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Hypovolemic shock complex: does the pancreatic perfusion increase or decrease at contrast-enhanced dynamic CT?

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ABSTRACT

Objective: The purpose of this study is to evaluate contrast enhancement effects of the pancreas at dynamic computed tomography (CT) to clarify whether pancreatic perfusion increases or decreases in severe trauma patients with hypovolemic shock. **Methods:** A total of 90 patients with (n=30) and without (n=60) blunt trauma and hypovolemic shock who underwent dynamic CT for abdomen was included. The measurement of CT attenuation values of the pancreas in the early phase and the late phase was performed to compare the contrast enhancement effects between patients with and without hypovolemic shock. **Results:** The mean CT attenuation values of the pancreas in the early phase of dynamic CT in patients with hypovolemic shock [95.4 ±29.1 Hounsfield units (HU)] were significantly lower (P < .001) than those in non-hypovolemic patients (136.6±17.9 HU), indicating decreased pancreatic perfusion in patients with hypovolemic shock. The mean CT attenuation values of the pancreas in the late phase of dynamic CT in patients with hypovolemic shock (95.9±17.6 HU) were significantly higher (P < .026) than those in non-hypovolemic patients (87.2±9.0 HU), indicating delayed or prolonged pancreatic enhancement in patients with hypovolemic shock. **Conclusions:** Decreased pancreatic perfusion in the early phase and delayed pancreatic enhancement in the late phase of contrast-enhanced dynamic CT was a common finding in patients with hypovolemic shock.

1. Introduction

Hypovolemic shock is a state of circulatory dysfunction resulting in a sudden decrease in the intra-vascular blood volume relative to the vascular capacity, to the extent that effective tissue perfusion cannot be maintained [1–3]. Hypovolemic shock is manifested by altered vital organ functions as well as perfusion, and as a result, various CT findings can be seen in the abdominal and pelvic organs owing to hypovolemia [4–11]. The main findings include dilated fluid-filled loops of bowel with hyperenhancing mucosa, intensely enhancing kidneys and mesenteric vasculature, dense aorta with small caliber, collapsed and slit-like inferior vena cava, increased enhancement of the adrenal glands, and decreased enhancement of the spleen. There have been also several previous reports describing the appearances of the pancreatic enhancement at contrast-enhanced CT in the setting of trauma and the hypoperfusion complex [12–17]. However, it is controversial whether pancreatic perfusion increases or decreases in patients with hypovolemic shock compared with non-traumatic and non-hypovolemic patients. Some clinical studies showed hypoenhancement of the pancreas while others demonstrated hyperenhancement at contrast-enhanced CT in patients with hypovolemic shock [12,14,16,17]. Hence, in this study, we tried to evaluate contrast enhancement effects of the pancreas at dynamic CT in severe trauma patients with hypovolemic shock to clarify whether pancreatic perfusion increases or decreases in hypoperfusion complex and discussed clinical relevance of this CT finding in patients with hypovolemic shock.

2. Materials and methods

2.1. Patients population

This study was approved by our institutional review committee. All patients and/or their family had given informed consent to undergo CT examinations. A retrospective search of electronic records of CT reports from July 2005 to July 2009 revealed 105 patients (73 male, 32 female, age range 9–89 years, median 47.6 years) who underwent contrast-enhanced dynamic CT for abdomen due to trauma. Then, CT and angiographic images as well as clinical records were reviewed to determine the presence of hypovolemic shock in each patient on the basis of several established clinical and biochemical findings according to the previous reports [18,19] as follows: hypotension (systolic blood pressure <90 mmHg), tachycardia, anemia, and presence of two or more vascular or visceral injury confirmed by imaging modalities. One patient with suspected pancreatic injury was excluded from this study. Among these 105 patients with blunt trauma, 68 patients had the injuries of the abdominal organs seen at imaging modalities. In these 68 patients,

