Functional Oesophageal Mapping: A New Concept

BSF Stacey, P Patel

Department of Gastroenterology, D Level East Wing, Southampton University Hospitals NHS Trust, Southampton Generla Hospital, Tremona Road, HANTS SO16 6YD

Abstract: We describe a novel technique that allows for the quantitative investigation and follow up of patients with delayed oesophageal transit based upon oesophageal scintigraphy and subsequent data analysis using image analysis and 3-D graphing software. Details of the analysis are discussed and an illustrative clinical example is given.

Functional Oesophageal Mapping: a new concept

Introduction

Oesophageal scintigraphy has been used for nearly 30 years in the assessment of oesophageal transit but advances in computer software and acquired image quality have meant that new and more sensitive means of interpreting the data are possible.

It is a quick, simple technique that is very acceptable to patients [1]. As methods have improved it has found to be over 95% sensitive and specific when compared to manometry as the gold standard [2].

The technique described here was developed from a scintigraphic study evaluating the effect of stenting inoperable malignant oesophageal strictures on transit times, symptoms and quality of life. However, as a normal range has been established its use is not restricted to this condition but may give valuable information and quantitative follow up data in any case of dysphagia.

In 1982, in this journal, Svedberg first published ideas on a bolus transport diagram applied to the oesophagus, which described the cranio-caudal movement of the bolus revealing transit velocity, hold-up and reflux [3]. This gave images showing the size and position of the bolus with time and was, in effect, an internal functional map from the aspects of the luminal contents.

In the traditional uses of scintigraphy the oesophagus is often divided into 'areas of interest' with activity counts being monitored in these sectors. Stier et al have developed this concept of relative regional transit times to investigate subtle differences in the transit times in Barrett's patients [4] and, like Svedberg before them, also to visualize the spatiotemporal pattern of oesophageal bolus transit. This allowed quantitative data analysis but also showed the increased accuracy of interpretation that is possible with newer software in making a visual functional analysis.

Other authors have also looked at oesophageal function but always from the point of the view of the bolus. This has provided further valuable information on bolus distribution [5, 6] but a functional map of the oesophagus itself has never before been produced. It is known that air precedes the bolus during its period of transit [5] and that the bolus separates as it travels down the oesophagus. However, as well as the intrinsic properties of fluid moving with gravity down a cylinder, much of this propagation and distortion is due to the peristaltic forces applied to the bolus by the longitudinal and circular muscle contractions. Therefore a functional map of the oesophagus is useful in predicting bolus transit patterns.

Image acquisition

The patient is seated in the erect position and the posterior view from the gamma camera is used. Dynamic image acquisition is continuous at 2 frames per second for 30 seconds. This gives a series of images, samples of which are shown here.

