PiCO$_2$ Monitoring of Transferred Jejunum Perfusion Using an Air Tonometry Technique After Hypopharyngeal Cancer Surgery

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Abstract: This study aimed to investigate the usefulness of intraluminal PCO$_2$ (PiCO$_2$) monitoring by air tonometry for the assessment of the vascular condition of the transferred jejunum after surgery for hypopharyngeal cancer.

PiCO$_2$ in the transplanted jejunum of 24 patients was monitored using air tonometry after radical surgery for hypopharyngeal cancer from 2003 to 2010.

All but 1 patient, who removed the catheter before monitoring began, were monitored safely. PiCO$_2$ in the transferred jejunum correlated with arterial PCO$_2$ (PaCO$_2$) that was measured concurrently, and dissociation of PiCO$_2$ from PaCO$_2$ was observed in cases with vascular complication. In those cases without postoperative vascular complication, the PiCO$_2$ value gradually increased for 3 hours but then decreased by 12 hours after surgery. Three patients experienced major vascular complication. All 3 patients had continuous elevation of PiCO$_2$ >100 mm Hg, although vascular flow in 1 patient recovered by removal of a venous thrombosis and reanastomosis of the vein 7.5 hours after surgery. Four other patients who experienced elevation of PiCO$_2$ had their skin suture released for decompression of their neck wound, resulting in a decrease in PiCO$_2$ after treatment.

The current results demonstrated that continuous monitoring of PiCO$_2$ by air tonometry accurately reflects the vascular condition of the transferred jejunum, and this method is one of the best options for postoperative monitoring of jejunum blood perfusion.

(*Medicine* 94(11):e632)

Abbreviations: PaCO$_2$ = arterial PCO$_2$, PiCO$_2$ = intraluminal PCO$_2$, TPL = total pharyngolaryngectomy, TPLE = total pharyngolaryngoesophagectomy.

INTRODUCTION

Regardless of the development of multidisciplinary treatment, including chemoradiation or radiotherapy, either with or without surgery, advanced-stage hypopharyngeal cancer is associated with a poor prognostic outcome, and the 5-year survival rate of this disease remains below 50%.[1,2] Total pharyngolaryngectomy (TPL) or total pharyngolaryngoesophagectomy (TPLE) followed by reconstruction using free jejunum transfer is one of the standard treatments for advanced hypopharyngeal cancer and cervical esophageal cancer. In recent years, salvage surgery is often necessary for patients who fail after radiotherapy or chemoradiotherapy, which increases the surgical and postsurgical risk of complication. About 5% of patients still experience failed pharynx reconstruction, mostly due to vascular complication.[3–5] Early detection of vascular problems and prompt treatment are critically important because salvage of the transferred jejunum with the removal of thrombosis and reanastomosis is challenging in most cases. The jejunum is intolerant to ischemia because ischemia lasting >3 hours can result in irreversible damage to the jejunum.[6,7] Impaired vascular perfusion of the transferred jejunum may require secondary reconstruction using less suitable vessels, a gastric pull-up procedure to restore a failed jejunum interposition, or establishment of pharyngocervical skin and esophagocervical skin fissures. Patients who undergo these secondary surgeries can be in a more jeopardized situation because of leakage of saliva or digestive juices, leading to a higher risk of infection and delayed wound healing. Thus, accurate blood flow assessment of the transferred jejunum and early detection of insufficient perfusion is crucial for free jejunum reconstruction.

