the pancreas [6,10–12]. These studies suggest that pus can be adequately drained via small bore-catheters, although early advocates of abdominal abscess catheter drainage encountered considerable scepticism from surgical colleagues about the efficacy of these small catheters.

Tube Positioning

The success of radiological small-bore catheters must, in part, be due to better positioning within collections. Conventional chest-tubes are often inserted 'blind' at the bedside using only the chest radiograph for localization. Consequently, positioning is often suboptimal. In a retrospective review of 26 patients with empyema undergoing chest computed tomography (CT) for inadequate drainage via a large-bore chest tube, 21 of the tubes were malpositioned: eight in the major fissure, seven anterior, one posterior and one cephalad to the empyema, three within lung and one kinked at the chest wall [13]. (Two smaller series in patients with empyema have also made the obvious point that drains located within a fissure tend to be associated with poor drainage [14,15].) Baldt *et al*. found 26% of chest tubes inserted for thoracic trauma to be malpositioned and 16 of 20 such tubes (including seven of nine within fissures) functioned poorly [16]. In a similar clinical setting Curtin *et al*. found 58% of tubes to be intrafissural but this did not affect outcome [17]. Imaging-guided catheter insertion does not entirely avoid fissural placement, but accurate location of the catheter within the deepest part of the collection can be easily achieved [18]. Repeat imaging with catheter re-positioning and insertion of additional catheters if required can help to optimize drainage. The use of the Seldinger technique for insertion can allow safe drainage of very small collections where conventional trocar insertion may be hazardous [19].

Tube Design

Flexible small-bore catheters can change configuration in a collection as it decreases in size, so avoiding erosion into expanding lung or migration into a fissure (Fig. 1), unlike conventional chest tubes which are less flexible. If contact with pleura does occur, small-bore catheters have holes on the inside curve of the distal pigtail or 'J' which allow drainage to continue, unlike conventional chest tubes where side-holes on the straight tip may become occluded. Further design features may aid drainage in small-bore catheters and help to compensate for their smaller size. The catheters are made of proprietary polymers of high tensile strength, which allows extrusion into a



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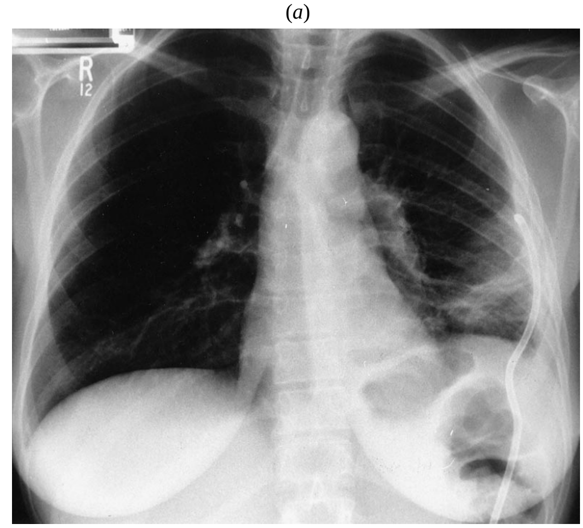

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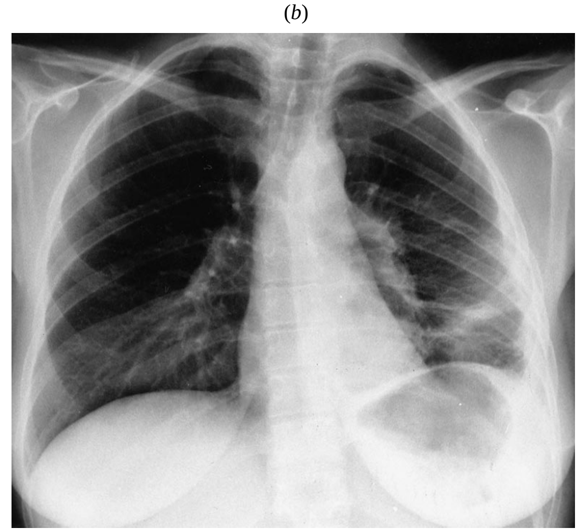

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Fig. 1 – (*a*) Pigtail catheter within moderate sized left parapneumonic effusion. (*b*) As the effusion decreases in size the catheter has moved laterally and re-orientated itself so that it remains within the deepest part of the collection. (*c*) Following catheter removal there is mild residual pleural thickening with volume loss and consolidation in the left lower lobe.

tube with a relatively high internal diameter relative to the outside diameter. Some catheters have a strengthening wire helix incorporated into the material which may allow this ratio to be increased further. The high tensile strength of these polymers also allows fashioning of large drainage holes along the shaft [20] and these are usually oval to increase the area available for drainage. Dissolvable tips are also available to maximize end-hole size. Kinking and deformation are prevented by the high strength of these materials and their possession of 'memory', the ability to resume their original configuration after distortion [20].

