



The EOS 2D/3D X-ray imaging system: A cost-effectiveness analysis quantifying the health benefits from reduced radiation exposure

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ARTICLE INFO

Article history:

Received 16 October 2012

Received in revised form 5 February 2013

Accepted 8 February 2013

Keywords:

Cost-benefit analysis

Radiography/adverse effects

Radiography/economics

Imaging

Three-dimensional/adverse effects

Imaging

Three-dimensional/economics

ABSTRACT

Objectives: To evaluate the cost-effectiveness of the EOS[®] 2D/3D X-ray imaging system compared with standard X-ray for the diagnosis and monitoring of orthopaedic conditions.

Materials and methods: A decision analytic model was developed to quantify the long-term costs and health outcomes, expressed as quality-adjusted life years (QALYs) from the UK health service perspective. Input parameters were obtained from medical literature, previously developed cancer models and expert advice. Threshold analysis was used to quantify the additional health benefits required, over and above those associated with radiation-induced cancers, for EOS[®] to be considered cost-effective.

Results: Standard X-ray is associated with a maximum health loss of 0.001 QALYs, approximately 0.4 of a day in full health, while the loss with EOS[®] is a maximum of 0.00015 QALYs, or 0.05 of a day in full health. On a per patient basis, EOS[®] is more expensive than standard X-ray by between £10.66 and £224.74 depending on the assumptions employed. The results suggest that EOS[®] is not cost-effective for any indication. Health benefits over and above those obtained from lower radiation would need to double for EOS to be considered cost-effective.

Conclusion: No evidence currently exists on whether there are health benefits associated with imaging improvements from the use of EOS[®]. The health benefits from radiation dose reductions are very small. Unless EOS[®] can generate additional health benefits as a consequence of the nature and quality of the image, comparative patient throughput with X-ray will be the major determinant of cost-effectiveness.

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1. Introduction

The evaluation of the EOS[®] 2D/3D X-ray imaging system, hereafter referred to as EOS[®], was the first diagnostic technology assessed as part of the new Diagnostics Assessment Programme instituted by the National Institute for Health and Clinical Excellence (NICE). NICE is an independent organisation responsible for providing national guidance on the use of health technologies within the National Health Service (NHS) in England and Wales. NICE has recently extended its remit to diagnostic technologies, in particular those with the potential to improve health outcomes but which also have increased costs for the NHS [1]. The process involves the submission of evidence by the manufacturers and other stakeholders, and the preparation of an effectiveness and cost-effectiveness evaluation by an independent organisation to NICE. The NICE Diagnostic Advisory Committee considers all

the evidence submitted to deliberate on whether the technology should be recommended as an effective and cost-effective use of NHS resources.

EOS[®] is a biplane X-ray imaging system, which allows the acquisition of two-dimensional, three-dimensional, biplane images while the patient is in an upright weight-bearing position [2]. Currently available imaging technologies that can be used in an upright weight-bearing position are X-ray film, computed radiography (CR) and digital radiography (DR), although film has been replaced by CR and DR in standard UK practice. EOS[®] appears to have four major advantages over the currently available technologies: (i) full body imaging without digital stitching, although some DR systems have automatic acquisition modes in which large length scans can be made without manual stitching, (ii) simultaneous posteroanterior and lateral images, (iii) production of 3D reconstructions of the spine, and (iv) lower radiation dose [3].

The objective of this study was to evaluate the cost-effectiveness of EOS[®] compared with standard X-ray for the diagnosis and monitoring of orthopaedic conditions from the perspective of the UK NHS. The indications considered were spinal deformity (principally scoliosis) in children, adolescents and adults,

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Table 1

Model assumptions regarding typical age at diagnosis, proportion of patients undergoing surgery and monitoring pattern for each relevant indication.

