Activated charcoal for pediatric poisonings: the universal antidote?

Robert Michael Lapus

Purpose of review

For decades, activated charcoal has been used as a 'universal antidote' for the majority of poisons because of its ability to prevent the absorption of most toxic agents from the gastrointestinal tract and enhance the elimination of some agents already absorbed. This manuscript will review the history of activated charcoal, its indications, contraindications, and the complications associated with its use as reported in the literature.

Recent findings

Recent randomized prospective studies, although with small numbers, have shown no difference in length of hospital stay, morbidity, and mortality between groups who received and did not receive activated charcoal. No study has had sufficient numbers to satisfactorily address clinical outcome in patients who received activated charcoal less than 1 h following ingestion.

Summary

If used appropriately, activated charcoal has relatively low morbidity. Due to the lack of definitive studies showing a benefit in clinical outcome, it should not be used routinely in ingestions. AC could be considered for patients with an intact airway who present soon after ingestion of a toxic or life-threatening dose of an adsorbable toxin. The appropriate use of activated charcoal should be determined by the analysis of the relative risks and benefits of its use in each specific clinical scenario.

Keywords

antidote, charcoal, decontamination, ingestion, overdose, poison

Curr Opin Pediatr 19:216–222. © 2007 Lippincott Williams & Wilkins.

Division of Pediatric Emergency Medicine, Department of Pediatrics, University of Alabama at Birmingham School of Medicine, Birmingham, Alabama, USA

Correspondence to Robert Michael Lapus MD, Division of Pediatric Emergency Medicine, Department of Pediatrics, University of Alabama at Birmingham School of Medicine, 1600 7th Ave South Midtown Center 205, Birmingham, AL 35233, USA
Tel: +1 205 939 9587; fax: +1 205 475 4623; e-mail: rlapus@peds.uab.edu

Current Opinion in Pediatrics 2007, 19:216–222

Abbreviations

ED	emergency department
MDAC	multiple dose activated charcoal
NAC	N-acetylcysteine
SDAC	single dose activated charcoal
TCA	tricyclic antidepressant

1040-8703

Introduction

According to the American Association of Poison Control Centers (AAPCC), in 2004, there were roughly 2.4 million poison exposures, 1.9 million of which were due to ingestion [1•]. About 93% of these occurred in the home and slightly more than half of the 2.4 million cases involved children less than 6 years of age. For all groups, most cases (77%) were managed in a nonhealthcare facility and 22.4% of cases were treated in a healthcare facility. In children less than 6 years of age, 10.2% were treated in a healthcare facility. Although they comprise the majority of calls to the poison centers, children less than 6 years of age accounted for 2.3% of the documented fatalities, with 27 reported. Overall there were 1183 reported fatalities, 75% were due to toxin ingestion and 77.7% were intentional [1•]. Thus, poisoning still remains a significant cause of morbidity in the pediatric age group. Activated charcoal has always been associated with treatment for poisonings, although, perhaps, this perception/practice should change based on emerging literature.

Activated charcoal has been used for the last century for gastric decontamination. It prevents absorption of substances in the gastrointestinal tract, thereby decreasing systemic absorption of potentially toxic agents. In the past it had been referred to as 'the universal antidote'; however, its use has been slowly declining from a peak use of 7.7% in 1995 to 5.6% in 2004. Further, more and more is being reported about its adverse effect profile, such as the potential to lead to bowel obstruction or aspiration pneumonitis. Is charcoal truly the 'universal antidote' or will it go the way of 'the medical anecdote'? The purpose of this article is to review the history of activated charcoal, discuss its indications, contraindications, and review the complications associated with its use as reported in the literature.

