*Technique***Effects of x -radiation on fiberoptic endoscopes**

B STERRY ASHBY AND D A GOODMAN

From the Departments of Endoscopy, and Clinical Physics and Bioengineering, Southend General Hospital, Southend, Essex

SUMMARY Fiberoptic endoscopes exposed to x -radiation showed increased optical density of the fibre bundles with a reduction in light transmission. The length irradiated was important as well as the total dose, and there was a linear relationship between the dose/length product (Rm) and the loss of light transmission. The minimum light transmission acceptable for performing ERCP was found to be 57% of that through an unused fibre bundle, and this degree of damage occurred after a total dose of 33.9 Rm. The radiation dose to the duodenoscope during ERCP examinations was measured. The endoscope sheath was shown to have screening properties, with a transmission factor of about 30% for the Olympus JFB-1 and about 11% for the JFB-2 and JFB-3 instruments. The actual dose received by the fibre bundle of an Olympus JFB-2 duodenoscope was 0.084 R per ERCP and the mean dose-length product to the fibre bundle was calculated as 0.028 Rm per ERCP. Some degree of recovery of light transmission occurred while a duodenoscope was 'resting'. The expected life of a duodenoscope was estimated to be about 1200 examinations, but might be much less than this in units where greater radiation doses and longer exposures were used, and the endoscope was in constant use. Ways of minimising the radiation exposure during ERCP and prolonging the useful life of the duodenoscope are outlined.

Fiberoptic endoscopes are being used increasingly for diagnostic and therapeutic procedures which involve exposure of the instrument to irradiation. Endoscopic retrograde cholangiopancreatography (ERCP) requires x -ray screening and exposure of static x -ray films, and therapeutic procedures such as papillotomy, retrieval of retained stones, dilatation of oesophageal strictures, and placing of indwelling tubes for inoperable carcinoma of the oesophagus are all associated with the use of x -rays. Exposure of an endoscope to x -irradiation shortens the life of the fiberoptic bundles, and this is of economic importance because replacing a damaged fibre-bundle is an expensive repair. Two aspects of this problem have been investigated, the effect of radiation on a fiberoptic bundle, and the radiation dose received by the fibre bundle within the endoscope during ERCP. The investigations were carried out using Olympus JFB duodenoscopes and components.

We presented this work to the British Society of Gastroenterology at Oxford in September 1975¹

but subsequent investigations have provided more data in the light of which we have modified our conclusions, and added some observations on the possible recovery of irradiated fiberoptic bundles.

Effect of radiation on a fiberoptic bundle

To study the effect of radiation on a fiberoptic bundle the optical density and the light transmission properties of the bundle were measured before and after irradiation.

Methods (Fig. 1)

A fibre bundle was embedded in Mix-D wax which has x -ray absorption and scatter properties similar to human soft tissues. A solid state light emitting diode, producing a constant and stable red light, was attached to one end of the fiberoptic bundle. A monitor photodiode maintained the constancy of the light source. The other end of the fibre led to a photodiode detector, the output from which was recorded. The apparatus was lead screened apart from the length of fibre being irradiated. When the fibre bundle was exposed to x -rays

Fig. 1 Diagram of system for measuring light transmission through a fibreoptic bundle during x-irradiation.

Fig. 2 A profound fall in light transmission occurred after 95 cm of fibre bundle were exposed to 24.3 r.

Fig. 3 A moderate fall in light transmission occurred after 22.0 cm of fibre bundle were exposed to 23.1 r.

changes in optical density were recorded as changes in light transmission.

The radiation source was a constant potential x-ray therapy machine, using 85 Kv (the average employed in clinical ERCP examinations). The output was monitored before and after each fibre irradiation, and the mean taken as the dose delivered to the fibre bundle.

Results

Irradiation of a fiberoptic bundle increased its optical density and thus decreased the light transmission. Irradiation of a large proportion of the fibre bundle length caused a marked deterioration in light transmission (Fig. 2). A comparable dose to a smaller proportion of the total fibre bundle length caused a less severe loss of light transmission (Fig. 3), and some slow recovery occurred subsequently. This recovery was about 2% in the first three days and additional recovery was so slow that it appeared insignificant. Additional observations have now been made over many months and are discussed below.