Tonometers, or gastric tonometers, have been developed for monitoring the splanchnic mucosal blood flow and have become extensively employed in clinical practice to monitor critically ill patients.[8,9] Recently, this technique has frequently been used in the detection and assessment of chronic gastrointestinal ischemia.[10–12] Tonometer catheters enable measurement of the pco$_2$ of the targeted organ by equilibrating the air in a silicone balloon placed on the catheter tip with the target luminal organ filled with secreted intestinal fluids. Formerly, pco$_2$ was measured using a saline-based method, but, at present, air-based and automated measurement of pco$_2$, known as air tonometry, is widely available, and this air tonometry technique has the great advantage of easy measurement and eliminating errors in manual fluid tonometry.[8]

Tonometry is considered to be useful in monitoring graft perfusion in an alternative model of intestinal autotransplantation,[13] and hence we previously reported the usefulness of the saline-based tonometry for monitoring blood flow in the transferred jejunum after TPL or TPLE.[14] This study therefore aimed to investigate the usefulness of intraluminal PCO$_2$ (PiCO$_2$)

monitoring by air tonometry as a new, easy-to-use, and alternative approach to evaluating blood flow in the transferred jejunum.

PATIENTS AND METHODS

Twenty-nine patients underwent total TPL or TPLE for hypopharyngeal cancer from 2003 to 2010. Twenty-five patients had a tonometry catheter (TRIP gastric catheter; GE Healthcare, Helsinki, Finland) inserted through the nose, so that the silicone balloon of the catheter tip was placed in the transferred jejunum during the operation (Figure 1). The catheter was connected to Tonocap (Datex-Ohmeda, Helsinki, Finland), and Pi_{CO_2} was measured continually and automatically. Approval of the protocol including the use of clinical data was obtained from our institutional review board. The patients' consent to undergo Pi_{CO_2} measurement was obtained before insertion of the catheter.

FIGURE 1. (A) Tonometry catheter was inserted through the nostril during surgery. The silicone balloon of the catheter tip was placed in the transferred jejunum. (B) Neck x-ray revealed the correct location of the catheter. White triangles indicate the shape of the silicone balloon, and the arrows indicate the markers of the catheter.

With regard to postoperative management, all patients stayed at least 1 night in the intensive care unit with ventilatory support; 23 cases were maintained under synchronized intermittent mandatory ventilation, whereas 2 cases were maintained under continuous positive airway pressure. Most patients were taken off the ventilator and returned to the general ward the day after surgery. All patients were treated with prostaglandin E1 0.1 µg/kg/min or Lipo-PGE1 120 µg/d for 1 week.

We started measuring Pi_{CO_2} after transfer to the intensive care unit. Pi_{CO_2} was recorded every hour up to 24 hours after the operation, then every 1 to 3 hours up to 48 hours after the operation, and finally every 3 to 6 hours up to 72 hours after the operation. Arterial P_{CO_2} (Pa_{CO_2}) was measured 1 to 10 times, as necessary, during postoperative management.

Based on our previous data,[14] neck skin sutures were removed for decompression of the transferred jejunum when the Pi_{CO_2} value exceeded 70 mm Hg. When Pi_{CO_2} was >80 mm Hg, we reopened the patient's neck wound to check the condition of the jejunum and vascular anastomosis.

Pa_{CO_2} and the corresponding Pi_{CO_2} were statistically assessed with regard to their correlation using Pearson correlation test. CO_2 in patients without vascular trouble was analyzed, whereas those with vascular trouble were evaluated individually to review the efficacy of our treatment for the transferred jejunum.
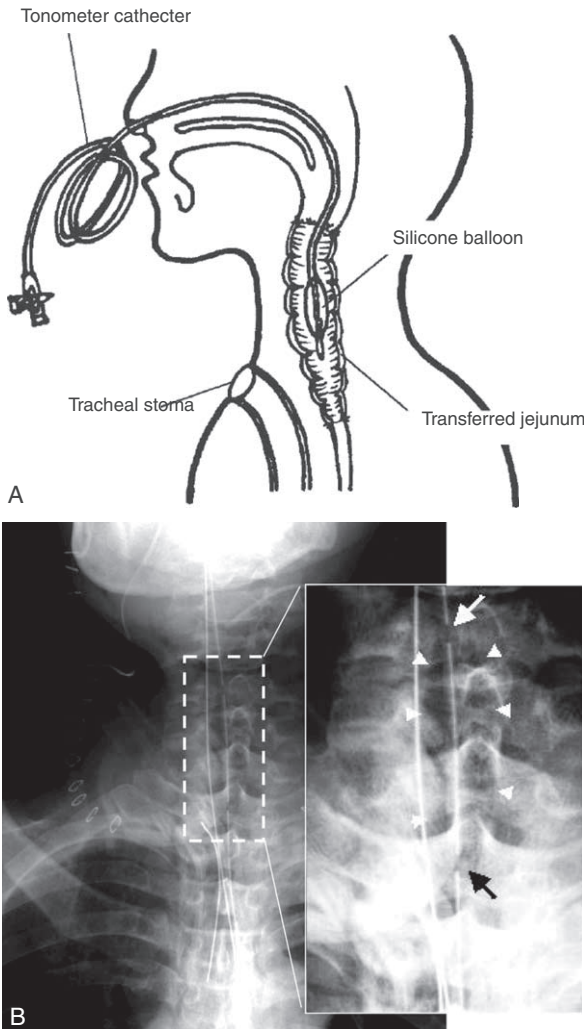
RESULTS