Sequential series of scintigraphic images from mouth to G-O junction

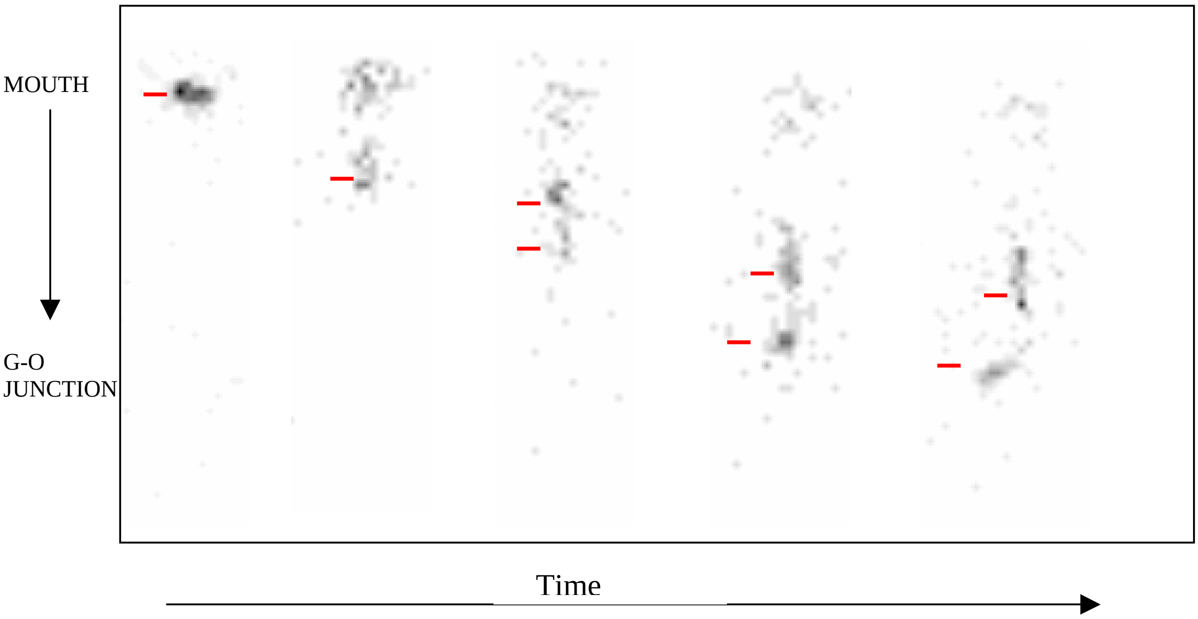

Figure 1

When the bolus is small (unfragmented) it is straightforward to measure the distance it has traveled along the oesophagus. However, when the bolus fragments – as happens especially in structuring disease, dysmotility or other causes of prolonged oesophageal transit – it is debatable as to where to measure the point of maximum bolus transit (see red markers). As the most distal point does represent true transit this has been taken as the ‘real’ point provided that the amount of the scintigraphic count is significant (to avoid mistaking a background signal or the signal from a previous swallow) – see Individual Image Analysis.

Individual Image Analysis

The density of the scintigraphic image is measured by a density analysis programme (Scion Image, National Institute of Health). As stated, this is straightforward if the bolus is not fragmented and the mode of the count is then a good representation of the distance traveled. The area to be analysed is standardized and the same for each plot: in this instance the x-axis range of 0 – 255 pixels represents the distance from mouth to beyond the G-O junction. The G-O junction itself consistently appears at 170 pixels in normal subjects. A measurement of, for example, 130 pixels equates to [(130/170) x 40] = 30cm traveled down the oesophagus. The level of the mouth is gauged by the point where the scintigraphic count is maximal on the first image of the scan (ie: as the patient is holding the labeled meal in the mouth) and the position of the G-O junction can be seen at the point where there is some hold-up at the ampulla prior to a sideways deviation of the image as the bolus enters the stomach. The higher count at the ampulla is a normal feature previously demonstrated by bolus imaging by ultra-fast CT in normal subjects [5].

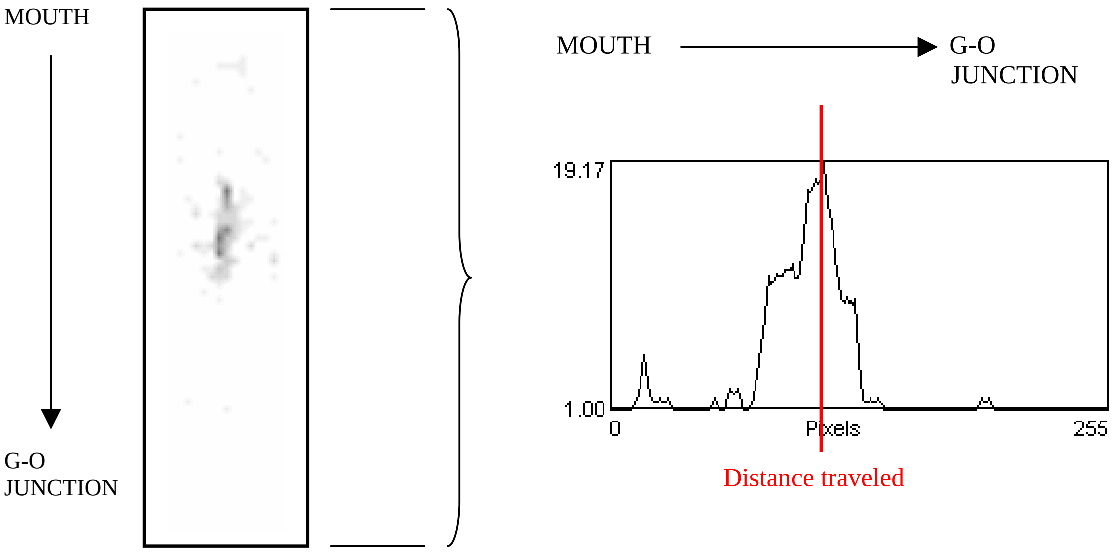

Figure 2

If the bolus has fragmented (eg: on passing through a stricture or a stent) then the most distal part of the majority of the count is measured. Bolus fragments under 50% of the modal count are discarded.