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30 patients (16 men, 14 women, age range 12–89 years, median 54.4 years) met the criteria of hypovolemic shock and were included in this study. The causes of injury included motor vehicle accidents as a passenger or driver in 9, pedestrians involved in a motor vehicle accident in 16, and a fall from a height in 5 patients. All patients with hypovolemic shock underwent adequate resuscitation including the transfusion by a team consisting of several emergency specialists in our institution before CT examinations. Additionally, 60 patients without trauma and hypovolemic shock (30 male, 30 female, age range 18–88 years, median 56.5 years) who underwent contrast-enhanced dynamic CT for the screening of metastasis in patients with malignant diseases or for the further examination of benign abdominal diseases were randomly selected from our CT records of last 5 months of the same periods and included as a control group. Patients with pancreatic diseases or with abdominal metastatic diseases were excluded from the control group.

2.2. Image technique

CT examinations were performed immediately after the arrival and after an attempted stabilization for patients with trauma and hypovolemic shock (mean interval time between CT scans and the injury, 185 min). After obtaining precontrast CT, contrast-enhanced dynamic CT during the early and late phases was subsequently performed in all patients using a multidetector-row CT (LightSpeed Ultra 16, General Electric Medical Systems, Milwaukee, WI, USA, or Asteon 4, Toshiba Medical Systems, Tokyo, Japan). Scanning parameters were 120 kVp, 180 mAs, 5-mm section collimation, and 5-mm/s table speed during a single breath-hold helical acquisition. Images were obtained in a craniocaudal direction and were reconstructed every 5 mm to provide contiguous sections. The early- and late-phase images were obtained with delays of 40 and 210 s, respectively. A rapid power-injected bolus of 2 ml/kg body weight (Nemotokyorindo, Tokyo, Japan), up to a maximum of 150 ml of non-ionic contrast material (Iopamidol 300 mg/ml or 370 mg/ml; Iohexol 300 mg/ml) at an injection rate of 3.3–5.0 ml/s was used. As the fixed injection duration of 30 s was used, the injection rate was automatically decided according to patients' weights.

2.3. Data analysis

Mean CT attenuation values [in Hounsfield units (HU)] of the pancreatic parenchyma were measured on the workstation by the two radiologists who had 5 and 11 years of experience in interpreting abdominal CT images. These radiologists were blinded to CT reports and clinical history regarding the presence of hypovolemic shock to avoid a potential bias in measurement, although they knew that patients with blunt trauma were randomly included in the study population. CT attenuation values were measured by using a circular region-of-interest (ROI) cursor on images of the pancreas to compare the difference in enhancement effects between patients with hypovolemic shock and control subjects. Three measurements of pancreatic head, body, and tail were obtained on the unenhanced and early- and late-phase images, and averaged values on each phase were used for data analysis. The ROIs used for the pre- and post-contrast evaluation of the pancreas were the same size and were obtained at the same location in the pancreas. Additionally, enhancement washout of the pancreas was calculated as follows: (attenuation value of the pancreas at arterial phase CT)−(attenuation value of the pancreas at late phase CT). Then, the enhancement washout percentages were also calculated with the following equation: percentage of enhancement washout=[(attenuation value of the pancreas at arterial phase CT−attenuation value of the pancreas at late phase CT)/attenuation value of the pancreas at arterial phase CT]×100. Unpaired *t* test was performed to evaluate statistical differences comparing the attenuation values of the pancreas between the two groups. A *P* value less than .05 was considered to indicate a statistically significant difference.

