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Jejunum versus colon for free oesophageal reconstruction: an experimental radiological assessment

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Summary—The reconstruction of the cervical oesophagus and the hypopharynx by revascularised bowel grafts has become a frequently described treatment option. Problems with the standard jejunal grafts have led us to suggest that the colon provides a suitable alternative. Experimental work in dogs demonstrates clear functional differences between colon and jejunum as free oesophageal grafts, and shows how structurally and functionally the colon integrates into the new position in the oesophagus better than the jejunum.

Surgical reconstruction of the oesophagus and hypopharynx for both benign and malignant disease has posed problems to every generation of surgeons since the late nineteenth century. Missotten (1983) reviewed the techniques which have been employed over the years, and the wide variety of methods attests to the unsatisfactory results that many of these have achieved. Since the development in the widespread application of microvascular techniques, many centres have advocated the use of revascularised bowel to achieve this reconstruction. Although the technique has its detractors, in certain units it is now the method of first choice and after 25 years of successful application it must be considered as an established first line option in the management of this difficult surgical problem.

Although the donor sites for revascularised bowel transfer have included ileum, sigmoid colon and stomach, the jejunum has been the region favoured by the vast majority of authors. The American series of McKee and Peters (1978), Gluckman *et al.* (1982) and Sasaki *et al.* (1982), and the European series of Reuther *et al.* (1984), all support the use of jejunum on the grounds that it is easy to harvest, the vessels are sufficiently large and accessible and the bowel lumen matches that of the cervical oesophagus more closely than any other part of the intestinal tract. However, there have been certain functional problems described with the use of jejunum as a free bowel graft of the oesophagus. Sasaki *et al.* (1980) and Reuther *et al.* (1984) have described complications arising from the secretory behaviour of the jejunum in its new site. Postoperative dysphagia has been described by at least two groups, namely McKee and Peters (1978) and Harashina *et al.* (1985), and led the latter group to propose their elaborate double-folded free jejunum technique. Gluckman *et al.* (1982) claimed that lymphoedema of the graft was a significant postoperative complication causing a degree of lumenal obstruction in the early stages. Finally, Meyers *et al.* (1980) have shown that the persisting peristalsis of the jejunal graft does not co-ordinate at all with the total action of the oesophagus during the passage of food.

As an alternative to free jejunum, the use of free colon grafts appears to have been largely ignored since the publications of Nakayama *et al.* (1964) and Chrystopathis (1966). However, in that the sigmoid colon is as easy to harvest as a loop of jejunum, and the transverse colon is little worse, the bowel has an absorptive rather than a secretory function, the mucosa is more resistant to the ischaemic trauma of the transfer (Robinson *et al.*, 1974), and the graft vessels are of a far greater size, we would suggest that the role of the colon as a free interpositional graft of the cervical oesophagus deserves serious reconsideration.

In view of these considerations we set up an animal model, after the manner of Siedenberg *et al.* (1959) and Green and Som (1966), to compare the behaviour of revascularised bowel grafts of colon versus jejunum.

Materials and Methods

The study involved setting up an animal model in which to study the behaviour of revascularised

lengths of colon and jejunum, which had been interposed into the cervical oesophagus. The animal selected was the greyhound since it possesses a long and accessible cervical oesophagus in which 10 to 14 cm could be replaced without any encroachment into the thorax. Furthermore, the unexcitable temperament of these dogs was well suited to the *in vivo* tests of oesophageal motility with which we planned to examine the grafts. We standardised onto mature female animals of mean weight 25.74 kg (22.5–29.0) and they underwent the primary replacement operation followed by *in vivo* radiological studies after a period of about 6 weeks. In the main experimental series, they were divided into three groups according to graft type. One group had isoperistaltic jejunal grafts, and the other two groups both had colon grafts, one isoperistaltically and the other antiperistaltically inserted.

Operation and postoperative care

The animals were operated upon under general anaesthesia with per-operative monitors of ECG, pulse, urine output and core temperature. The only bowel preparation required was routine deworming in all the subjects and an enema administered to the subjects for colonic grafting on the morning of their operation.