History of activated charcoal in medicine

Charcoal has been used for medical purposes for thousands of years. The Egyptian papyri document the use of charcoal to 1500 BC [2]. The ancient Egyptians used charcoal to adsorb the odor from rotting wounds. Hindu documents from 450 BC record the use of charcoal and sand filters for the purification of drinking water. In 400 BC, Hippocrates and Pliny used charcoal to treat epilepsy, chlorosis, and anthrax. In 157 BC, Claudius Galvanometer wrote 500 treatises, some about the use of carbon for medical purposes. In 1773, Scheele

recognized the specific adsorptive powers charcoal had with various gasses [2,3]. Twelve years later, Lowitz reviewed these properties and published accounts of charcoal's ability to adsorb vapors from various chemicals. He is credited with the first account of charcoal's adsorptive ability in the liquid phase. This led to a much cited bold demonstration by a pharmacist named Touery in 1831. At a meeting at the French Academy, he ingested several times the lethal dose of strychnine with equal amounts of charcoal, and survived. The Academy was, however, unimpressed and charcoal continued to be used more for industrial purposes [3]. Over the next several decades, newer methods of refining and activating charcoal in order to improve its adsorptive properties were pioneered. In 1911, 'Eponit', the first industrially produced activated charcoal, was produced in Austria. Shortly thereafter, the use of toxic gasses in World War I served as a driving force for the mass production of activated charcoal suitable for respirators [2]. It was not until 1963, after Holt published a review article in the *Journal of Pediatrics* entitled 'The black bottle', that activated charcoal became more widely accepted in the management of ingested toxins [4].

Indications for activated charcoal

Activated charcoal has been universally used to adsorb a variety of agents, with the exceptions of hydrocarbons, acids, alkalis, ethanol, and heavy metals (Table 1) [5]. It has been studied with hundreds of substances *in vitro*, in animals, in human volunteers, and in actual patients with overdoses. Although no controlled studies demonstrating changes in clinical outcome have ever been performed with activated charcoal, these previous data probably are convincing enough to warrant its use in selected cases.

In their position paper on single dose activated charcoal (SDAC), the American Academy of Clinical Toxicology and the European Association of Poison Centres and Clinical Toxicologists [6••] remind us that activated charcoal should not be given routinely in the treatment of poisoned patients. The recommended oral dose is 0.5–1 g/kg, with a maximum of 100 g (Table 2), although there is no single correct dose of activated charcoal. The optimum dose of activated charcoal cannot be known with certainty in any given patient. Optimum dosage is dependant on many variables such as the physical properties of the charcoal formulation and the substance ingested, the volume and pH of gastric and intestinal fluid, and the presence of other agents or food adsorbed by activated charcoal [7••,8–11].

Table 1 Activated charcoal not helpful/caution/contraindicated

PHAILS	
P	– Pesticides, petroleum distillates, unprotected airway
H	– Hydrocarbons, heavy metals, >1 h
A	– Acids, alkali, alcohols, altered level of consciousness, aspiration risk
I	– Iron, ileus, intestinal obstruction
L	– Lithium, lack of gag reflex
S	– Solvents, seizures

Modified from Erickson [5].

Table 2 Recommended dosage of activated charcoal

Children up to 1 year of age	10–25 g or 0.5–1.0 g/kg
Children 1–12 years of age	25–50 g or 0.5–1.0 g/kg
Adolescents and adults	25–100 g

Volunteer studies suggest that SDAC is more likely to be beneficial if given within 1 h following ingestion; however, benefit after 1 h cannot be excluded for poisons which slow gastric motility (e.g. anticholinergic substances/drugs, opiates, salicylates) [6••]. Some authors even suggest that activated charcoal is beneficial more than 4 h following acetaminophen overdose [12–15]. In a prospective, observational case series of 145 patients, Spiller *et al.* [16•] sought to evaluate whether administration of activated charcoal more than 4 h following overdose of acetaminophen in addition to standard N-acetylcysteine (NAC) provided additional benefit over NAC alone. To measure outcome, they used hepatic transaminases, prothrombin time, and international normalized ratio (INR). There were 58 patients who received NAC alone and 87 patients who received NAC and charcoal. They found that 23 patients had elevated transaminases greater than 1000 IU/l. Of those, 21 patients received NAC alone and two patients received NAC and charcoal. This difference is statistically significant; however, to say whether these findings are clinically significant, since all patients survived with no reported long-term sequelae, requires further study. Interestingly, the proposed explanation for the reduction in transaminases despite the late administration of charcoal was not the interruption of the absorption of the acetaminophen, but more of a postabsorption or 'gastrointestinal dialysis' effect.