Indication	Typical age at diagnosis	Proportion of patients undergoing surgery	Monitoring pattern
Congenital scoliosis	6 months–1 year	75%	If surgery indicated: Pre-op, post-op, 3 months, 6 months, then every year up to age 20.
Early-onset idiopathic scoliosis	1–5 years	95%	If adult, last scan taken 2 years post-surgery.
Late-onset idiopathic scoliosis	10–18 years	10%	
Adult scoliosis	50–60 years	20%	
Congenital kyphosis	Birth–10 years	75%	
Scheuermann's disease (adolescent)	12–18 years	3%	If surgery not indicated: Every 6 months up to age 15.
Scheuermann's disease (adult)	40–50 years	3%	Every year up to age 20.
Ankylosing spondylitis	35–65 years	1%	
Other deforming dorsopathies (children and adolescents)	2–20 years	50%	
Other deforming dorsopathies (adults)	40–70 years	50%	
Congenital deformities of hips and lower limbs	Birth–1 year	75%	If surgery indicated: pre-op, post-op, 6 weeks, 3 months, 6 months, 12 months, 2 years, and every 2 years up to age 10. If surgery not indicated: every 6 months up to age 20.

and leg length discrepancy and alignment in children and adolescents.

2. Methods

2.1. Overview

The cost-effectiveness of EOS® depends on how the health outcomes and costs associated with EOS® compare with those of standard X-ray for each relevant indication. EOS may be of particular benefit in those pathologies which change under load, where rotational deformity is relevant or require repeated imaging [4]; therefore, the indications considered were scoliosis, congenital kyphosis, ankylosing spondylitis, Scheuermann's disease, other deforming dorsopathies and congenital deformities of the hips or lower limbs. Reviews were conducted to identify evidence on the costs and benefits associated with EOS®. A decision analytic model was developed to synthesise the evidence identified, and compare the costs and health outcomes associated with each technology. The model calculates the lifetime risk of cancer from radiation exposure associated with the diagnosis and monitoring pattern required for each orthopaedic indication. This lifetime cancer risk was translated into a loss of quality-adjusted life years for patients and increased costs for the UK NHS using published sources [5–8].

The model evaluates costs from the perspective of the NHS and Personal Social Services, expressed in UK pound sterling at a 2011 price base. Health outcomes are expressed in terms of quality-adjusted life years (QALY) with costs and outcomes discounted at 3.5% per annum [9]. All stages of the work were informed by discussion with clinical advisors. Full modelling details can be found at <http://www.hta.ac.uk/fullmono/mon1614.pdf>.

2.2. Model inputs

2.2.1. Clinical effectiveness

A systematic review of the clinical effectiveness of EOS® aimed to identify evidence on the effect of EOS® use on patients' health outcomes, either due to lower radiation dose, or due to health benefits derived from the nature or quality of the image obtained [4]. The review identified three relevant studies, all comparing the entrance surface dose associated with EOS® with standard X-ray: (i) Kalifa et al. compared EOS® with film radiography in children [10]; (ii) Le

Bras et al. (unpublished) compared EOS® with film radiography in adolescents; and (iii) Deschenes et al. compared EOS® with CR in adolescents [11]. Entrance surface dose is a method of measuring radiation dose to the body using dosimeters placed on the patient's skin, and was expressed in terms of milligray for both EOS and standard X-ray. The reduction in entrance surface dose with EOS® varied considerably both within and between these studies. The dose reductions reported in Kalifa et al. were between 11.6 and 18.8 [10], whereas those for the other two studies ranged between 2.9 and 9.2 depending on where the entrance surface dose, in milligray, was being measured (e.g. neck, centre of back) [11]. Therefore, the model assumes a mean entrance surface dose reduction of 6.7, which corresponds to the average value in Dechenes et al. [11] and Le Bras et al. (unpublished). The study by Kalifa et al. was not included in the average because it used an earlier version of the technology (the Charpak system) and did not report whether tube voltage was similar between the two radiographic systems used in the study. Entrance surface dose refers to the radiation received by the skin, whereas for the cancer risk calculations the relevant quantity is effective dose, which refers to the radiation absorbed by the body. Although entrance surface dose rather than effective dose was the radiation quantity reported in the studies, the ratio of mean entrance surface dose was considered a reasonable approximation for the reduction in radiation exposure achieved with EOS® in light of the lack of studies comparing EOS® with DR. The impact of assuming a greater reduction in radiation exposure achieved with EOS® was explored in the scenario analysis. No evidence was found for health benefits from EOS due to the nature or quality of the image obtained. Both studies comparing EOS® with film X-ray imaging found image quality to be comparable or better with EOS® overall [10,12]. The study comparing EOS with CR found image quality to be comparable or better with EOS for the majority of images [11].