The operative technique was similar to that described by Green and Som (1966) in the dog. The vessels of the left side of the neck were used and in all our subjects an end to side arterial anastomosis was performed on to the common carotid artery; the venous anastomosis was achieved by end to end anastomosis to the anterior facial vein which was mobilised to its junction with the external jugular vein, and turned down to lie next to the carotid sheath. After extraction of the graft from the abdomen it was not subjected to any vascular irrigation, but its lumen was irrigated with cold Hartmann's solution at 4°C containing 0.22% dextrose to help to reduce the ischaemic trauma suffered by the graft mucosa as suggested by Robinson *et al.* (1974). This also acted as a thorough mechanical cleansing of the graft. The graft was secured into the oesophagus before the vascular anastomoses were performed, and although this prolonged the ischaemic time it did minimise the potential of trauma to these anastomoses. Total ischaemic time for the grafts was between 2¼ and 2½ hours. A standard length of 10 cm of the cervical oesophagus was replaced and the total operation time was between 4¼ and 5 hours. Postoperatively the dogs were monitored overnight, sedated and maintained on sufficient analgesia as assessed by their pulse rate and their levels of consciousness. Oral intake was started with water on Day 2 and a high calorie, high protein fluid diet started on Day 3 and gradually thickened over the first week. By the second week they were on a sloppy diet of their normal rations.

Radiological investigations

After 6 weeks a settled feeding pattern had been established and the subjects had fully recovered from the trauma of the operation. The dogs were then given a barium swallow examination, recorded by videofluoroscopy.

The animals were not sedated, and the examination was carried out in the standing position, although the subjects were restrained at the shoulder and the pelvis. The head was held upright throughout the investigation. Marker clips inserted at the oesophageal anastomoses during the operation indicated the grafted zone of the cervical oesophagus, and a 2 cm calibrator was attached to the neck to give an estimate of the dimensions of the anastomoses and the graft lumen.

A bandage muzzle was applied to the dogs, and a 10 French gauge, blue line infant feeding tube was passed through the mouth and screened down the oesophagus, into the grafted section. A bolus of 20 ml barium solution was delivered into the graft and the response was recorded. This first test demonstrated the dimensions of the graft and the degree of stenosis at the distal anastomosis as well as the dynamic response to the effect of bolus distension. The catheter was then withdrawn to just above the graft where a second bolus was delivered. This initiated peristaltic activity in the cervical oesophagus which briskly passed the bolus on to the graft. Information as to the dimensions of the proximal anastomosis and the activity between the normal oesophagus and the graft at this interface could be gained from this record. Finally, barium was injected over the back of the tongue to demonstrate the incorporation of the graft into the overall swallowing action. It was necessary to watch the graft for 30 to 40 seconds following the last active swallow in order to gain information as to whether, and to what degree, induced motor activity persisted after the bolus of barium has passed.

Results

From the 25 subjects operated upon in the full experimental series following the initial pilot work,

9 survived into the period of investigation. This is comparable to the only other fully documented canine series, that of Green and Som (1966), in which there were 5 survivors of 15 operations. All the deaths occurred in the first week with 10 succumbing within 48 hours from pulmonary congestion and irreversible shock in the recovery phase. Two animals died with a small bowel intussusception and there were four vascular failures of the graft, divided equally between the venous and arterial sides (Table 1). The survivors

Table 1 Postoperative deaths.

Full study no.:	*25*	*Colon*	*17*	*Jejunum*	*8*
Survivors:	*9*		*6*		*3*
Immediate Deaths (4–48 hours)			Pulmonary congestion		7
			Recovery phase shock		3
Deaths in 1st week (2–7 days)			Intussusception		2
			Venous thrombosis		2
			Carotid blow out		1
			Arterial thrombosis		1
				Total	16

divided equally between our 3 experimental groups. From the pilot work, there was one surviving subject in which the graft was antiperistaltically orientated jejunum, and its barium examination will be described separately.