Tube Patency

Chest drains may become occluded by fibrinous debris or viscous pleural fluid. Small-bore catheters are more susceptible to this and maintenance of catheter patency is clearly vital for their effective use. Various authors recommend flushing with 10–100 ml of normal saline every 6 h to maintain patency [21–24]. This is readily achieved via small-bore catheters as they can be attached to a three-way tap to allow aspiration, flushing or suction without introducing air. It is more difficult with conventional chest tubes, which have to be repeatedly disconnected, increasing the risk of pneumothorax or infection. The use of intra-cavitary thrombolytic agents may also contribute to maintaining tube patency as they have been shown to decrease abscess fluid viscosity *in vitro* [5] and to increase volume of fluid drained by stimulating pleural fluid production in a rabbit experimental model of empyema [25].

Multiloculation and Septation

The presence of multiloculation or septation impairs drainage by preventing access of fluid to the draining catheter (Fig. 2), and can be problematic in empyema, haemothorax and malignant effusions. Non-communicating locules can be drained by placement of multiple catheters, following delineation by CT or ultrasound. The use of guide-wires during Seldinger insertion of catheters may help to break down septations, although evidence to support this is lacking. The mode of action of intrapleural fibrinolytics may be largely due to lysis or prevention of formation of septations; in a rabbit model there was a reduction in the number of interpleural adhesions in streptokinase-treated rabbits with empyema when compared to saline-treated controls [25]. Fibrinolytics have been shown to be effective in the treatment of empyema when tube thoracostomy alone has failed, and this is likely to be due to reducing septation [26–30].

SPECIFIC INDICATIONS

Parapneumonic Effusion and Empyema

The evolution of complicated parapneumonic effusion (CPPE) and empyema has been previously described [31,32] and it is now widely accepted that reduced pleural pH and the presence of pus or organisms are indications for drainage [3,33–35]. Once septations and a thick pleural peel have developed patients often require surgery. At present the optimal treatment of CPPE and empyema remains highly controversial and management varies widely. In this country and the U.S.A. the frequency of use of imaging-guided catheter drainage appears to be low [36,37]. Early surgical intervention has its advocates [38], but it is invasive and has a potential morbidity and mortality, particularly in a patient group with a high rate of co-existing serious pathology [39]. Newer, less invasive techniques such as video-assisted thoracic surgery (VATS) have also been shown to be effective [40]. In a randomized, controlled trial of VATS vs large-bore tube drainage with fibrinolytics, the former had a significantly higher primary treatment success [41]. However, the success rate for tube drainage was considerably lower than in other series, possibly due to the blind insertion of the 36 F drains in the non-VATS patient group.

Disappointingly, thoracostomy with conventional chest-tubes probably remains the most widely used initial treatment for CPPE and empyema. Many workers believe that large-bore tubes (often of 32 F and above) are necessary, particularly for the drainage of thick pus [32]. Although there are no randomized, controlled trials comparing large and small-bore catheters, there