The increase in optical density of the fiberoptic bundle and loss of light transmission was dependent on the length of fibre bundle exposed as well as on the irradiation dosage. The longer the length exposed the greater was the damage to the fibre bundle. The effective radiation dose received by the bundle may be expressed as the product of dose $\times$ length exposed, and we propose the term 'roentgen-meter' (Rm).

When filters of varying optical density were placed in the system, and the light transmission with each filter expressed as a percentage of the light transmission with no filter at all, a linear relationship was demonstrated between optical density and the logarithm of the percentage light transmission (Fig. 4).

Relationship between optical density and Rm product

Various lengths of fiberoptic bundle were irradiated using 85 Kv. Changes in optical density were recorded as percentage loss of light transmission compared with that of a new bundle. Two fibre bundles were investigated.

Fig. 4 Relationship between optical density and the logarithm percentage change in light transmission.

Fig. 5 Relationship between the dose-length product (Rm) and the logarithm percentage change in light transmission.

There is a linear relationship between the length-dependent radiation dose (Rm) and the logarithm of the percentage loss of light transmission of the bundle. Figure 5 shows the relationship for one of the fibre bundles, and the other was closely similar.

Clinical effect of irradiation on duodenoscope

Method

To assess the minimum acceptable light transmission through a fibreoptic bundle we investigated the degree of damage sustained by fibre bundles discarded from instruments at repair because light transmission was inadequate. Nine fibre bundles were investigated. The light transmission of each was measured and expressed as a percentage of the light transmission of a new unused bundle.

Results (Table 1)

Two of the bundles (B and E) were excluded because they showed very low values due to an excessively large number of broken fibres, which also affected

the light transmission. The mean light transmission in fibre bundles damaged by radiation until clinically useless was 57% of that recorded in a new bundle (range 45%–68%). Figure 5 shows that a reduction to 57% light transmission would occur after a total dose-length product of 34.7 Rm for that bundle. The curve obtained from the second fibre bundle (not illustrated) showed that 57% light

Table 1 Light transmission through used fibre bundles, as percentage of that through a new bundle

Fibre bundle	Transmission (%)
N (new)	100.0
A	51.6
(B)	(22.3)
D	57.6
(E)	(36.3)
G	65.9
J	63.7
K	50.2
L	67.9
M	45.2
Mean (exclude B and E)	57.4

Fig. 6 Dose of x-radiation used in 72 ERCP examinations (mean=0.716 r).

transmission would occur after 33.0 Rm. The mean of these two figures, 33.9 Rm, was taken as the total effective dose required to reduce light transmission below the critical level of 57%.

Radiation dose to duodenoscope fibre bundle during ERCP

1. DOSE RECEIVED BY DUODENOSCOPE

Method

Two sets of three lithium fluoride thermoluminescent dosimeters were attached to the duodenoscope sheath diametrically opposite each other (to eliminate the screening effect of the instrument itself) during 72 consecutive ERCP examinations. They were placed immediately proximal to the angulating section so that they were within the radiation field but did not interfere with the function of the instrument. The dosage measured included x-ray screening, static x-ray films, and exposures with a 70 mm camera.

Results

The mean screening time was 71 seconds per case (range 25–215 seconds). Figure 6 shows the spread of radiation dosage over the 72 examinations. The mean dose per ERCP was 0.716 R. The total dose to the instrument over this period was 51.55 R.

2. DOSE RECEIVED BY FIBRE BUNDLE WITHIN DUODENOSCOPE

Figure 7 illustrates the radiographic appearances of each of the Olympus JFB duodenoscope models,

and it is apparent that there are differences in construction of the sheath. The JFB-1 is clad by two concentric helices of stainless steel strip, whereas the JFB-2 and JFB-3 sheaths have a triple concentric helix of copper-iridium strip, and the JFB-3 is of slightly greater diameter than the JFB-2.

Fig. 7 Radiographic appearances of Olympus duodenoscopes, showing differences in construction of sheaths.

The screening effect of the sheaths of these three duodenoscopes was investigated.