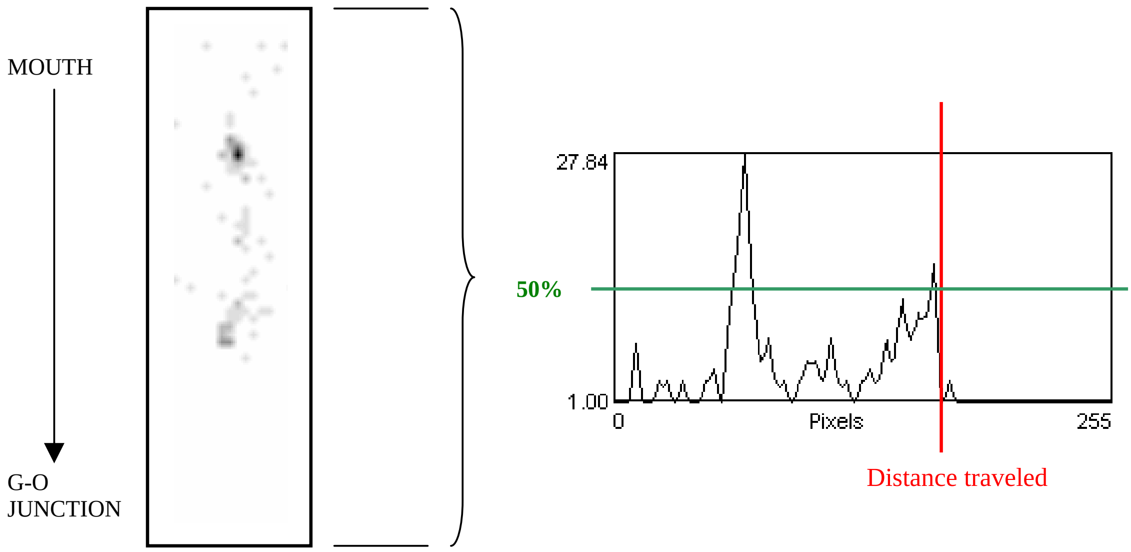

Figure 3

This latter technique obviates the problem that occurs when only measuring clearance of, for example, 90% of the total count. If, for instance, a part of the bolus remains stuck in the proximal lip of a stent (not uncommon) or within an ulcer crater then the scintigraphic count which that part contributes would artificially ‘drag’ the mean count back up the oesophagus.
The standard deviation of the curve is a measure of the degree of fragmentation of the bolus and graphs similar to the one below can be plotted to show the degree of break up of the bolus against time.

Bolus transit curve

The distances thus obtained are then plotted against their times and a curve demonstrating bolus progress through the tubular oesophagus against time is obtained. This plot is from a normal subject:

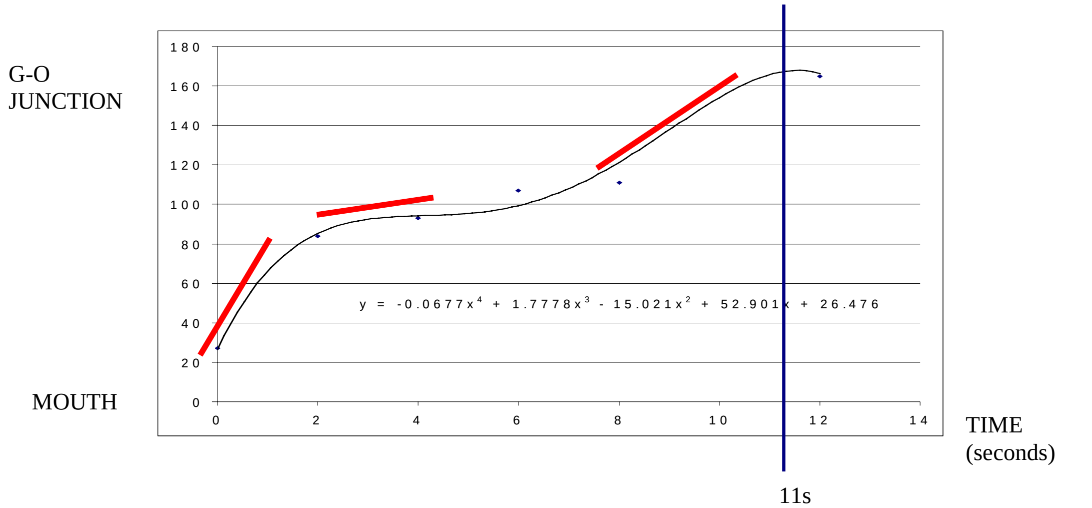

Figure 4

A 4th order polynomial curve of best fit is then generated by computer using MS Excel 2000, and its equation shown.
This equation is then differentiated to give the slope of the curve, which is shown to be varied at different points as indicated by the three red lines superimposed on the graph. In this example the equation