2.2.2. Radiation exposure

Total radiation exposure over a patient's lifetime depends on age at diagnosis, pattern and frequency of monitoring, type of radiographs used for diagnosis and monitoring and radiation dose associated with each type of radiograph. Given the limited evidence in the published literature, expert advice was sought to establish the pattern of monitoring and type of radiographs used for each indication. Table 1 shows the typical age at diagnosis, the

Table 2

Assumptions regarding the type of radiograph required for monitoring and associated radiation dose for children, adolescents and adults [14,23].

Indications	Children			Adult and adolescents		
	Type of radiograph	Age	Effective dose (mSv)	Type of radiograph	Effective dose (mSv)	
Spine-related Indications ^a	Spine AP/PA ^b [23]	1–2	0.0600	Thoracic spine AP [14]	0.24	
		3–6	0.0490			
		7–12	0.0290	Thoracic spine LAT [14]	0.14	
		13–18	0.0300			
	Spine LAT [23]	1–2	0.0780 ^c	Lumbar Spine AP [14]	0.39	
		3–6	0.0780			
		7–12	0.0580	Lumbar spine LAT [14]	0.21	
		13–18	0.0480			
	Congenital deformities of hip and lower limbs	Pelvis AP [14]	1–4	0.01	Pelvis AP [14]	0.28
			5–9	0.06		
10–14			0.08			
15–18			0.11			
Femur AP ^d		1–4	0.00022	Femur AP [14]	0.011	
		5–9	0.00514			
		10–14	0.00209			
		15–18	0.00286			
Knee AP ^d		1–4	0.000002	Knee AP [14]	0.0001	
		5–9	0.000014			
	10–14	0.000019				
	15–18	0.000026				

mSv – millisievert; AP – anterior–posterior; PA – posteroanterior; LAT – lateral.

^a Spine-related indications include scoliosis, congenital kyphosis, ankylosing spondylitis, Scheuermann's disease, other deforming dorsopathies, and congenital deformities of spine.^b Spine AP/PA assumed the same as spine PA/AP where data were not available.^c Spine LAT for age 1–2 years assumed the same as 3–6 years as data were not available.^d Based on ratio of adult to children doses observed for Pelvis AP when following guidelines for best practice [24].

proportion of patients undergoing surgery (which affects monitoring pattern) for each indication and the radiographic monitoring pattern assumed in the model. The type of radiographs used for the monitoring of each indication and their respective effective dose according to age are presented in Table 2. Effective doses were obtained from a recent report by the Health Protection Agency. This report provides the typical effective doses used in the UK between 2001 and 2006, which were calculated from data reported in the most recent (2005) review of the UK National Patient Dose Database [13]. Less than one-quarter of the radiographic examinations recorded in the UK National Patient Dose Database specified the type of equipment. Of those where this was recorded, 55% used a film-screen combination, 40% used CR and 5% DR. Consequently, the same effective doses were assumed applicable to CR and DR. The impact of assuming lower radiation exposure for DR was explored in a scenario analysis.

2.2.3. Cancer risk

The lifetime risk of radiation-induced cancer unit of effective dose as a function of age at exposure and gender for uniform whole body irradiation was obtained from the Health Protection Agency report [14]. The estimates provided in the report were calculated using computer models developed at the Health Protection Agency in accordance with the risk models of the International Commission on Radiological Protection publication 103 [15].

2.2.4. Health-related quality of life

In order to estimate QALY loss, it was necessary to quality-adjust the effects of cancer for the period of time that the patient was alive within the model. Previously developed cancer models provided the costs, QALY loss and typical age at diagnosis for colorectal [7], prostate [8], breast [6] and lung cancer [5] (see Table 3), corresponding to the most incident radiation-induced cancers [16]. The average of costs and QALY loss for each of these cancers, weighted using the incidence reported in seventh report from the Committee to Assess Health Risks from Exposure to Low Levels of Ionising Radiation, US National Research Council, on the Biological Effects

of Ionising Radiation (BEIR VII), was assumed to apply to all cancers [16].