This explanation is similar to the mechanism behind multiple dose activated charcoal (MDAC) which is based on the theory that after absorption, drugs will reenter the gut by passive diffusion if the concentration there is lower than in the blood [17]. By administering more than two doses of activated charcoal it is believed that a concentration gradient is maintained and the drug continuously passes into the gut where it is adsorbed to the charcoal. This 'gastrointestinal dialysis' has been best demonstrated for theophylline and salicylates. MDAC is also likely to be of benefit to decrease drug absorption when large amounts of drugs are ingested and dissolution is delayed (masses and bezoars, i.e. salicylates), when drugs exhibit a delayed or prolonged release phase (enteric coated, sustained release), or when reabsorption can be prevented (enterohepatic circulation of active drug or

active metabolites, i.e. carbamazepine). MDAC may also be considered in the ingestion of life-threatening amounts of potentially lethal drugs. Although MDAC increases the elimination of digitoxin, phenobarbital, carbamazepine, phenylbutazone, dapsone, nadolol, theophylline, salicylate, quinine, cyclosporine, propoxyphene, nortriptyline, and amitriptyline, its clinical utility remains to be defined. The optimum dose of MDAC is unknown, but after the initial appropriate single dose, a dose of 0.25–0.5 g/kg every 2–6 h has been recommended. The total dose may be more important than frequency of administration. Continuous nasogastric administration of activated charcoal can be employed, especially when vomiting is a problem, that is, theophylline toxicity. Smaller doses are recommended in children. Reported complications and adverse effects of MDAC have included diarrhea, constipation, vomiting, pulmonary aspiration, and intestinal obstruction. Some authors feel that, in the absence of accurate, scientific data indicating effectiveness and risk, a sound recommendation for the use of MDAC cannot be made [18]. Again, the treating physician must weigh the theoretic benefit against the potential for complications in each clinical scenario.

Benefits

Recently, the benefits of activated charcoal have come under serious scrutiny. To reiterate, there have never been any controlled studies that have demonstrated that activated charcoal has resulted in a positive clinical outcome in overdose patients. Many would not hesitate to administer activated charcoal to a comatose patient who presents within 1 h to the emergency department (ED) and has a protected airway; however, the debate seems to focus on the alert and awake patient, with stable vital signs. In a prospective, randomized, controlled study, Merigian *et al.* [19] compared clinical outcome in 1479 self-poisoned patients receiving activated charcoal and supportive care or supportive care alone. They compared the incidence of vomiting, length of stay, and incidence of complications associated with the overdose or the treatment between the two groups. They found that there was a significantly higher incidence of emesis in the activated charcoal group compared with those receiving no activated charcoal (23% versus 13%, $P < 0.01$). There was a statistically significant longer ED stay in those given activated charcoal; however, there was a significantly shorter inpatient hospital stay for those given charcoal. Upon review of the charts, it was found that the time to medical clearance was not significantly different; what prolonged the length of stay was time to transfer to a mental health institution and time to be seen by a psychiatrist. Based on these results and the fact that none of the inpatients who received supportive care alone deteriorated, they concluded that gastric decontamination procedures were unnecessary in their study population. It is important to note, however, that patients who ingested a potentially toxic dose of acetaminophen (>140 mg/kg) were excluded from the study. Additionally, there was no information provided as to the time frame of ingestion of the drug and administration of charcoal.

A more recent randomized, controlled, unblinded study by Cooper *et al.* [20••] also found no benefit in the administration of charcoal when looking at length of stay, vomiting, intensive care unit (ICU) admission, and mortality. Cooper *et al.* acknowledge that their study lacked the power to detect significant differences in less frequent outcomes such as aspiration or death. They suggest that charcoal should not be used routinely in intentional overdose. The basis for this stems from the following facts: drugs commonly seen today in intentional overdose such as acetaminophen, benzodiazepines, and the newer antidepressants have a lower case fatality rate than drugs seen in overdose 10–20 years ago; there have been significant advances in supportive care; and the lack of statistical difference in outcome between the two groups, particularly in those presenting after 1 h. They conclude that 'charcoal should be restricted to those situations where there is a substantial risk from the poisoning and a significant amount of the poison likely to still be present in the gut'.