3. Results

The mean CT attenuation values of the pancreas in the early phase of dynamic CT in patients with hypovolemic shock (95.4±29.1 HU, range 45–175 HU) were significantly lower ($P<.001$) than those in non-traumatic and non-hypovolemic patients (136.6±17.9 HU, range 100–179 HU), indicating decreased pancreatic perfusion in patients with hypovolemic shock (Figs. 1, 2). However, in three patients who died during the clinical follow-up, the mean CT attenuation values of the pancreas in the early phase (137, 161 and 175 HU) were higher than 136.8 HU which was the mean CT value of the pancreas in control subjects, indicating the preserved or increased pancreatic enhancement. Conversely, the mean CT attenuation values of the pancreas in the late phase of dynamic CT in patients with hypovolemic shock (95.9±17.6 HU, range 72–137 HU) were significantly higher ($P<.0026$) than those in non-traumatic and non-hypovolemic patients (87.2±9.0 HU, range 70–111 HU), indicating delayed or prolonged pancreatic enhancement in patients with hypovolemic shock (Figs. 1 and 2).

The mean enhancement washout of the pancreas in patients with hypovolemic shock (1.3±22.7 HU, range −54 to 42 HU) was

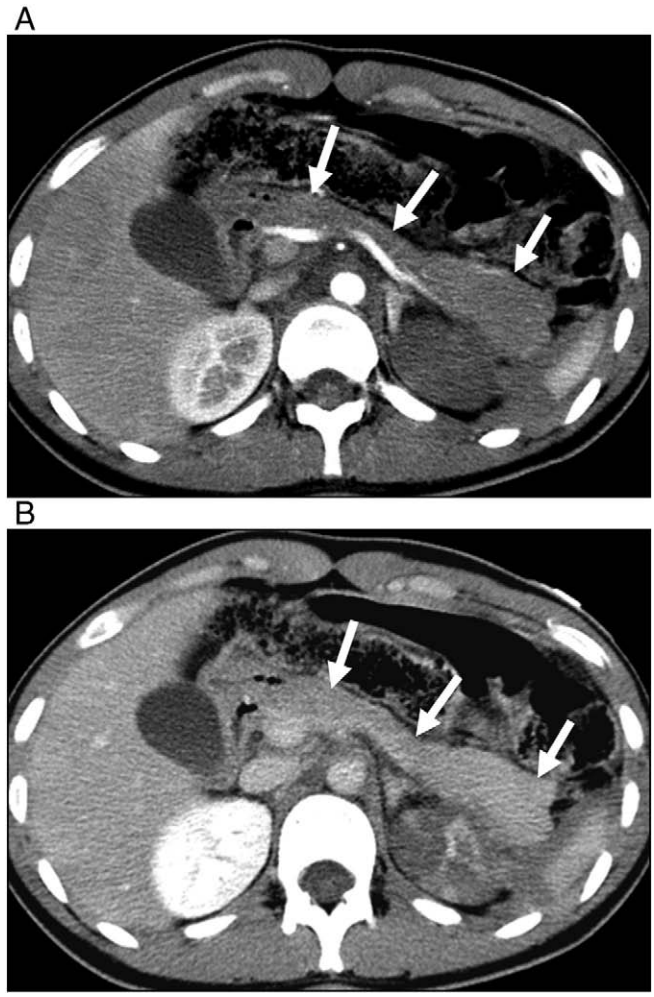

Fig. 1. A 23-year-old woman with hypovolemic shock. (A) Arterial-phase contrast-enhanced dynamic CT shows decreased enhancement (73 HU) of the pancreas (arrows). Note the poor enhancement of the left kidney due to renal injury. (B) On the late-phase contrast-enhanced dynamic CT, the pancreas shows higher attenuation (96 HU) compared with arterial-phase CT, indicating delayed enhancement (arrows).