Dynamic behaviour

Barium swallows of control subjects showed the normal pattern to be a smooth, co-ordinated cycle of dilatation, to accommodate the bolus of barium, followed immediately by contraction. Once the bolus had passed, there was no residual peristaltic action. The dimensions of the lumen with a 20 ml bolus are shown in Figure 1. There was no regurgitation and no tracheal spillage. The jejunal subjects all demonstrated a markedly more dynamic and irritable response both to direct presentation of barium to the graft and a normally swallowed bolus. The first action of the graft to the food stimulus was to contract, in a peristaltic fashion. This had the effect of representing a dynamic, functional reduction in the luminal size (Fig. 1 and 2). Whereas a proportion of the bolus was propelled downwards, there was also a certain amount of upward regurgitation, as demonstrated by clear delineation of the proximal anastomosis and hypopharynx from a bolus delivered to the middle of the

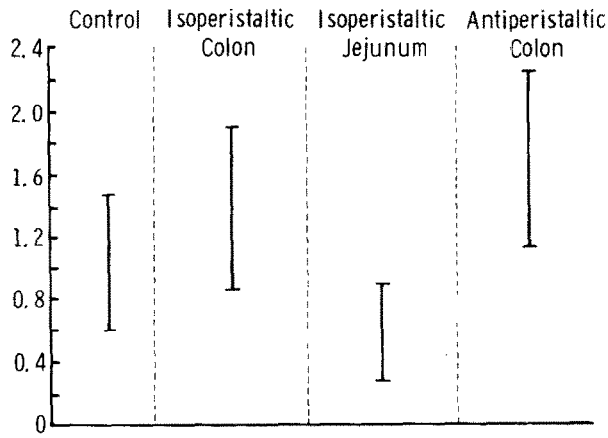

Fig. 1

Figure 1—Mean maximum and minimum lumen diameters as assessed from barium videofluoroscopy.

graft. The peristaltic waves persisted in the graft up to 30 seconds following their initiation, after which they gradually subsided. The colon grafts showed an altogether more passive pattern of behaviour and there was no essential difference between isoperistaltically and antiperistaltically orientated grafts. As in the control subjects, the first action of the colon grafts was to dilate, and mid-graft filling demonstrated no upward regurgitation, merely a downward run-off. This dilatation was followed after a period of 5 to 10 seconds by a contraction, probably due to an elastic recoil of the wall rather than an active muscular contraction. When presented with barium from the hypopharynx the colon behaved as a passive conduit, demonstrating no regurgitation through the proximal anastomosis (Fig. 2). Once the bolus had run-off downward there remained a dilated sump, as indicated by the residual air-contrast pattern, which gradually resumed its previous dimensions.

Anastomoses

Figure 3 shows the mean dimensions of both the proximal and distal graft-oesophagus anastomoses. Although there was an identical 2 layer technique used in all three groups, the colonic graft anastomoses were consistently about twice the diameter of the jejunal anastomoses. In all the subjects the diameter of the distal anastomosis was less than that of the proximal one.

Graft integration

Taking the action of swallowing overall, the colon

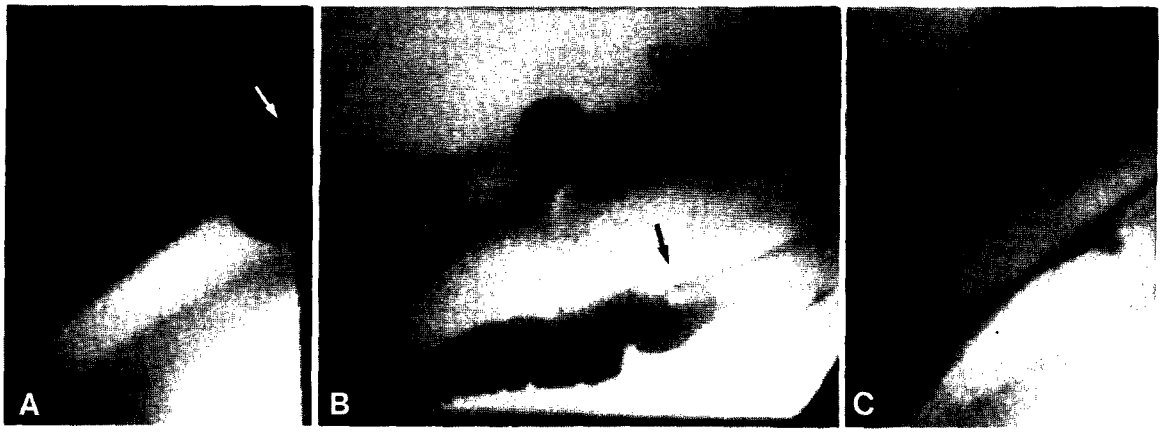

Fig. 2 (i)