Time of administration

Several studies have confirmed that the 1 h time frame for the administration of charcoal to have its best efficacy often cannot be achieved in the 'real' clinical setting. Kornberg and Dolgin [21] found that the mean time from ingestion to arrival at the ED for pediatric patients less than 6 years of age with unintentional ingestions was 1.2 h, and the mean time from ED arrival to charcoal was 0.9 h. A more recent study by Osterhoudt *et al.* [22] of 319 patients less than 18 years of age showed very similar results for their median times; however, their mean times were 2.1 and 1.1 h, respectively. In their study, about 30% of children arrived within 45 min of ingestion and only 7.8% of all patients received charcoal within 1 h following ingestion. Thus, it appears that timely administration of activated charcoal in the hospital setting is often difficult. Currently, some poison control centers advise home administration of activated charcoal for pediatric ingestions. In addition, some prehospital personnel administer activated charcoal. In a study by Alaspää *et al.* [23•], 555 patients with a mean age of 38 years and only five patients less than 7 years of age showed that prehospital administration of activated charcoal is feasible with no observable adverse effects if a protocol is followed. The editors, however, acknowledged that the study was too small to unequivocally establish safety. Furthermore, there have been no consensus guidelines or studies to demonstrate whether these practices change clinical outcome.

Table 3 Common items with petroleum distillates

Automotive cleaners	Mineral oils
Automotive fuel additives	Paraffin wax
Furniture polish	Pesticides
Gasoline	Petroleum jelly
Kerosene	Pine oil cleaners
Lighter fluids	Varnish

Contraindications

SDAC is contraindicated in patients with unprotected airways and decreased levels of consciousness who are not intubated [6••]. Charcoal is not indicated in patients who have ingested acids or alkalis (corrosives) because it has not shown any benefit in these cases. In this scenario, charcoal administration may induce vomiting, obscure endoscopic visualization, and in cases of perforation, there is a risk of charcoal leaking into the peritoneum or mediastinum [24]. Charcoal may be considered, however, if a corrosive is coingested with a systemic toxin. Charcoal is contraindicated if its use increases the risk or severity of aspiration, such as with hydrocarbons [6••] (Table 3), particularly the low-viscosity, aliphatic hydrocarbons such as kerosene, lighter fluid, and lamp oil. In cases of hydrocarbons which have systemic toxicity (i.e. benzene) or coingestion with a systemic toxin, charcoal can be considered [24]. Careful risk–benefit analysis, however, must be carried out. Caution should be used when administering charcoal in patients who are at risk of gastric hemorrhage or perforation. Caution should also be used in patients who have ingested a substance that puts them at risk for sudden onset of seizures or sudden decrease of mental status, such as clonidine or tricyclic antidepressants (TCAs). Charcoal is not indicated for use in isolated ingestions of lithium, iron, heavy metals, or ethanol [24].

Complications

In light of its universal use, there are considerably few reports of adverse events related to the use of activated charcoal. In 2004 activated charcoal was given to 130 000 patients [1•]. The most common reported complication is emesis. Most adverse events with significant morbidity are related to aspiration of activated charcoal into the lung, be it through direct administration into the lung via a misplaced gastric tube, or use in a patient with an unprotected airway. Other often cited, but rarely reported complications are gastrointestinal perforation, small bowel obstruction in multiple dose therapy, and corneal abrasions.

Emesis

Emesis is the most common adverse effect in the administration of activated charcoal, with a reported incidence of 6–26% [25–29]. Reasons for emesis are thought to be multifactorial, such as addition of sorbitol or charcoal's gritty texture. Volunteers who drank charcoal had a lower incidence of emesis [30]. In a recent prospective study, Osterhoudt *et al.* [31] examined risk factors for emesis associated with the administration of activated charcoal. Emesis was defined as the forceful regurgitation of stomach contents within 2 h of receiving activated charcoal, as judged by the patient's nurse in the ED. Osterhoudt *et al.* also examined the influence of other potential patient-specific, poison-specific, and procedure-specific risk factors that may be associated with emesis and the administration of activated charcoal. They found that 56 of 275 (20.4%) patients vomited after receiving activated charcoal, with half vomiting within 10 min of initiation of activated charcoal. Statistically significant risk factors associated with vomiting of activated charcoal were vomiting prior to administration of activated charcoal and the use of a naso or orogastric tube. The presence of nausea and age over 12 approached statistical and clinical significance; however, this could not be confirmed due to the sample size. Surprisingly, not strongly associated with emesis were the presence of signs or symptoms of poisoning, emetogenic properties of certain toxins, agitation, level of consciousness, large volumes of charcoal, rapid administration, drugs that slow gastric motility, or the addition of sorbitol to the activated charcoal.