2.2.5. Resource use and unit costs

A systematic review of EOS[®] and costs relating to standard X-ray did not retrieve any published information on costs in the UK. In the absence of published literature, information from the manufacturer was used to estimate the costs of EOS[®]. Similarly, expert advice was sought from manufacturers and hospital accounting systems for information on the costs of CR and DR. Increased patient throughput reduces the average cost per procedure, therefore two alternative assumptions were used: (i) throughput assumption 1, where EOS[®] is assumed to have the same patient throughput as standard X-ray at 30 examinations per working day (251 working days per year); and (ii) throughput assumption 2, which assumes a higher utilisation for EOS[®] at 48 patients per working day compared to standard X-ray at 30 patients per working day.

Table 4 presents the set-up and recurring costs associated with the technologies. These costs were annuitized over 10 years (the expected useful life of the technologies) at a rate of 3.5% per annum [17] to estimate annual costs. Including value added tax at 20%, and under the contract 1 (cheaper contract), the annual cost for EOS[®] was £103,616. The annual costs for CR and DR were £25,760 and £46,369 respectively. This resulted in an average cost per scan of £3.42 and £6.16 (corresponding to an annual throughput of 7530 patients) for CR and DR, respectively, while the cost of each EOS[®] scan was £14.54 under TA1 and £9.09 under TA2.

2.3. Modelling approach

Fig. 1 shows a simple schematic picture of the modelling approach. Since the primary benefit of EOS[®] is its lower radiation dose, the model estimated the costs and QALY loss due to cancer attributable to radiation exposure over a lifetime for the diagnosis and long-term monitoring of the relevant indications for both standard X-ray and EOS[®].

Table 3

Estimated total costs and QALY loss due to cancer, discounted at 3.5% per annum to age of cancer diagnosis [5–8].

Cancer	Age of diagnosis	Costs of cancer	QALYs lost due to cancer	Weights ^a	
				Males	Females
Breast	40 years	£14,990	5.6988	NA ^b	34%
Breast	60 years	£13,927	3.4219	NA ^b	
Lung	72 years	£22,712	6.8011	42%	50%
Colorectal	74 years	£14,075	3.4493	46%	NA ^b
Prostate	74 years	£12,389	4.6226	12%	16%

^a In the absence of cancer models for all types of cancer, a weighted average of costs and QALYs for the four cancers was used to provide an estimate of costs and QALYs associated with all cancer. This weighting was based on the incidence of radiation-induced cancer reported by type of cancer in BEIR VII [16].

^b NA – not applicable.

2.4. Analytical methods

Mean lifetime costs and QALYs for EOS[®], CR and DR were calculated and their cost-effectiveness compared using incremental cost-effectiveness ratios (ICERs) as appropriate [18]. The ICER represents the extra cost per additional QALY gained from using EOS[®] compared with standard X-ray. Since DR is more expensive than CR and no evidence was found of a differential effect on health outcomes, DR is ruled out on the basis that it is dominated by CR. Therefore, the base-case analysis simplifies to a comparison of the total costs and QALYs of EOS[®] and CR. The ICER of EOS[®] was compared to conventional cost-effectiveness thresholds used by NICE, which ranges from £20,000 to £30,000 per QALY gained. This represents the maximum amount the NHS is willing to pay for an additional unit of health [9] and reflects the health forgone elsewhere in the system when additional costs are imposed [19].

Although no evidence was found of health benefits from EOS[®] over and above those associated with lower radiation exposure, the nature of the image may affect the quality of medical or surgical care with implications for patient health outcomes. Threshold analysis was used to explore the necessary size of these additional health effects for EOS[®] to be considered cost-effective. Threshold analysis was also used to explore the level of patient throughput required for EOS[®] to be considered more cost-effective than standard X-ray.