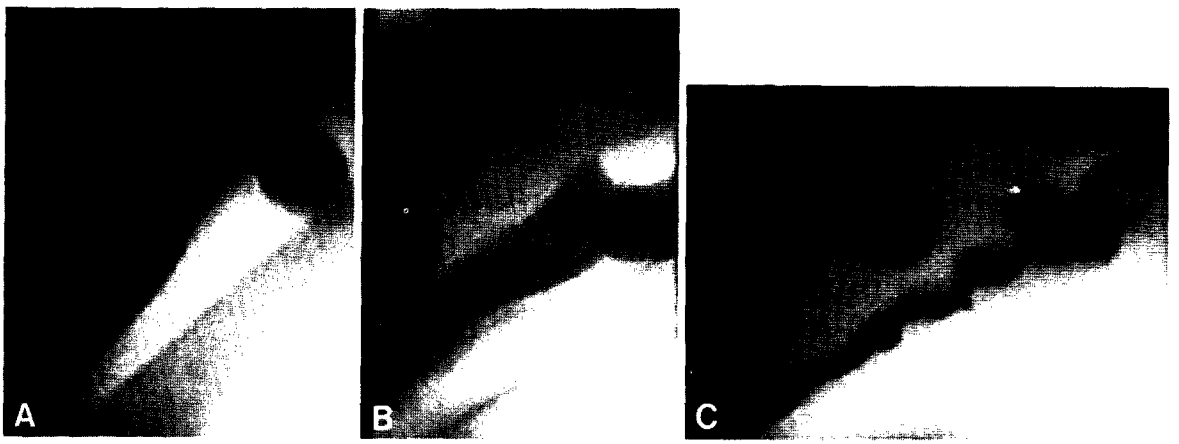

Fig. 2 (ii)

Figure 2—Radiographs of barium swallows: (i) Midgraft injection, arrowed. (ii) Full swallow: (A) control, (B) isoperistaltic colon, (C) isoperistaltic jejunum.

subjects on X-ray showed their graft to be a passive conduit with little hold up at its anastomoses and no dynamic interference of the graft to the passage of food propelled from above and assisted downward by gravity. The jejunal subjects, however, showed marked hold up at the graft, especially if a second bolus was presented soon after the first. This was due to a combination of persisting peristalsis in the graft and the small proximal anastomosis which resulted in about a four-fold difference in the area between the two graft types through which food had to pass to enter the graft. The jejunal subjects would therefore choke more readily and showed more evidence of tracheal spillage.

In day-to-day kennel observations the colon dogs experienced less feeding problem compared to their jejunal counterparts as evidenced by second bolus regurgitation, time taken to complete feeds and the required sloppiness of their rations. They also showed a more complete and rapid return of condition following their operative trauma, as demonstrated by the weight charts (Fig. 4).

Antiperistaltic jejunal graft

One pilot subject was given a reversed graft of jejunum in an attempt to test the oft-quoted assumption that the peristaltic orientation of the graft is critical. After an initial 2 week period in which no problems were encountered, the dog developed a dysphagia which became gradually

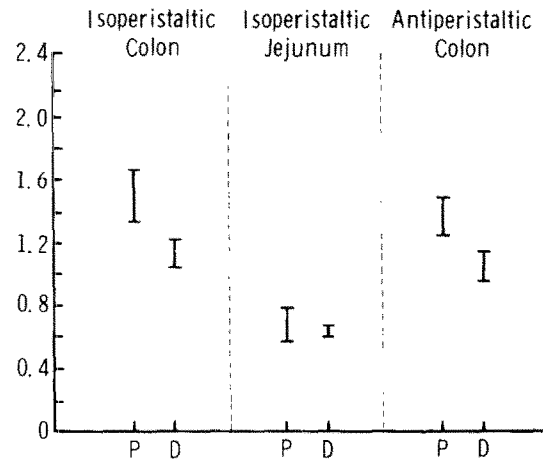

Fig. 3

Figure 3—Mean maximum and minimum anastomotic diameters as assessed from barium videofluoroscopy: P = Proximal, D = Distal.

more complete. Profound regurgitation occurred with any fluid except water and feeding was possible only by direct gastric filling twice daily. A barium swallow examination showed a strong reversed peristalsis with the regurgitation or tracheal aspiration of a large part of the single presented food bolus (Fig. 5). There was gross muscular hypertrophy in the graft and the upward peristalsis persisted for some 4 to 5 minutes after the presentation of the bolus. Such were the problems with this subject that no further animals were subjected to this branch of the experiment.