In this cohort, there was a 13% incidence of emesis prior to administration of activated charcoal. This incidence of vomiting was identical to the no activated charcoal arm of the previously mentioned randomized control trial by Merigian *et al.* [19].

Some authors recommend medicating the patient prior to charcoal administration with an antiemetic; however, this practice raises the concern of further polypharmacy in the setting of overdose, complicating the clinical scenario, and making an alternative method desirable. In a preliminary prospective study, Eizember *et al.* [32] found that placement of acupressure bands 5 min prior to administration of activated charcoal reduced the incidence of charcoal-associated emesis by 46%. Further studies are warranted.

Aspiration

Of the complications seen concurrently with the administration of activated charcoal, aspiration has the potential to be the most serious [33•]. There have been several studies examining the occurrence of aspiration after overdose and charcoal administration. In a retrospective study at eight tertiary care hospitals, Dorrington *et al.* [34] sought to determine the frequency of 'clinically significant' aspiration in patients receiving two or more doses of activated charcoal. Part of the criteria for 'clinically significant' aspiration required decreased oxygen saturation or increased respiratory effort, or need for intubation or supplemental oxygen. They found that 0.6% (5.7 per 1000) had met all their criteria for significant

aspiration. Four of the five aspirated after the first dose. All five required intubation and ventilation for 1–3 days; there were no deaths due to aspiration or long-term sequelae. The authors concluded that significant complications occur infrequently [34]. It has been pointed out, however, that the study was underpowered and that MDAC was indicated in only 7% of the patients [18]. In a retrospective study, Liisanantti *et al.* [35] concluded that in unconscious patients (Glasgow Come Score (GCS) < 8), those at highest risk for aspiration were those with the longest time without intubation and those given charcoal without securing the airway. From their data, it did not appear that there was a significant difference in risk of aspiration between unconscious patients not immediately intubated in the field and unconscious unintubated patients receiving charcoal in the hospital setting. One could therefore argue that activated charcoal itself is not a risk factor for aspiration. There was also no difference in risk for aspiration between an unconscious patient who was immediately intubated in the field compared with an unconscious intubated patient given charcoal. They concluded that to decrease the risk of aspiration pneumonitis in a poisoned patient with a GCS less than 8, intubation in the field is recommended [35]. Isbister *et al.* [36] similarly concluded that the occurrence of aspiration pneumonia in a patient given activated charcoal is not due to the charcoal itself, but to other factors such as decreased level of consciousness, spontaneous emesis, seizure, TCA ingestion, and time from ingestion to presentation. They recommended that in patients with any of these defined risk factors for aspiration and an unprotected airway, activated charcoal should be reserved for those most likely to benefit and intubation mandatory prior to administration.

Isbister *et al.* did not find a difference in mortality of patients with aspiration who did and did not receive charcoal. Activated charcoal is thought to be an inert compound; however, there are animal studies that show charcoal directly administered into the lung can cause inflammation and changes in microvascular permeability [37]. Graff *et al.* [38] reported a patient who received charcoal directly into the lung due to a misplaced gastric tube. The patient subsequently required intubation and mechanical ventilation for 5 days. The patient was eventually discharged but subsequently diagnosed with asthma and seen several times in the ED for respiratory symptoms. Lung biopsy revealed chronic lung changes with macrophages containing charcoal. Seger [39] reviewed the AAPCC Toxic Exposure Surveillance System (TESS) data from 1993 to 2002 and described seven reported deaths in which aspiration of activated charcoal was at least a contributing factor in their deaths. Four presented with altered level of consciousness and received activated charcoal with subsequent emesis then intubation to secure the airway. Seger also described two pediatric deaths directly related to the aspiration of activated charcoal. Both ingestions were with TCAs. One death occurred 14 weeks after the intentional ingestion of 60 nortriptyline tablets, indicating that death was not due to drug toxicity. The patient died of respiratory failure. Autopsy showed bronchiolitis obliterans with massive amounts of charcoal within bronchiolar scar tissue [40]. The second death was a toddler who ingested an unknown amount of amitriptyline. The patient was given charcoal, aspirated, and then became asystolic. Resuscitation efforts failed. Cause of death was charcoal aspiration and airway compromise [41]. Seger [39] reminds us that TCAs can cause a rapid decrease in the level of consciousness and subsequently questions if activated charcoal should even be given for the ingestion of drugs that cause such a rapid decline.