Scenario analysis was used to assess the sensitivity of the results to changes in the model assumptions. The following alternative scenarios were considered: 1) reducing the age of radiation-induced cancer diagnosis from 60 to 40 years for breast cancer, 72 to 55 years for lung cancer, and 74 to 55 years for colorectal and prostate cancer, so that it is earlier than the general population; 2) using the highest dose reduction ratio of entrance surface dose (18.8) for EOS[®] compared to standard X-ray [10]; 3) using lifetime risk estimates for radiation-induced cancer reported in the BEIR VII report [16]; and 4) reducing the radiation dose of DR to two-thirds of the dose for CR and comparing EOS[®] to DR.

3. Results

3.1. Base-case analysis

Table 5 presents the results of the cost-effectiveness and threshold analyses for EOS[®] compared to CR in each indication under throughput assumptions TA1 and TA2. Standard X-ray is associated with a maximum health loss of 0.001 QALYs (in deforming dorsopathies in non-adults), which translates into approximately 0.4 of a day in full health. EOS[®] is associated with a maximum health loss of 0.00015, in the same indication (a loss of 0.05 of a day in full health). Hence the improvement in health obtained from using EOS[®] is up to 0.000869 QALYs or one third of a day in full health. The increase in costs with EOS[®] was in the range of £10.66 to £224.47 per patient, depending on the indication considered and the throughput assumption employed. However, the increase in cost and the small improvement in QALYs results in an ICER well above conventional thresholds of £20,000 and £30,000 per additional QALY in all indications, suggesting that EOS[®] is not cost-effective for any indication.

3.1.1. Threshold analysis: patient throughput

The results in Table 5 indicate that a daily workload of between 60 and 106 patient appointments per working day (equivalent to 15,100 to 26,500 per year) would be required to achieve an ICER of £30,000 per QALY, or between 71 and 110 patients per working day to achieve an ICER of £20,000 per QALY, while assuming that utilisation of CR is 30 appointments per working day. Therefore, EOS[®] would need to be used much more intensively than conventional X-ray in order to be considered cost-effective under base-case assumptions.

3.1.2. Threshold analysis: health benefits

Table 5 also presents threshold analysis showing the necessary size of the health effects needed to be achieved, in addition to the effect on cancer risk, in order for EOS[®] to be considered cost-effective. Under throughput assumption 1, health benefits would need to increase by between 0.001 and 0.003 QALYs (factors of

Table 4Costs of EOS[®], CR and DR (2010/2011 prices, excluding VAT).

Costs	EOS [®]		CR	DR
	Contract 1	Contract 2		
Set-up costs ^a	£400,000	£400,000	£95,000	£167,500
Recurring costs: Maintenance	£32,000 per year ^b	£48,000 per year ^b	£10,000 per year	£18,000 per year
Recurring costs: Other	£25,000 (X-ray tube)	–	£150–£200 (cassette)	£2000 (software upgrades)

Note: Prices shown exclude value added tax.

^a Set-up costs include the capital cost of the complete system, staff training and installation costs.

^b The manufacturer has two service contracts available; both include replacement of detectors, but contract 2 also includes replacement of X-ray tubes. An X-ray tube requires replacement every 3–5 years.