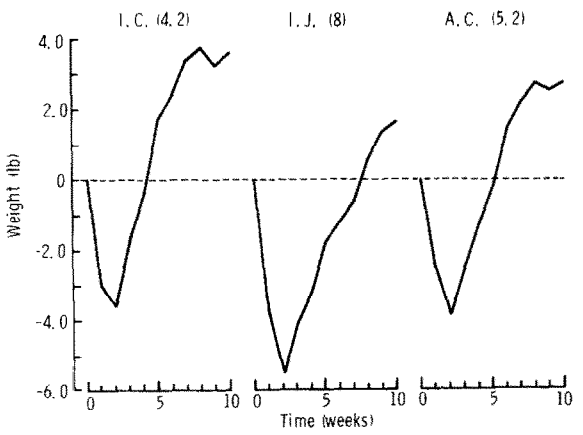

Fig. 4

Figure 4—Mean postoperative weight profiles with average time in weeks to recovery of preoperative levels: IC = Isoperistaltic Colon, IJ = Isoperistaltic Jejunum, AC = Antiperistaltic Colon.

Fig. 5

Figure 5—Radiograph of barium swallow: Antiperistaltic jejunal graft, with tracheal aspiration arrowed.

Discussion

We have here reported our findings following videoflouroscopic barium swallow examination of the behaviour of colon and jejunal free bowel grafts of the cervical oesophagus in dogs. We have confirmed the findings of Meyers *et al.* (1980) that the jejunal grafts strongly retain their peristaltic behaviour and that this peristalsis, while being initiated by the action of swallowing, does not thereafter co-ordinate with the behaviour of the oesophagus above or below it. We would go further and suggest that we have demonstrated that the peristaltic action of the jejunal graft, which persists well after the presentation of a bolus to it, causes what is in effect a functional stenosis of the body of the graft. Thus the contention by Gluckman *et al.* (1982) that "the jejunal lumen matches that of the cervical oesophagus more closely than any other part of the gut" can be seen to apply only to the passive bowel in the anaesthetised, operative situation. Furthermore we have shown that this effect is compounded by the physical narrowing at the levels of the graft-oesophagus anastomoses. It could be argued that our technique of anastomosis promoted such a stenosis, but the same technique was employed for both types of bowel and only the

jejunum demonstrated stenoses. We therefore speculate that the muscular activity within the graft could contrive to accentuate this physical narrowing at the anastomoses.

The colonic grafts, on the other hand, have been shown to behave like the normal oesophagus. Although there was no peristaltic action, the graft could not be described as "adynamic" in the same way as skin-lined reconstructions. The graft did act essentially as a passive conduit, but even with a fluid bolus it dilated when filled and contracted as it emptied. It is our contention that this is an action of elastic recoil in the muscles of the bowel wall, but this could only be proven by implantation of electrodes into them. Although Meyers *et al.* (1980) did this in human subjects with jejunal grafts, the technique requires too high a level of co-operation to be feasible in the animal analogue.

The orientation of the grafts was important only when jejunum was used, for only it retained peristalsis. The colonic grafts demonstrated no residual peristaltic behaviour and so the grafts functioned in an identical fashion whether antiperistaltically or isoperistaltically orientated. They would therefore permit the orientation to be determined by what best suited the local anatomy. The retention of peristalsis of the jejunal grafts is a demonstration of the muscle innervation of the gut as discussed by Howard (1984), who described the jejunum as being relatively independent of its extrinsic nerve supply, with muscle action mediated by intrinsic myenteric circuits although local or hormonal influences may superimpose an effect on its behaviour. It is interesting to note that in our subjects there appeared to be an initial period of about 2 weeks before this peristaltic behaviour became re-established. On the evidence that we have, we would confirm that when using the jejunum as the graft, it is essential to interpose it in an isoperistaltic orientation.

Conclusions

The results of our studies on the motility of revascularised grafts of colon and jejunum interposed into the cervical oesophagus support our contention that the colon represents a potentially more natural functional replacement of the cervical oesophagus than the jejunum. Although it behaves essentially as an elastic, passive conduit, the colon integrates more satisfactorily into the overall swallowing action of the oesophagus and permits the subjects to return to a more normal diet than is possible with the jejunal grafts.

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