Method

Four sets of lithium fluoride thermoluminescent dosimeters were placed within the duodenoscope sheath and one set attached to the outside. The sheath was then irradiated, using 85 Kv x-radiation (with a 2.5 mm aluminium filter). The mean dose recorded within the sheath was expressed as a percentage of the maximum dose recorded on the outside of the sheath, and a 'transmission factor' thus obtained.

Results (Table 2)

The transmission factor for the JFB-1 sheath was 32.9%, whereas that for the JFB-2 was 11.7% and for the JFB-3 11.0%. Thus at 85 Kv about one

Table 2 Radiation transmission factors of duodenoscope sheaths (85 Kv x-rays)

	(%)
Olympus JFB-1	32.9
Olympus JFB-2	11.7
Olympus JFB-3	11.0

third of the radiation dose received by a JFB-1 actually reaches the fiberoptic bundle, but the construction of the JFB-2 and JFB-3 duodenoscopes provides a considerable increase in screening effect, so that only about 11% of the incident dose reaches the bundle. With the use of the 11.7% transmission factor (the JFB-2 was used in the 72 ERCPs), the mean radiation dose received by the fibre bundle per ERCP was therefore 11.7% of 0.716 $r=0.084 r$, and the total dose received by the fibre bundle within our duodenoscope over the 72 examinations was 11.7% of 51.55 $r=6.03 r$.

3. EFFECTIVE LENGTH OF FIBRE BUNDLE IRRADIATED

The length of fibre bundle irradiated is as important as the dose received in determining the damage to the bundle. We calculated a mean effective length of duodenoscope irradiated during the period over which ERCP measurements were being made. Three modes of irradiation were used involving different lengths of duodenoscope—fluorescent screening, static x-ray film exposures, and 70 mm camera.

Method

The following parameters were monitored during 72 ERCP examinations. (a) During screening—the screening time, the exposure current in milliamperes

(mA) and the length and diameter of endoscope on the screen; (b) during static x-ray film and 70 mm camera exposures—the number of exposures, the exposure in milliamp seconds (mAs), and the length and diameter of endoscope on the films.

There is some magnification or minification effect in the images obtained by these x-ray techniques, and the measurements obtained were corrected for this.

Table 3 Exposure parameters—72 ERCP examinations

Radiation mode	Total mAs	Mean length exposed (m)
Screening	7186	0.162
x-ray film	949	0.226
70 mm camera	2370	0.153

Results (Table 3)

The radiation dosage to the fiberoptic bundle from each of the three modalities was in the ratio of the mAs used (7.57:1:2.50). These ratios were applied to the mean lengths of fibre exposed by each radiation modality, and a mean effective length of fibre exposed per investigation was obtained. This was 0.166 m. The total effective radiation dose-length product to a fibre bundle within the duodenoscope is therefore 6.03 $r \times 0.166 m = 1.001 Rm$. But there are two fibre bundles within the duodenoscope, the coherent image bundle and the light conducting bundle, so that the total effective dose-length product is 2.002 Rm, and the mean effective dose-length product per ERCP examination is 2.002 $\div 72 = 0.028 Rm$.

LIFE OF A DUODENOSCOPE

The mean effective dose-length product to the fibre bundle per ERCP examination is 0.028 Rm. And the minimum acceptable light transmission through the duodenoscope is 57% and 33.9 Rm would be necessary to reduce the light transmission to this level. Therefore the total number of ERCP examinations that could be carried out before optic renovation became necessary would be 33.9 $\div 0.028 = 1210$ cases.

Discussion

We must emphasise that this calculation is based on the practice and techniques of one particular endoscopy unit and x-ray department where special care has been directed to reducing the radiation exposure of the endoscope to a minimum. The average screening time per ERCP was only 71 seconds, the mean effective length of endoscope exposed was only 16.6 cm, and the minimum number of x-ray films were exposed, and extensive use made of the 70 mm camera.