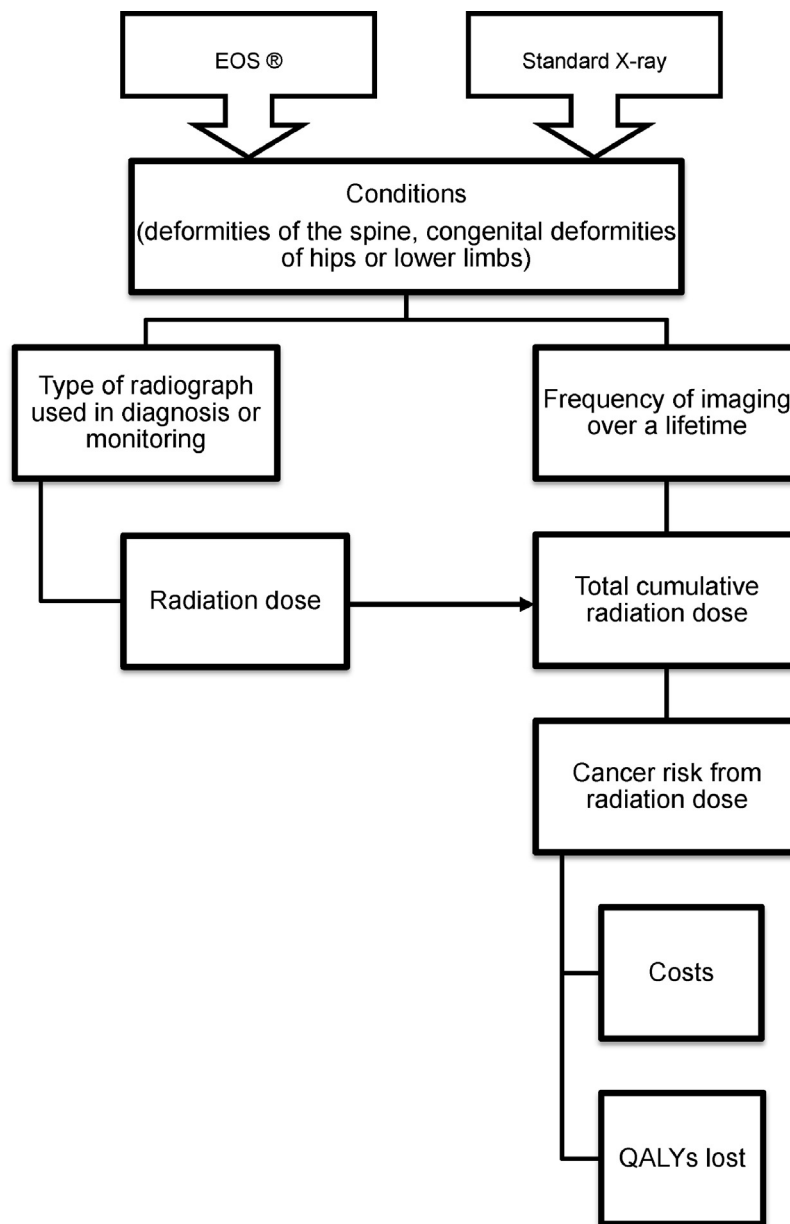


Fig. 1. Model schematic.

between 4 and 35 compared with radiation only) and between 0.0002 and 0.002 QALYs (factors between 2.3 and 17) for throughput assumption 2.

3.2. Alternative scenarios

Table 6 presents the results of the alternative scenarios for each indication under the same throughput assumptions, and these suggest similar conclusions to the base-case analysis. Under throughput assumptions 1 and 2, the ICERs were above conventional thresholds of cost-effectiveness in all indications and scenarios, with the exception of two: i) the earlier age of cancer diagnosis compared to the general population; and ii) using BEIR VII as the source for the estimate of lifetime attributable risk of radiation-induced cancer [16]. The threshold analyses on patient throughput and additional health benefits provided similar results to those performed under base-case assumptions. Across all scenarios tested, the patient throughput required for EOS® to be considered cost-effective is always above 12,800 patients per year

or 51 per day, assuming that the throughput for CR would be capped at 30 per day. To be cost-effective, EOS® would have to deliver health benefits over and above those achieved from the reduction in radiation-induced cancers. These additional health benefits varied widely (by factors between 1.3 and 38.8), depending on patient throughput, indication and scenario.

4. Discussion

The model is the first to fully quantify the long-term costs and health losses associated with diagnostic imaging using EOS® and standard X-ray. The estimation of lifetime cancer risk attributable to radiation exposure from diagnostic X-ray imaging was based on the most up-to-date evidence on the effects of ionising radiation and typical radiation doses from the most recent UK data [14–16,20,21].

The results indicate that the health losses from diagnostic imaging with standard X-ray are small, and although EOS® may

Table 5

Results of the cost-effectiveness and threshold analyses for EOS® compared with CR.