These scenarios bring forth another question. How well does intubation protect against aspiration of activated charcoal? Moll *et al.* [42] found the incidence of aspiration when given activated charcoal after intubation to be 4%, which is similar to the 3.5% incidence of aspiration in urgent intubations alone in a study by Thibodeau *et al.* [43]. Even in cases when a cuffed endotracheal tube is in place, nasogastric tube (NGT) placement must still be verified. There is an abstract in the AAPCC TESS 2004 report [44] of a 63-year-old man who was found with a decreased level of consciousness and pill bottles lying around him. His medications included acetaminophen/butalbital/caffeine, clonazepam (Klonopin), and zolpidem (Ambien). From the sequence presented in the abstract, he was intubated prior to receiving activated charcoal; however, the NGT was inadvertently placed into the lung. The patient was found to have suffered an anoxic brain injury and support was withdrawn. Autopsy showed charcoal-induced pneumonitis.

Other complications

In the literature there are case reports of unusual gastrointestinal complications such as esophageal perforation with lavage tube resulting in charcoal mediastinum [45], gastrointestinal perforation with charcoal peritoneum [46], charcoal stercolith with perforation [47], charcoal bezoar from multiple doses of charcoal, causing small bowel obstruction [48], and a manually disimpacted charcoal 'briquette' that caused constipation after a single dose of charcoal [31].

There are also reports of corneal abrasions due to charcoal spilling into the eyes when being administered in two combative patients. The abrasions were transient and resolved without complications [34,49].

Conclusion

Activated charcoal has been used as the universal antidote for decades. When one considers how often it is

administered, it has a relatively low incidence of adverse events; however, there are case reports of significant morbidity and perhaps deaths associated with charcoal administration. Since benefit has not been shown when given more than 1 h following ingestion, it should not be routinely administered, especially in most asymptomatic patients or those that present after this 1 h window. It should be considered in patients who have ingested a toxic or lethal dose of an adsorbable drug, who present within 1 h, and have a protected airway. It is contraindicated in certain situations and strongly cautioned in others. Careful analysis of the relative risks and benefits must be applied in each specific clinical situation. Since most pediatric ingestions are unintentional, a gram of prevention is truly the only universal antidote.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 239).

1 • Watson WA, Litovitz TL, Rodgers GC. 2004 annual report of the American Association of Poison Control Centers Toxic Exposure Surveillance System. Am J Emerg Med 2005; 23:589–666.
Annual comprehensive report which provides statistics on exposures reported to poison centers in 2004.

2 Historical production and use of carbon materials. http://www.caer.uky.edu/carbon/history/carbonhistory.shtml. [Accessed 26 October 2006]

3 Marketos SG, Androutsos G. Charcoal: from antiquity to charcoal artificial kidney. J Nephrol 2004; 17:453–456.

4 Derlet RW, Albertson TE. Activated charcoal: past present and future. West J Med 1986; 145:493–496.

5 Erickson TB. Toxicology: ingestions and smoke inhalations: APLS. In: Gausche-Hill M, Fuchs S, Yamamoto L, editors. The pediatric emergency resource. 4th ed. Massachusetts: Jones and Bartlett; 2004. p. 239.

6 •• Chyka PA, Seger D, Krenzelok EP, Vale JA. American Academy of Clinical Toxicology and European Association of Poison Centres and Clinical Toxicologists. Position paper: Single-dose activated charcoal. Clin Toxicol 2005; 43:61–87.
Evidence-based position paper regarding the use of single dose activated charcoal: indications, contraindications, dosages, adverse effects. Summarizes clinical studies and provides abstracts of the role of charcoal for ingestion of several drugs.