Patients' Data and Characteristics

One of the 25 patients was excluded because his catheter was pulled out before measurement of Pi_{CO_2}. Clinical data and Pi_{CO_2} values for 24 cases were analyzed. Clinical data of the 24 patients are summarized in Table 1. The average duration of catheter placement was 96 hours (13–135 hours) because 1 patient pulled out the catheter 13 hours after surgery. No problems were observed with regard to measuring Pi_{CO_2}.

Pi_{CO_2} of the Transferred Jejunum Correlates With Pa_{CO_2}

Pi_{CO_2} value is influenced by the respiratory status and blood oxygenation of the patient. The oxygenation level of each patient can be expected to vary because of individual differences in preoperative lung function. Therefore, we at first analyzed the correlation between Pi_{CO_2} and Pa_{CO_2} that was measured concurrently with Pi_{CO_2} measurement. In 17 patients without vascular complication of the transferred jejunum during their postoperation course, Pi_{CO_2} correlated significantly with Pa_{CO_2} (Figure 2). On the other hand, Pi_{CO_2} in patients with vascular trouble and who had skin decompression treatment showed no correlation with Pa_{CO_2} (data was not shown). These data suggest that the Pi_{CO_2} value reflects the blood flow of the jejunum mucosa in the normal postoperative course, and dissociation of Pi_{CO_2} from Pa_{CO_2} is a convincing indicator of vascular complication.

Pi_{CO_2} Measurement Elucidates the Vascular Condition of the Jejunum After Transplantation

This tonometry system enabled monitoring of the oxygenation status of the transferred jejunum automatically and seamlessly, and also enabled us to presume an event happening to the transferred tissue in the postoperative process. Figure 3 exhibits the averages of serial Pi_{CO_2} in those cases without postoperative vascular complication. The $P_i_{CO_2}$ value gradually increased for

TABLE 1. Patient's Characteristics

Sex (male/female)	21/3	
Age	52–74, average 64	
Stage	II 4	
	III 3	
	IV 17	
Pretreatment	None	8
	CTx (PF or TPF)	7
	CTx followed by RTx	3
	CRTx (concurrent PF or Doc)	5
	Partial resection of hypopharynx + RTx	1
Surgical procedure	Total pharyngotomy	22
	Total pharyngectomy + transhiatal esophagectomy	1
	Partial pharyngectomy + cervical esophagectomy	1
	Neck dissection	
	None	2
	Unilateral	3
	Bilateral	19
Vascular anastomosis	Artery	
	Suprascapular artery	11
	Suprathyroidal artery	8
	Facial artery	1
	Tongue artery	4
	Vein	
	External jugular vein	15
	Facial vein	3
	Suprathyroidal vein	2
	Internal jugular vein	3
	Cervical transverse vein	1
Measuring time, h	13–135, average 96	

CRTx = chemoradiotherapy, CTx = systemic chemotherapy, Doc = docetaxel 10 mg/m² /wk, PF = cisplatin 60 mg/m² (4 days) + 5-fluorouracil 600 mg/m², RTx = radiotherapy, TPF = docetaxel 60 mg/m² + cisplatin 60 mg/m² + 5-fluorouracil 700 mg/m² (4 days).