$y = -0.0677x^4 + 1.7778x^3 – 15.021x^2 + 52.901x + 26.476$ differentiates to:

$dy/dx = -0.2708x^3 + 5.3334x^2 – 30.042x + 52.901$

<u>Oesophageal mapping</u>

The equation for the gradient of this curve (given by the differential equation) is superimposed upon a length of a straight cylinder (a good approximation of the tubular oesophagus) using a 3D graphing programme (3D Grapher, ©Roman Laboratories), to give a *functional* map of the oesophagus. The length of the cylinder represents 100% of the normal oesophagus (0-170 pixels - see above) so if the curve plateaus before this (eg: due to a stricture) it is in proportion to the distance traveled. For example, a pinching of the cylinder (indicating no further transit) at 70% of normal cylinder length implies functional hold-up at (0.7 x 40cm) = 28cm. It is emphasized that this does not necessarily correspond to the siting of an anatomical stricture as the dysmotility often associated with it (for example, due to sub-mucosal invasion) can start some way above. Similarly, one can have hold-up with no gross anatomical abnormalities in conditions such as diffuse oesophageal spasm, eosinophilic oesophagitis or of course achalasia.
Wider parts of the cylinder plot represent regions of faster transit and narrower sections correspond to slower transit. The ‘fourth dimension’ of this map is *time,* which represents

the time taken for the scintigraphic count to plateau, ie: the time from the initiation of swallowing to traversing the G-O junction. It is indicated alongside the map.
The normal range of this is in the erect subject is 4-8 seconds [7], [8], [9], though there is considerable variation.

This is the plot for the above bolus transit curve (from a normal subject):

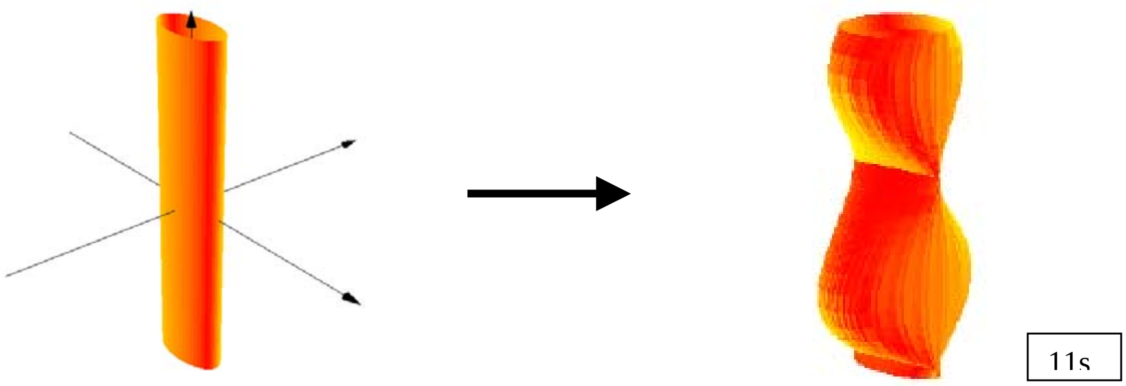

Figure 5

The mid-section of slower transit corresponds to the anatomical transition zone within the mid-oesophagus where striated muscle changes to smooth muscle. Other authors too have documented a slowing in transit rates at this level [10]. Oesophageal mapping is least accurate at either end (ie: cricopharyngeus and the G-O junction) but it is designed to look more for *intra*-oesophageal dysmotility and/or structuring and can give quantitative functional data that can be reliably reproduced for follow-up.

The technique applies to the initial swallow alone. Once there is radiolabelled material in the stomach that it is able to reflux back into the oesophagus there is the possibility of the scintigraphic count in the lower oesophagus *increasing* again, which eventuality falls outside the analytical scope of this method.

<u>Example</u>:

In this example a patient was found to have a 5cm malignant stricture starting at 33cm from the incisors at endoscopy. Staging and assessment deemed him unsuitable for surgery and/or chemotherapy so he was treated with a self-expanding metal stent.