7 •• Gaudreault P. Activated charcoal revisited. Clin Ped Emerg Med 2005; 6: 76–80.
Concise review article that discusses indications, dosages, adverse effects and benefits of SDAC and MDAC.

8 Olkkola KT, Neuvonen PJ. Do gastric contents modify antidotal efficacy of oral activated charcoal? Br J Clin Pharmacol 1984; 18:663–669.

9 Neuvonen PJ, Olkkola KT, Alanen T. Effect of ethanol and pH on the adsorption of drugs to activated charcoal: studies in vitro and in man. Acta Pharm Toxicol 1984; 54:1–7.

10 Andersen A. Experimental studies on the pharmacology of activated charcoal. II: The effect on pH on the adsorption by charcoal from aqueous solutions. Acta Pharmacol 1947; 3:199–218.

11 Andersen A. Experimental studies on the pharmacology of activated charcoal. III: Adsorption from gastric contents. Acta Pharmacol 1948; 4:275–284.

12 Spiller HA, Krenzelok EP, Grande GA, Safir EF. A prospective evaluation of the effect of activated charcoal before oral N-acetylcysteine in acetaminophen overdose. Ann Emerg Med 1994; 23:519–523.

13 Montoya-Cabrera MA, Escalante-Galindo P, Nava-Juarez A, Terrobo-Larios VM. Evaluation of the efficacy of the N-acetylcysteine administration alone or in combination with activated charcoal in the treatment of acetaminophen overdose. Gac Med Mex 1999; 135:239–243.

14 Rose SR, Gorman RL, Oderda GM, Klein-Schwartz W. Simulated acetaminophen overdose: pharmacokinetics and effectiveness of activated charcoal. Ann Emerg Med 191; 20:106–108.

15 Sato RL, Wong JJ, Sumida SM, Marn RY. Efficacy of superactivated charcoal administered late (3 h) after acetaminophen overdose. Am J Emerg Med 2003; 21:189–191.

16 • Spiller HA, Winder ML, Klein-Schwartz W, Bangh SA. Efficacy of activated charcoal administered more than four hours after acetaminophen overdose. J Emerg Med 2006; 30:1–5.
Multicenter, prospective observational study examining the impact late administration of charcoal has on hepatic transaminases in acetaminophen overdose.

17 Vale JA, Krenzelok EP, Barceloux GD. Position statement and practice guidelines on the use of multi-dose activated charcoal in the treatment of acute poisoning. Clin Toxicol 1999; 37:731–751.

18 Tenenbein M. Multiple doses of activated charcoal: time for reappraisal II. Ann Emerg Med 2003; 42:597–598.

19 Merigian KS, Blaho KE. Single-dose oral activated charcoal in the treatment of the self-poisoned patient: a prospective, randomized, controlled trial. Am J Therapeut 2002; (9):301–308.

20 •• Cooper GM, Le Couteur DG, Richardson D, Buckley NA. A randomized clinical trial of activated charcoal for the routine management of oral drug overdose. Q J Med 2005; 98:655–660.
Randomized, controlled trial comparing outcome in overdose patients who did and did not receive charcoal.

21 Kornberg AE, Dolgin J. Pediatric ingestions: charcoal alone versus ipecac and charcoal. Ann Emerg Med 1991; 20:648–651.

22 Osterhoudt KC, Alpern ER, Burden D, *et al.* Activated charcoal administration in the pediatric emergency department. Pediatr Emerg Care 2004; 20:493–498.

23 • Alaspää AO, Kulsma MJ, Hoppu Kalle, Neuvonen PJ. Out-of-hospital administration of activated charcoal by emergency medical services. Ann Emerg Med 2005; 2: 207–212.
Prospective study in a developed country examining the feasibility of prehospital administration of activated charcoal.

24 Holstege CP, Baer AB. Decontamination of the poisoned patients: In: Roberts JR, Hedges J, Chanmugam AS, editors. Clinical procedures in emergency medicine. 4th ed. Philadelphia: WB Saunders; 2004. pp. 824–837.

25 Fischer TF, Singer AJ. Comparison of the palatabilities of standard and superactivated charcoal in toxic ingestions: a randomized trial. Acad Emerg Med 1999; 6:895–899.