Indication	QALY loss		QALYs saved EOS® vs. CR	Cost difference EOS® vs. CR		ICER EOS® vs. CR		Throughput required for threshold of		Additional QALYs required for threshold of £20,000/QALY (ratio TA: base-case)	
	X-ray	EOS®		TA1	TA2	TA1	TA2	£20,000/QALY	£30,000/QALY	TA1	TA2
Congenital scoliosis	0.000769	0.000114	0.000655	£224.47	£111.47	£342,703	£170,185	25,200	23,500	0.01122 (17.1)	0.00557 (8.5)
Early-onset idiopathic scoliosis	0.000731	0.000109	0.000623	£205.89	£102.21	£330,479	£164,061	25,000	23,300	0.01029 (16.5)	0.00511 (8.2)
Adolescent or late-onset scoliosis	0.000951	0.000141	0.000810	£87.15	£42.44	£107,590	£52,401	18,600	15,900	0.00436 (5.4)	0.00212 (2.6)
Adult scoliosis	0.000270	0.000040	0.000230	£22.73	£10.98	£98,846	£47,756	17,900	15,200	0.00114 (4.9)	0.00055 (2.4)
Congenital kyphosis	0.000792	0.000118	0.000674	£194.96	£96.65	£289,252	£143,405	24,400	22,600	0.00975 (14.5)	0.00483 (7.2)
Congenital deformities	0.000290	0.000043	0.000247	£173.69	£86.64	£703,218	£350,776	27,600	26,500	0.00869 (35.2)	0.00434 (17.5)
Scheuermann's disease adolescent	0.000733	0.000109	0.000624	£66.89	£32.57	£107,191	£52,196	18,600	15,900	0.00335 (5.4)	0.00163 (2.6)
Scheuermann's disease adult	0.000122	0.000018	0.000104	£11.98	£5.81	£115,158	£55,904	18,900	16,300	0.00060 (5.8)	0.00029 (2.8)
Ankylosing spondylitis	0.000101	0.000015	0.000086	£10.66	£5.19	£123,951	£60,332	19,400	16,900	0.00053 (6.2)	0.00026 (3.0)
Deforming dorsopathies non adult	0.001021	0.000152	0.000869	£151.19	£74.44	£173,983	£85,659	21,700	19,400	0.00756 (8.7)	0.00372 (4.3)
Deforming dorsopathies adults	0.000506	0.000075	0.000431	£41.80	£20.18	£96,983	£46,823	17,700	15,100	0.00209 (4.8)	0.00101 (2.3)

TA1, Throughput assumption 1 – patient throughput based on capacity (100% utilisation) of EOS® at 30 patients per working day for 251 working days per year, equivalent to the utilisation of CR.

TA2, Throughput assumption 2 – patient throughput based on full capacity (100% utilisation) of EOS® at 48 patients per working day for 251 working days per year, while utilisation of CR is 30 patients per working day.

Table 6

Incremental cost-effectiveness ratio (ICER) for the two alternative assumptions for the four scenario analyses tested.