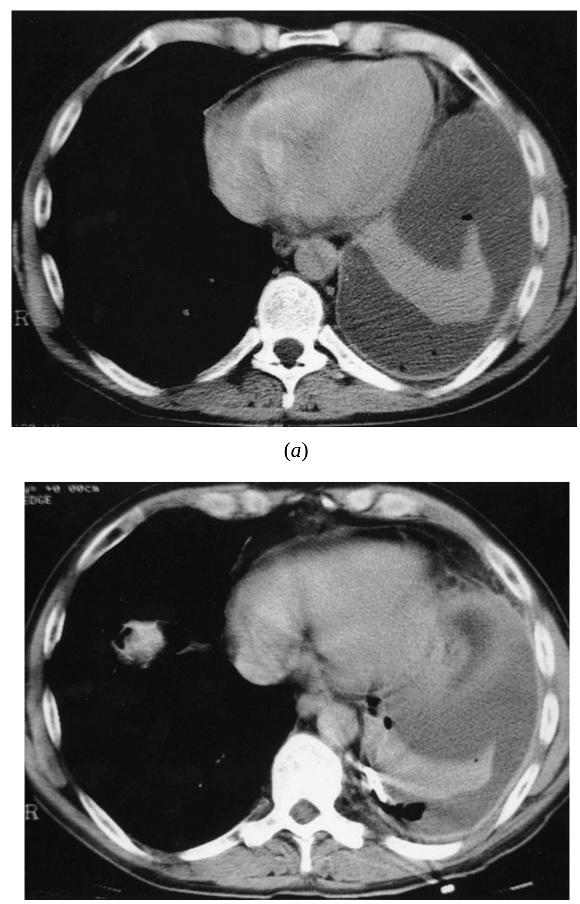

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Fig. 2 – Contrast-medium-enhanced chest CT in patient with empyema. (*a*) Large left pleural effusion with enhancing pleural thickening, increased thickness and attenuation of extrapleural fat and slight reduction in volume of left hemithorax. Following diagnostic aspiration there are multiple separate bubbles of gas within this indicating septation. (*b*) A pigtail catheter has been placed within the posteromedial part of this collection, which has decreased in size. The remainder of the collection is largely unchanged indicating that septation has prevented fluid accessing the draining catheter.

are a large number of observational case series showing that small-bore catheters inserted under imaging guidance are highly effective in the treatment of CPPE and empyema [11,21,22,42–45]. Several of these studies have successfully used small-bore catheters as salvage treatment in patients in whom conventional tube drainage has failed [22,42,44]. In van Sonnenberg's series of 17 patients, 13 had undergone previous chest tube drainage and failed to respond: 10 of the tubes were malpositioned, one had been dislodged and two were draining a minor locule. Of these, radiologically guided catheter drainage was successful in 10, partly successful in two (empyema drained but cavity remained open) and only one patient required surgery [42]. A recent literature review found the success rate for radiologically guided small-bore catheters (8–14 F) to be 81% (range 72–92%) compared to 47% (range 6–93%) for conventional chest tubes [24]. Optimal placement of the catheter within the collection was postulated as the reason for this high success rate.

Malignant Pleural Effusions and Pleurodesis

Pleural effusion is a common problem in patients with disseminated malignancy. The most frequent tumours causing malignant effusion are carcinoma of the breast, bronchus and lymphoma which together account for approximately two out of three cases [46,47]. The aim of treatment is to palliate symptoms and therefore any treatment must be well tolerated, cost effective and preferably require minimal hospital stay. Thoracocentesis alone is only suitable for patients with short life-expectancy as there is a 97% recurrence rate at 1 month, the majority of effusions recurring within 1–3 days. Tube thoracostomy alone is also associated with an unacceptably high recurrence rate of up to 100% at 1 month [46]. Tube thoracostomy with chemical pleurodesis is the initial treatment of choice for most patients, with thoracoscopy and talc poudrage, pleuroperitoneal shunting and pleurectomy being reserved for those failing to respond.

Large-bore chest tubes have traditionally been used for pleurodesis but they are uncomfortable to insert and limit patient mobility. Small-bore catheters have been used for drainage and pleurodesis in malignant pleural effusion, and a variety of sclerosants have been tried including tetracycline [48–51], bleomycin [50,52–54], doxycycline [55] and talc [56]. Success rates (defined in most series as clinical and radiographic response at 30 days) ranged from 61 to 92%. Outpatient treatment has also been described and appears to be safe and effective [53]. Two series have compared large-bore chest tubes with radiological small-bore catheters [49,51]. A retrospective review of 20 patients with 24 pleural effusions showed success rates of 62% for 8.3 or 10 F pigtail catheters vs 36% for 32–38 F chest tubes using tetracycline [49]. Clementsen *et al*. performed a prospective randomized study to compare tetracycline pleurodesis using either a 10 F percutaneous catheter or a 24 F conventional chest tube [51]. There was no significant difference in radiographic response at 3, 6 and 9 weeks or in need for further thoracocentesis. The majority of patients described the small-bore catheter insertion as no more unpleasant than thoracocentesis (seven out of nine) and the presence of the tube as not unpleasant (seven out of nine). The large-bore tube was inserted during diagnostic thoracoscopy and therefore insertion was less well tolerated, however, following insertion all nine patients described the presence of the tube as somewhat or very unpleasant.