26 Harchelroad F, Cottington E, Krenzelok EP. Gastrointestinal transit times of a charcoal/sorbitol slurry in overdose patients. J Toxicol Clin Toxicol 1989; 27:91–99.

27 Pond SM, Lewis-Driver DJ, Williams GM. Gastric emptying in acute overdose: a prospective, randomized control trial. Med J Aust 1995; 163:345–349.

28 Rangan C, Nordt SP, Hamilton R. Treatment of acetaminophen ingestion with superactivated charcoal-cola mixture. Ann Emerg Med 2001; 37:55–58.

29 Minocha A, Krenzelok EP, Spyker DA. Dosage recommendations for activated charcoal–sorbitol treatment. J Toxicol Clin Toxicol 1985; 23:579–587.

30 Neuvonen PJ. Clinical pharmacokinetics of oral activated charcoal in acute intoxications. Clin Pharmacokinet 1982; 7:465–489.

31 Osterhoudt KC, Durbin D, Alpern ER, Henretig FM. Risk factors for emesis after therapeutic use of activated charcoal in acutely poisoned children. Pediatrics 2004; 113:806–810.

32 Eizember FL, Tomaszewski CA, Kerns IIWP. Acupressure for prevention of emesis in patients receiving activated charcoal. J Toxicol Clin Toxicol 2002; 40:775–780.

33 • Heard K. The changing indications of gastrointestinal decontamination in poisoning. Clin Lab Med 2006; 26:1–12.
Review article discussing the various methods of gastric decontamination with recent literature citations and summary recommendations.

34 Dorrington CL, Johnson DW, Brant R. The frequency of complication associated with the use of multiple-dose activated charcoal. Ann Emerg Med 2003; (42):370–377.

35 Liisanantti J, Paivi K, Matti M. Aspiration pneumonia following severe self-poisoning. Resuscitation 2003; 56:49–53.

36 Isbister GK, Downes F, Sibbritt D. Aspiration pneumonitis in an overdose population: frequency, predictors, and outcomes. Crit Care Med 2004; 32:88–93.

37 Arnold TC, Willis BH, Xiao F. Aspiration of activated charcoal elicits an increase in lung microvascular permeability. J Toxicol Clin Toxicol 1999; 37:1–8.

38 Graff GR, Stark J, Berkenbosch JW. Chronic lung disease after activated charcoal aspiration. Pediatrics 2002; 109:959–961.

39 Seger D. Single-dose activated charcoal: back up and reassess. J Toxicol Clin Toxicol 2004; 42:101–110.

40 Elliot CG, Colby TV, Kelly TM, Hicks HG. Bronchiolitis obliterans after aspiration of activated charcoal. Chest 198; 96:672–674.

41 Aaron CK, Primack WA, Manno MA, Fairfield S. Cardiac arrest from aspirated magnesium citrate/charcoal slurry. Clin Toxicol 1997; 35:505.

42 Moll J, Kerns IIW, Tomaszewski C. Incidence of aspiration pneumonia in intubated patients receiving activated charcoal. J Emerg Med 1999; 17:279–283.

43 Thibodeau LG, Verdile VP, Batfield JM. Incidence of aspiration after urgent intubation. Am J Emerg Med 1997; 15:562–565.

44 American Association of Poison Control Centers. Toxic Exposure Surveillance System report; 2004. Case 133.

45 Caravati EM, Knight HH, Linscott MS Jr. Esophageal laceration and charcoal mediastinum complicating gastric lavage. J Emerg Med 2001; 20:273–276.

46 Mariani PJ, Pook N. Gastrointestinal tract perforation with charcoal peritoneum complicating orogastric intubation and lavage. Ann Emerg Med 1993; 22:606–609.

47 Gomez HF, Brent JA, Munoz DC IV. Charcoal stercolith with intestinal perforation in a patient treated for amitriptyline ingestion. J Emerg Med 1994; 12:57–60.

48 Chan JC, Saranasuriya C, Waxman BP. Bezoar causing small bowel obstruction after repeated activated charcoal administration. Med J Aust 2005; 183:537.

49 McKinny P, Phillips S, Gomez HG, Brent J. Corneal abrasions secondary to activated charcoal. Vet Hum Toxicol 1992; 34:336.