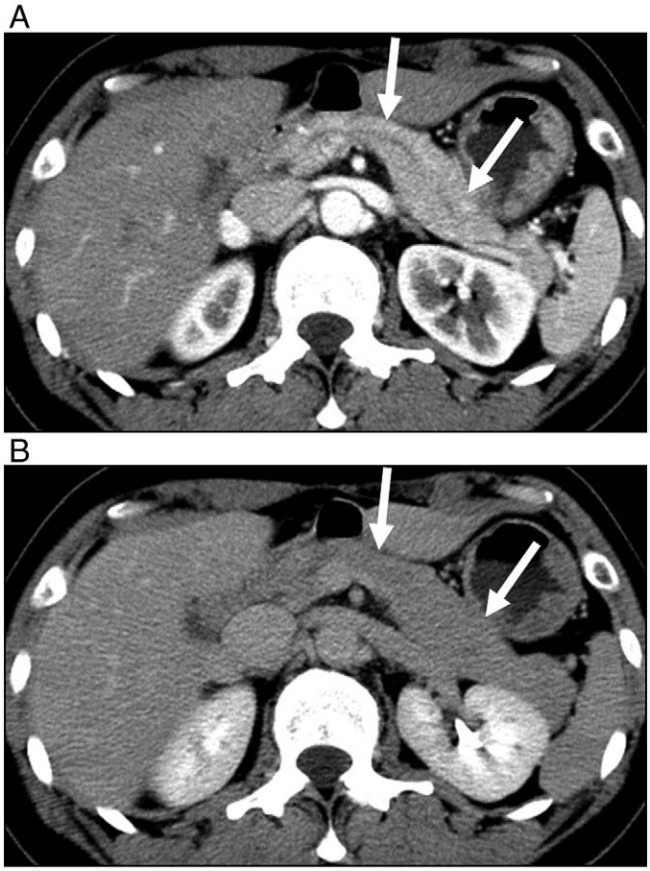

Fig. 2. A 38-year-old woman without hypovolemic shock (control subject). (A) Arterial-phase contrast-enhanced dynamic CT demonstrates early enhancement (131 HU) of the pancreas (arrows). (B) On the late-phase contrast-enhanced CT, the enhancement washout (85 HU) of the pancreas is observed (arrows). Contrast enhancement pattern of the pancreas in this control subject is different from that in the patient with hypovolemic shock.

significantly lower ($P<.001$) than that in control subjects (49.5±14.4 HU, range 25–87 HU). Additionally, the mean percentage (−6.9±29.7 %, range −108% to 31%) of enhancement washout of the pancreas in patients with hypovolemic shock was also significantly lower ($P < .001$) than that (35.6±6.8%, range 23–50%) in control subjects. These results indicated that, in most patients with hypovolemic shock, pancreatic perfusion in the early phase of dynamic CT decreased while pancreatic parenchyma in the late phase showed delayed or prolonged enhancement, compared with control subjects (Table 1).

4. Discussion

There have been several previous reports showing hyperenhancement of the pancreas at contrast-enhanced CT in the setting of trauma and hypovolemic shock complex [12,14]. This was the opposite of our observation. Conversely, some other reports demonstrated hypoenhancement of the pancreas in patients with hypovolemic shock [16,17], supporting our observation. Our study showed that the mean CT attenuation values of the pancreas in the early phase of dynamic CT in patients with hypovolemic shock were significantly lower than those in non-traumatic patients, indicating decreased pancreatic perfusion in patients with hypovolemic shock. One reason for this difference may be based on the study population. The patients in the previous studies were limited to children while a majority of our patients were adults. The second reason may be the difference in the severity of hypovolemic shock. In the previous studies, more than 85% of patients died, indicating severe irreversible shock, while approximately two-thirds of our patients survived, suggesting compensated or reversible shock. The sympathetic reflex to hypovolemia causes arterial vasoconstriction that is likely responsible for the decreased early enhancement of the pancreas. Therefore, hypoperfusion of the pancreas may indicate compensated conditions with the pancreatic arterial vasoconstriction required in maintaining blood flow to the vital organs [3,12]. The third reason may be the difference in the method for contrast-enhanced CT. In the previous studies, hand bolus injection of contrast agents was performed by the use of old-fashioned CT scanner, resulting in slow scanning and missing decreased pancreatic perfusion in the early phase of contrast-enhanced CT. Conversely, in our study, a mechanical power bolus injection with the fixed injection duration of 30 s was performed by the use of multidetector-row CT, achieving very fast scanning and detecting early hypoperfusion of the pancreas. Decreased pancreatic enhancement may lead to the erroneous impression that pancreatic necrosis is present. Therefore, our results suggested that it would be clinically important to recognize that hypoenhancement of the pancreas in the early phase of dynamic CT is a common finding in patients with hypovolemic shock. Familiarity with this CT finding that is a part of the hypovolemic shock should help avoid unnecessary laparotomy for the mistaken suspicion of pancreatic injury.