Pico₂ and Paco₂ of cases without complications

$r = 0.6443 \ (P < 0.001)$
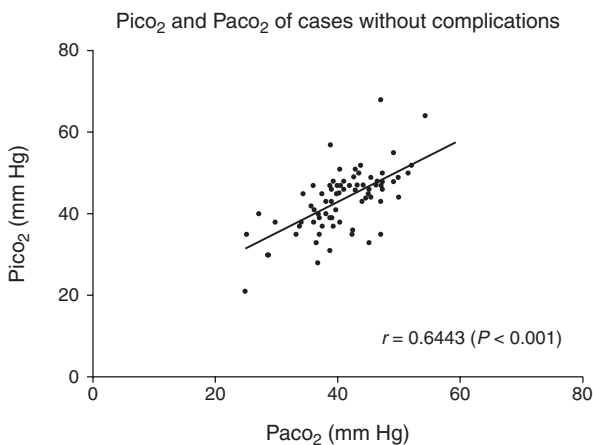
FIGURE 2. Pico₂ and Paco₂ correlated significantly in 17 cases without vascular complication. Paco₂ was measured concurrently with Pico₂. Pico₂ = intraluminal Pco₂.

Average Pico₂ transition of cases without complications
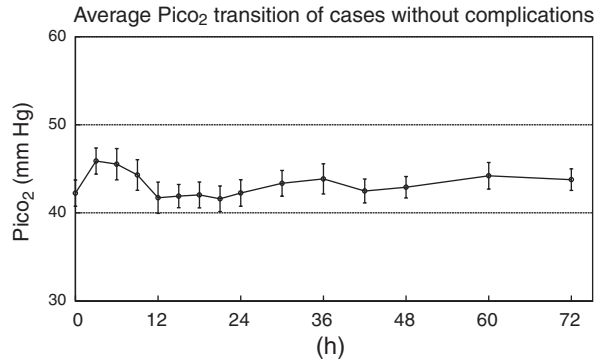
FIGURE 3. In cases without complications, Pico₂ values gradually increased for 3 hours but then decreased up to 12 hours postoperation. From 12 to 72 hours after surgery, the average Pico₂ value was between 40 and 50 mm Hg. Error bars indicate the standard error. Pico₂ = intraluminal Pco₂.

3 hours, then decreased within 12 hours postoperation. From 12 to 72 hours after surgery, average Pico₂ values were between 40 and 50 mm Hg. Vascular problems after free jejunum transfer mostly ensue within 4 to 72 hours[15,16]; thus, the increase in Pico₂ coincided with this hazardous period. This transient increase in Pico₂ may represent a congestion of the transferred jejunum induced by compression of the operated tissue, and this subacute change of operation field has the possibility of increasing risk of blood flow obstruction leading to jejunum necrosis.

Pico₂ Measurement Enables Vascular Complication of the Transferred Jejunum to be Avoided

Three patients experienced major vascular complications. Pico₂ in all 3 patients was elevated to above 100 mm Hg and their vascular condition was evaluated in the operating room because of such continuous elevation. Jejunum blood flow in 1 patient recovered by removal of a venous thrombosis and reanastomosis of the vein 7.5 hours after the initial surgery (Figure 4A). However, transplants in the other 2 patients needed to be sacrificed (Figure 4B and C). In the patient with vessel reanastomosis, his elevated Pico₂ decreased temporarily after restoration of vessel patency, but started to increase again 12 hours after the initial surgery, but the removal of skin sutures and decompression resulted in normalizing the Pico₂ level. He had no trouble in his postoperative course subsequently (Figure 4A).