Pneumothorax

Pneumothorax is usually managed without the need for imaging guidance other than plain radiography for diagnosis and follow-up. Current British Thoracic Society guidelines recommend treatment for primary spontaneous pneumothoraces (those occurring in otherwise healthy individuals) where there is complete lung collapse and/or significant dyspnoea, and in all secondary spontaneous pneumothoraces (those associated with underlying lung disease) except if small and asymptomatic [57]. Initial treatment is with simple aspiration via an 18G intravenous cannula. If this fails, tube thoracostomy is usually required and a conventional large-bore tube is most commonly employed. An early report using a 13 F catheter to treat spontaneous pneumothorax showed a poor success rate of only 53% [58]. In contrast, later studies have shown excellent success rates ranging from 84.5 to 97% using small-bore catheters (5.5–9.4 F) for both spontaneous [59–61] and iatrogenic pneumothorax [59,60,62–65]. The catheters were inserted as a one-step procedure, either 'over-needle' or via a trocar. Imaging guidance was used in the minority and then only in studies where the pneumothorax followed lung biopsy [62,63]. In most of the studies the catheters were attached to a one-way (Heimlich or flutter) valve which removes the need for underwater-seal drainage and allows the patient to remain ambulatory [60–65], making out-patient treatment possible [60]. This type of valve can be incorporated with the catheter into a one-piece unit [64]. The presence of pleural fluid and persistent large air leak predispose to small-bore catheter failure and may require large-bore tube insertion [60]. Non-resolving, bilateral or recurrent pneumothorax are indications for surgical referral [57].

Radiologists may become involved in the treatment of pneumothorax when it complicates percutaneous lung biopsy, which occurs in approximately one-quarter of cases [60]. Immediate drainage within the radiology department will be required if there is evidence of tension and this can be easily and safely carried out with a small-bore catheter and Heimlich valve [59,63]. It is also possible to use such a catheter to re-expand the lung and allow the biopsy to continue [63]; this is likely to be most useful for CT-guided biopsies where a small pneumothorax can be accurately localized.

Focal or loculated pneumothoraces present a particular problem to the clinician as they are difficult to diagnose and accurately localize from a plain radiograph, and frequently occur in critically ill patients, often in association with multiple trauma, mechanical ventilation or ARDS. In a review of 74 patients with ARDS undergoing chest CT, 32% were found to have a loculated pneumothorax, the majority of which were anteromedial. [66]. CT [67,68], and more recently CT fluoroscopy [69] have proved useful for accurate delineation and subsequent percutaneous catheter drainage of these localized pneumothoraces, particularly in traumatized and ventilated patients. Boland *et al*. reported 16 loculated pneumothoraces in nine ventilated patients, of which 12 were percutaneously drained under imaging guidance with 16–24 F catheters [67]. Gas exchange and arterial oxygenation improved in all patients. As such pneumothoraces are usually small and not associated with persistent air-leak it seems likely that small catheters would be equally effective for this purpose.

COMPLICATIONS OF LARGE- AND SMALL-BORE CATHETERS

The commonest complication of chest tube thoracostomy is malpositioning and this is identified more frequently by CT than plain radiography [16,70]. Using CT, Baldt *et al*. found 6% of chest tubes to lie within lung parenchyma and 3% outside the chest. Milliken *et al*. analysed 447 chest tubes placed using blunt dissection and found major complications in four patients (0.9%) including diaphragmatic, lung and liver lacerations and avulsion injury of the lesser curve of the stomach [71]. Complication rates are even higher for tubes placed using a trocar, which is associated with the risk of over-penetration and subsequent damage to intra-thoracic structures (Fig. 3). Injuries to lung, stomach, spleen, liver, heart and great vessels may occur and are potentially fatal [72,73]. Hunnam and Flower describe a hepatic haematoma caused by conventional large-bore drain insertion in a patient with empyema, subsequently salvaged by small-bore catheter drainage [23]. Although complications occur more frequently with inexperienced operators, this is not invariable; in a recent study a conventional chest tube was inserted through a high-riding diaphragm under the supervision of a senior clinician [41]. The use of suction can also be hazardous, and can lead to lung entrapment and subsequent infarction within the tip of large-bore chest tubes [74].