In our 30 hypovolemic shock complex patients, however, three patients showed intense enhancement of pancreas with CT attenuation values higher than 136.8 HU in the early phase of dynamic CT, and these three patients died. Also in the previous report, increased pancreatic enhancement was observed in one patient who died [16]. The etiology of intense pancreas enhancement of these patients may represent progression to decompensated or irreversible shock. Therefore, it should be noted that intense pancreatic enhancement in hypovolemic shock complex patients may be associated with severe injury and a poor outcome.

Regarding the late-phase CT findings, the mean CT attenuation values of the pancreas in the late phase of dynamic CT in patients with hypovolemic shock were significantly higher than those in non-traumatic patients. Delayed enhancement will be related to the increased permeability of shocked pancreatic parenchyma leading to leakage of recirculating contrast material into the interstitial space.

Our study is limited by the fact that the stages of the hypovolemic shock, which may affect dynamic CT findings, were not considered in this study. Hypovolemic shock typically progresses through three stages [3]. In compensated shock, the factors of systemic autoregulation alter circulation by preserving blood flow to vital organs and shifting flow away from the splanchnic vessels. In uncompensated shock, the sympathic response is no longer able to maintain cardiac output. Consequently, cardiac depression and loss of vascular tone develop, manifested by decreased blood pressure. Eventually, irreversible shock develops, and cardiac output and blood pressure fail to return to normal even with replacement of lost volume [3,12,14]. However, it would be clinically difficult to determine whether the patient was in the compensated, uncompensated or irreversible stage of the hypovolemic

Table 1
Comparison of mean CT attenuation value and enhancement washout at contrast-enhanced dynamic CT between patients with hypovolemic shock and control subjects

	Patients with shock ($n=30$)	Control ($n=60$)	*P* value
Mean CT value			
Arterial-phase	95.4±29.1 HU (45–175)	136. 6±17.9 HU (100–179)	p<.001
Late-phase	95.9±17.6 HU (72–137)	87.2±9.0 HU (70–111)	p<.026
Mean enhancement washout	1.3±22.7 HU (−54 to 42)	49.5±14.4 HU (25–87)	p<.001
Mean enhancement washout percentage	−6.9±29.7 % (−108 to 31)	35.6±6.8 % (23–50)	p<.001

Note. Data are mean±SD. The numbers in parentheses are range.

shock at the time of CT examinations. In this study, CT scan had been performed in patients who had responded appropriately to resuscitative measures and appeared hemodynamically stable. Another limitation is that we used fixed scan delays without individualizing scan delays for each patient by means of a test bolus or bolus-tracking techniques. We recognize that the time to peak contrast enhancement would be certainly affected by an altered cardiac output and circulation times in hypovolemic patients. However, we believe that it would be clinically more important to analyze the difference in contrast enhancement effects under these critical situations.

In conclusion, decreased pancreatic perfusion in the early phase and delayed pancreatic enhancement in the late phase of contrast-enhanced dynamic CT were seen in patients with hypovolemic shock. This alteration of pancreatic enhancement may be caused by preserving blood flow to vital organs such as brain and lung. It will be clinically important to know the pancreatic perfusional changes at contrast-enhanced dynamic CT in patients with hypovolemic shock for accurate and timely interpretation of findings.

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