Four other patients from among the 24 cases who had elevated Pico₂ had their skin suture released for decompression of the transferred jejunum (Figure 5A–D). Pico₂ in all 4 cases decreased after removal of their skin suture, and they did not experience any postoperative complications, except for 1 patient who experienced salivary leakage and fistula formation that recovered following conservative treatment. The maximum elevation of Pico₂ in these cases was observed about 3.5 to 43 hours after the surgery when it was coincident with the hazardous period of the jejunum transfer. Moreover, Pico₂ elevation started from >12 hours after the surgery in 3 of the 4 patients (Figure 5A, C, and D), which was deviated from normal Pico₂ transition (Figure 3). The Pico₂ transition of these cases indicated that cervical skin suture has the possibility of compressing jejunum perfusion continuously, and removal of
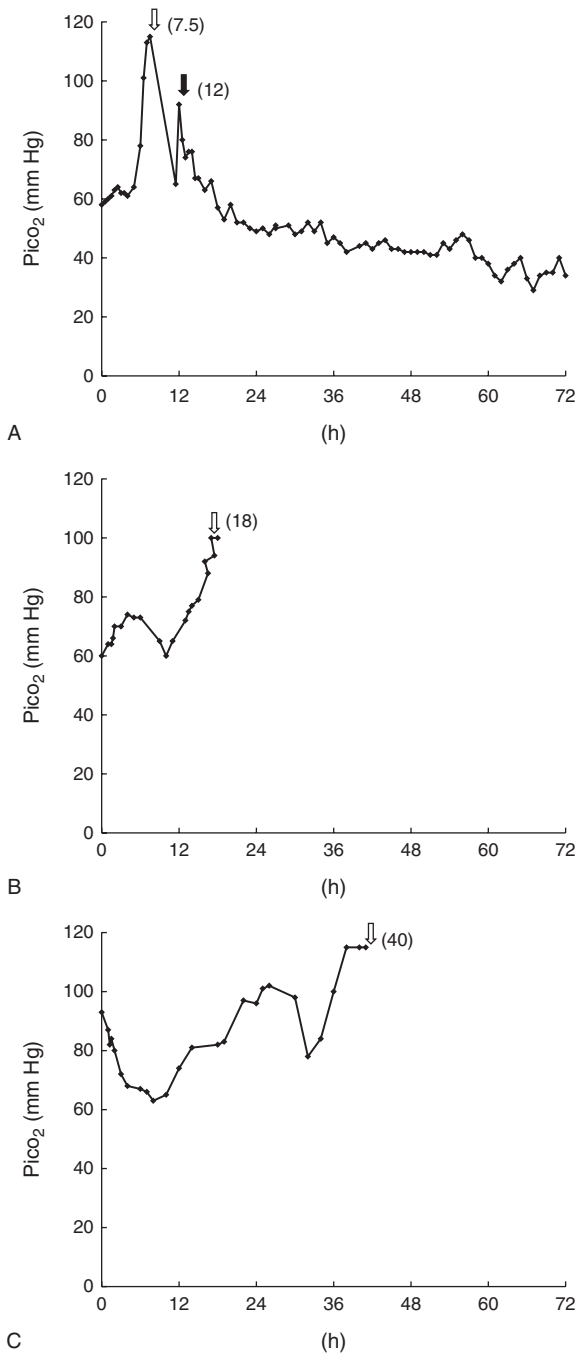
FIGURE 4. Three of the 24 patients experienced major vascular problems. $Pico_2$ in all the 3 patients rose >100 mm Hg, and their vascular condition was evaluated in the operating room. The white arrows indicate the time at which they returned to the operating room. The transplanted jejunum in 1 patient (A) was rescued by removal of venous thrombosis and reanastomosis of the grafted vein. However, transplants of the 2 other patients (B and C) needed to be sacrificed. In the case with vessel reanastomosis, elevated $Pico_2$ at one time decreased after restoration of vessel patency but started to increase again at 12 hours after the initial surgery (black arrow). However, removal of the skin suture and decompression resulted in normalizing the $Pico_2$ level. $Pico_2$ = intraluminal Pco_2.

the suture and release of the neck wound pressure may improve blood flow in the transferred jejunum.