The image on the left shows his functional oesophageal map prior to stenting with slow and incomplete transit with a complete block at 30cm – ie: higher than the anatomical stricture. A 10cm length Ultraflex stent was placed from 28-38cm thus covering the whole of the stricture *and* the dysmotile area and the repeat study 4 weeks later in shown on the right. Note that not only has the total distance traveled increased to include the whole length of the oesophagus but also the diameter of the plot has increased, indicating increased transit time at all levels (also shown by the reduced total transit time from 18 to 9 seconds).

The improvement in this patient was mirrored by an improvement in his both his overall quality of life score and swallow score as assessed by the European Organization for Research and Treatment of Cancer (EORTC) QLQ C30 and OES24 questionnaires respectively.

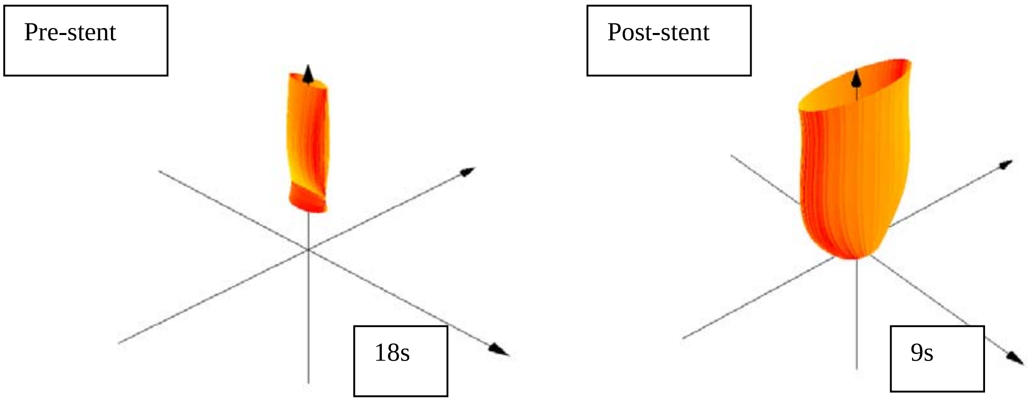

Figure 6

Conclusion:

This is a simple, effective technique – highly acceptable to patients – that allows accurate, repeatable images of actual oesophageal function to be recorded for the investigation and follow up of cases of delayed oesophageal transit in both benign and malignant disease, thus allowing an improved method of determining the effects of treatment on these patients in whom quantative data was previously unavailable.

References:

1. Blackwell JN, Hannan WJ, Adam RD, Heading RC. Radionuclide transit studies in the detection of oesophageal dysmotility. *Gut* 1983; 24: 421-6.

2. Tatsch K, Voderholzer WA, Weiss MJ, Schrottle W, Hahn K. Reappraisal of quantitative esophageal scintigraphy by optimizing results with ROC analyses. *J Nucl Med* 1996; 37: 1799-805.

3. Svedberg, J. B. The bolus transport diagram: a functional display method applied to oesophageal studies. *Clin Phys Physiol Meas* 1982; 3(4), 267-272.

4. Stier, A. W., Stein, H. J., Allescher, H. D., Feith, M., and Schwaiger, M. A scintigraphic study of local oesophageal bolus transit: differences between patients with Barrett's oesophagus and healthy controls. *Gut* 2002; 50: 159-164.

5. Pouderoux, P., Gulchin, A. E., Shezhang, L., and Kahrilas, P. J. Esophageal bolus transit imaged by ultrafast computerized tomography. *Gastroenterology* 1996; 110: 1422-1428.

6. Nguyen, H. N., Silny, J., Albers, D., Roeb, E., Gartung, C., Rau, G., and Matern, S. Dynamics of esophageal bolus transport in healthy subjects studied using multiple intraluminal impedancometry. *Am J Physiol Gastrointest Liver Physiol* 1997; 273: G958-G964.

7. Kjellen, G. and Svedberg, J. S. Oesophageal transit of a radionuclide solid bolus in normals. *Clin Physiol* 1983; 3(1): 69-74.

8. Sand, A., Ham, H., and Piepsz, A. Oesophageal transit patterns in healthy subjects. *Nucl Med Commun* 1986; 7(10): 741-745.

9. Klein HA,.Wald A. Normal variation in radionuclide esophageal transit studies. *Eur J Nucl Med* 1987; 13: 115-20.

10. Stier, A. W., Stein, H. J., Schwaiger, M., and Heidecke, C. D. Modeling of esophageal bolus flow by functional data analysis of scintigrams. *Dis.Esophagus* 2004; 17(1): 51-57.