Major complications of imaging-guided small-bore catheter placement are infrequent. There are two reported episodes of cardio-pulmonary arrest during catheter insertion, both responding to resuscitation and presumably related to vagal stimulation [11,44]. There is also a single report of transient bacteraemia [42] and one report of moderate haemorrhage not requiring treatment [11]. To our knowledge no other major complication, and specifically no complication involving tube misplacement, has been described. Although this is still a relatively new technique and patient numbers are significantly smaller than for conventional chest tubes, first principles suggest that use of imaging guidance in combination with Seldinger insertion should be safer than the blind trocar technique still widely employed for the insertion of large-bore tubes.

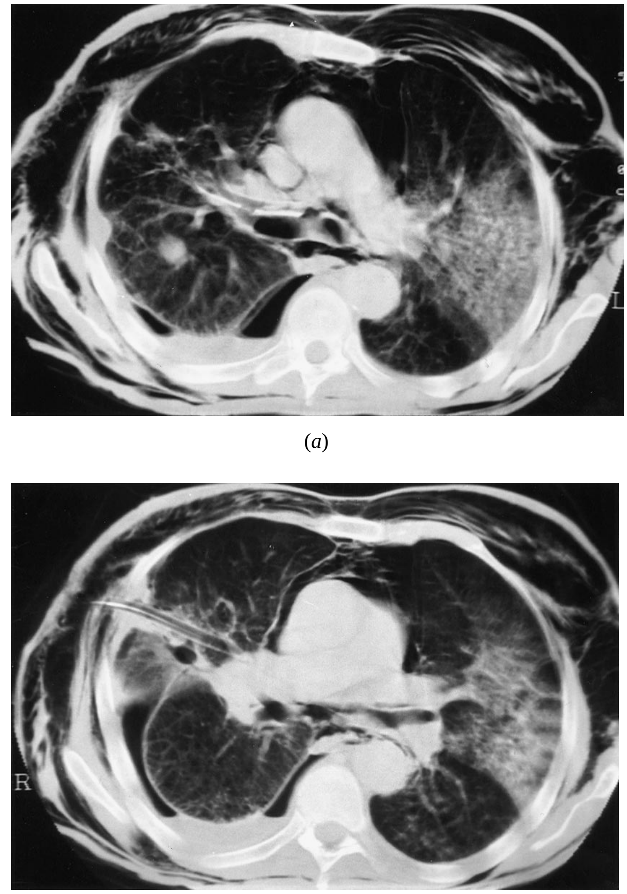

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Fig. 3 – (*a*), (*b*) Chest CT demonstrating large-bore chest drain misplaced into the mediastinum. The drain tip lies between the right main pulmonary artery and bronchus intermedius and there is a pneumomediastinum, a right hydropneumothorax and gross surgical emphysema. There is parenchymal haemorrhage along the drain track.

CONCLUSION

Small-bore catheters are effective for the treatment of para-pneumonic effusion and empyema, malignant pleural effusion and pneumothorax. Fibrinolytics are a useful adjunct for collections in which septation is a potential problem. The catheters appear to be safer and better tolerated than their larger counterparts. Imaging guidance is recommended for all but very large collections and non-loculated pneumothorax, as it allows optimal catheter placement. Although there are, as yet, no large scale randomized trials comparing large vs small bore catheters for the drainage of intra-thoracic collections, there is little or no hard evidence to support the continued advocacy of large-bore drains and, at least in the first instance, patients should benefit from an evidence-based approach with the use of a small-bore catheter.

Addendum

Articles discussing pleural fluid diagnosis and treatment frequently refer to aspiration via a standard gauge needle (such as 20 or 22G) but drainage via a French gauge catheter or drain. Needle diameters are measured using the British Standard Wire Gauge whose increments are in multiples of 4/1000 of an inch [75]. However, the sequence of sizes of a gauge is non-linear and, confusingly, diameter decreases as gauge size increases. Chest drain diameter is measured using the French Gauge or size which is both linear and metric. The French Gauge is a synonym for Charrière, one French Gauge or Charrière equaling 1/3 of a millimetre [75]. Hence, a standard 21G (green) needle has an external diameter of 32/1000 inches (approximately 0.8 mm) and a 6 F catheter an external diameter of 2 mm.

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