DISCUSSION

Free transferred tissues need to be monitored carefully and accurately since graft failure often leads to severe complications in head and neck cancer patients who often have poor nutrition or are in poor physical condition due to their tumor or previous therapy. TPL with free jejunum transfer is the standard surgical treatment for advanced hypopharyngeal cancer, but monitoring vascular flow in the transferred jejunum is difficult because the transferred jejunum is covered by cervical skin.[15] Two conventional methods for monitoring the buried flap are transcutaneous Doppler ultrasound monitoring of the pedicles[17] and monitoring flap.[18] Even if the experienced surgeon tries to find the pedicle using ultrasonography, it is sometimes impossible to exclude the local vascular system with certainty, which can lead to a misunderstanding of the intestinal blood flow.[15] It is sometimes difficult to use a monitoring flap to estimate the condition of the blood flow because of torsion or tension of the perforator, or an unclear determination of the monitoring flap.[18] Furthermore, the change in color of the jejunum resulting from ischemia requires a long interval after vascular obstruction.[19]

The current results demonstrate that continuous monitoring of $Pico_2$ by air tonometry accurately reflects the vascular condition of the transferred jejunum, and this method is one of the best options for postoperative monitoring of jejunum blood flow. In the present study, $Pico_2$ of the transferred jejunum correlated significantly with systemic $Paco_2$ that was measured concurrently. The average $Pico_2$ value in patients with a normal postoperative course was 45.4 mm Hg, and the dissociation of $Pico_2$ from $Paco_2$, together with the continuous elevation of $Pico_2$, reflected occlusion of the anastomotic vein. The $Pico_2 - Paco_2$ gradient is considered to be the most sensitive and specific parameter of gastrointestinal perfusion, independent of systemic metabolic and respiratory changes.[10] There is no consensus on the normal $Pico_2$ value for the transferred jejunum and the critical level of $Pico_2$ indicating mucosal malperfusion. Otte et al[10] reported that the average $Pico_2$ of healthy volunteers was 4.9 kPa (36.8 mm Hg), whereas Kolkman et al[8] reviewed the upper limit of normal values for $Pico_2$ and found it to be 6.5 kPa (49 mm Hg) in the gastric tonometry and 1.2 kPa (9 mm Hg) for the $Pico_2 - Paco_2$ gradient. In an alternative animal model of intestinal autotransplantation, histological change of the intestinal mucosa started to be observed at 11.2 mm Hg of the gradient of $Pico_2 - Paco_2$, and extensive mucosal damage was observed at 32.9 mm Hg.[13] An increase in $Pico_2$ of >60 mm Hg indicated the development of compromised perfusion in the series in which saline-based tonometry was employed.[14] From these data and our average $Pico_2$ data, it is feasible that $Pico_2$ >60 mm Hg is critical for the transferred jejunum. This $Pico_2$ measurement by air tonometry is a compelling technique for estimating the blood flow of the transplanted jejunum.