It is likely that the radiation exposure per ERCP in many endoscopy units, especially of those engaged in teaching the technique, is considerably greater than the figures obtained in this study. The endoscope may not be in the ideal straight position in the field, and twice the length may easily be exposed to radiation. Similarly exposure times may be considerably extended. Peters *et al.*,² from a very large and active endoscopy unit, quote a mean ERCP screening time of 238 seconds, which is more than three times the exposure we were using. These factors could decrease our calculated life expectancy of the duodenoscope by a factor of three or four, and the use of an observer attachment or closed-circuit television for teaching purposes would require better than 57% light transmission, so that the endoscope would appear to deteriorate quicker. In practice most of the major endoscopy units performing many ERCP and related procedures find it necessary to renew the fibre bundle after about 250–400 examinations.

RECOVERY OF LIGHT TRANSMISSION

These estimates for the useful life of a duodenoscope assume little or no recovery of light transmission while the fibre bundle is not being irradiated. However, the recovery phenomenon in irradiated fibre bundles has been studied in some detail over a period of two years and these investigations suggest that quite marked recovery does take place.

Method

Three fibre bundles were initially irradiated, each at different Kv factors—55, 85, and 100 Kv. The light transmission of each fibre bundle was measured within 30 minutes of completion of irradiation, and at subsequent intervals of one day, 11 days, 75 days, and two years afterwards. The measured light transmission at each interval was expressed as percentage recovery on the measurement at 30 minutes after irradiation.

Results (Table 4)

Measurements were made on three fibre bundles, each irradiated at a different Kv factor and therefore different quality of radiation, but it was evident that considerable recovery occurred. Two years after irradiation at 85 Kv, for example, there was 46% recovery of light transmission. The useful life expectancy of a duodenoscope under our conditions was about 1200 examinations. If all these were completed within two years a recovery of about 40% could occur during the endoscopic 'rest time', so that the life of the instrument would be extended to $1200 \times 40\% = 1680$.

It thus appears that the effective life of the

Table 4 Recovery of light transmission after irradiation

Kv	Time lapse (%)			
	1 day	11 days	10 weeks	2 years
55	2.5	6.9	17.2	27.5
85	4.0	12.1	31.8	46.2
100	5.8	14.9	28.1	65.3

duodenoscope depends on the endoscopic and radiological technique to keep the radiation dose as low as possible, and the intensity of use. If many examinations are being performed the use of two instruments alternating, say, monthly, would prolong the life of both.

Conclusions

The effective life of a duodenoscope used for ERCP examinations depends not only upon the care and skill with which the instrument is used to prevent mechanical damage, but also on the endoscopic and radiological technique to keep the radiation dose to the instrument at a minimum, and on the intensity of use. These observations were made on an endoscopy unit where particular attention was given to keeping the radiation exposure of the endoscope to a minimum. But it is likely that the dose factors and screening times may be higher in many busy endoscopy units and therefore the life of the duodenoscope may be appreciably shorter than our figures suggest.

Fig. 8 A straight duodenoscope during ERCP reduces the length of fibre bundle irradiated.

To reduce radiation damage to a minimum attention to the following points is suggested:

1. Keep the duodenoscope as straight as possible to minimise the length of fibre bundle exposed to radiation (Fig. 8).
2. Use the minimum necessary *x*-ray screening time.
3. Make the minimum number of static *x*-ray exposures with the endoscope in the field.
4. Use small-film techniques—for example, 70 mm camera—where possible.
5. Remove the endoscope from the field as soon as possible after the required ducts have been filled.
6. A very busy endoscopy unit engaged in teaching should possess two duodenoscopes, to allow each a period of recovery.

We wish to thank the directors of Messrs. KeyMed Limited for providing fiberoptic bundles for light transmission measurement, and other components of Olympus duodenoscopes used in this investigation. We would also like to thank Mr A V Stockley and the technical staff of the Medical Physics Department at Southend Hospital for access to much specialised equipment, and to Mrs Hilary Kay for her cheerful secretarial assistance.

References

- ¹Ashby BS, Goodman DA, Marlton AP. Some observations on the effects of radiation on the fiberoptic duodenoscope (abstract). *Gut* 1976; **17**: 78.
- ²Peters PE, Katz G, Safrany L, Weitmeyer R. Radiation exposure in patients undergoing endoscopic retrograde cholangiopancreatography and endoscopic papillotomy. *Gastrointest Radiol* 1978; **3**: 353–5.