$Pico_2$ monitoring has the potential to contribute to early detection of vascular complications, which may enable a staged strategy for the graft vessels of the transferred jejunum. In the present study, an elevated $Pico_2$ level of >60 mm Hg is considered abnormal, and it is highly indicative of vascular complications of the transferred jejunum based on our previous data.[14] In patients with continuous elevation of $Pico_2$ >70 mm Hg, we decided to remove the surgical skin suture for decompression of the jejunum and their vessels before checking their vessels in the operating room. Intestinal blood flow is
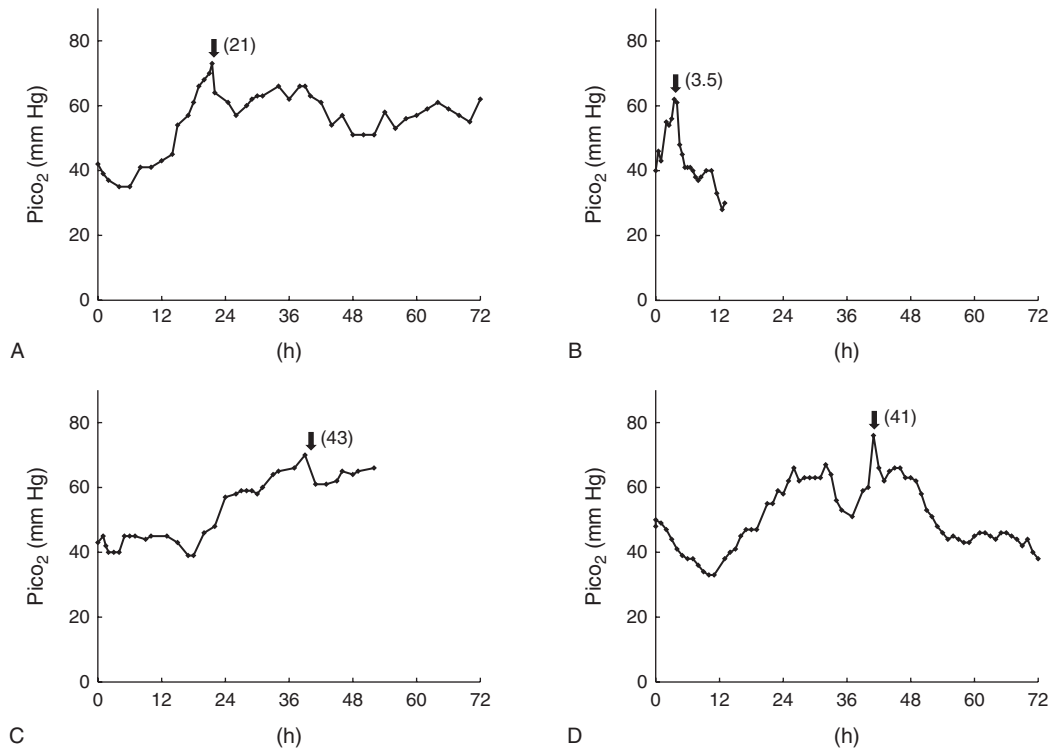
FIGURE 5. Four other patients who had elevated $Pico_2$ had their skin suture released for decompression of the transferred jejunum. $Pico_2$ in all 4 cases decreased after removal of the skin suture. Black arrow indicates the time at which their skin sutures were removed. $Pico_2$ = intraluminal Pco_2.

vulnerable to the surrounding pressure,[20] and one of the main reasons for vascular occlusion after reconstruction surgery is the excessive pressure to the graft vessels caused by a tight wound closure, hematoma, or extrinsic compression from tapes or strips around the neck.[21,22] In this study, the $Pico_2$ value of those patients with decompressed cervical wound decreased after treatment, and we believe that some of these cases were prevented from having jejunum vascular occlusion. In the case that wound compression is highly predicted, like a patient receiving chemoradiotherapy, the neck wound might be left open to weigh the timing of wound closure based on $Pico_2$ value. Further accumulation of patient data and a prospective study is needed to clarify whether skin decompression is effective or not, and to determine appropriate criteria for $Pico_2$ levels in the staged treatment of impaired vascular perfusion of the transferred jejunum.

In conclusion, $Pico_2$ measurement with a gastric tonometer is useful for monitoring the transferred jejunum blood flow and early detection of vascular complications. As $Pico_2 > 60$ mm Hg is considered to indicate abnormal blood flow of the jejunum, the $Paco_2 - Pico_2$ gap should be assessed, and patients with continuous increase in $Pico_2$ need to have their graft vessel status checked urgently. Cervical skin decompression may contribute to restoring jejunum perfusion.

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