Indication	Scenario 1: Earlier age of cancer diagnosis			Scenario 2: Higher radiation dose reduction for EOS®			Scenario 3: Lifetime attributable risk of radiation-induced cancer from BEIR VII [16]			Scenario 4: Radiation dose associated with DR = 2/3 of CR		
	TA1	TA2	TR ^a	TA1	TA2	TR ^a	TA1	TA2	TR ^a	TA1	TA2	TR ^a
Congenital scoliosis	£156,867 (7.8)	£77,623 (3.9)	21,400	£307,851 (15.4)	£152,727 (7.6)	24,700	£163,585 (8.2)	£80,480 (4.0)	21,400	£378,290 (18.9)	£119,513 (6.0)	15,700
Early-onset idiopathic scoliosis	£151,252 (7.6)	£74,811 (3.7)	21,100	£296,859 (14.8)	£147,220 (7.4)	24,600	£160,753 (8.0)	£79,061 (4.0)	21,300	£364,807 (18.2)	£115,181 (5.8)	15,600
Adolescent or late-onset scoliosis	£47,431 (2.4)	£22,813 (1.1)	12,900	£96,441 (4.8)	£46,816 (2.3)	17,800	£56,428 (2.8)	£26,792 (1.3)	14,000	£118,974 (5.9)	£36,191 (1.8)	13,600
Adult scoliosis	£98,846 (4.9)	£47,756 (2.4)	17,900	£88,525 (4.4)	£42,586 (2.1)	17,100	£64,404 (3.2)	£30,504 (1.5)	14,800	£109,384 (5.5)	£32,750 (1.6)	13,400
Congenital kyphosis	£130,406 (6.5)	£64,373 (3.2)	20,200	£259,788 (13.0)	£128,646 (6.4)	23,900	£146,837 (7.3)	£72,086 (3.6)	20,700	£319,337 (16.0)	£100,567 (5.0)	15,400
Congenital deformities	£323,074 (16.2)	£160,880 (8.0)	25,100	£632,018 (31.6)	£315,110 (15.8)	27,300	£285,990 (14.3)	£141,797 (7.1)	24,400	£775,919 (38.8)	£247,256 (12.4)	16,000
Scheuermann's disease adolescent	£46,542 (2.3)	£22,372 (1.1)	12,800	£96,081 (4.8)	£46,631 (2.3)	17,800	£57,753 (2.9)	£27,450 (1.4)	14,100	£118,535 (5.9)	£36,043 (1.8)	13,600
Scheuermann's disease adult	£115,158 (5.8)	£55,904 (2.8)	18,900	£103,187 (5.2)	£49,908 (2.5)	18,200	£78,597 (3.9)	£37,590 (1.9)	16,200	£127,381 (6.4)	£38,500 (1.9)	13,700
Ankylosing spondylitis	£123,951 (6.2)	£60,332 (3.0)	19,400	£111,099 (5.6)	£53,894 (2.7)	18,700	£70,521 (3.5)	£33,568 (1.7)	15,500	£137,074 (6.9)	£41,646 (2.1)	13,900
Deforming dorsopathies non adult	£77,040 (3.9)	£37,645 (1.9)	16,500	£156,140 (7.8)	£76,721 (3.8)	21,100	£87,997 (4.4)	£42,606 (2.1)	17,200	£192,203 (9.6)	£59,717 (3.0)	14,700
Deforming dorsopathies adults	£96,983 (4.8)	£46,823 (2.3)	17,700	£86,850 (4.3)	£41,747 (2.1)	16,900	£63,959 (3.2)	£30,281 (1.5)	14,700	£107,330 (5.4)	£32,090 (1.6)	13,300

TA1, Throughput assumption 1 – patient throughput based on capacity (100% utilisation) of EOS® at 30 patients per working day for 251 working days per year, equivalent to the utilisation of CR.

TA2, Throughput assumption 2 – patient throughput based on full capacity (100% utilisation) of EOS® at 48 patients per working day for 251 working days per year, while utilisation of CR is 30 patients per working day.

^a TR – Throughput required for ICER to meet threshold of £20,000 per additional QALY. Figures in parenthesis are the ratio between additional QALYs needed, over and above those from radiation reduction, to achieve a cost-effectiveness ratio of £20,000 per additional QALY and the incremental QALYs achieved for each indication and scenario

reduce the radiation exposure, it is not a cost-effective use of NHS resources. However, two major sources of uncertainty remain. The first is comparative patient throughput; the greater the throughput for EOS® or the lower for CR, the more cost-effective EOS® will appear. Patient throughput depends on the number of centres using EOS® and the intensity of its use during an average working day.

The other key issue is whether there are any additional health benefits from EOS® as a result of changes in medical or surgical care. Due to the absence of any evidence on other health effects over and above radiation exposure, the base-case assumed that health benefit was achieved solely from reduced radiation exposure and hence lower incidence of cancer. Although no evidence has been identified, there may be health benefits from EOS® as a result of the nature and quality of the image, which could prompt therapeutic benefits and potentially lead to better outcomes.

The threshold analysis suggests that the health gain from any therapeutic change as a result of the EOS® image would need to be significantly greater than those from reduced radiation dose alone (between 0.001 and 0.003 QALYs under throughput assumption 1 and between 0.0002 and 0.002 QALYs under throughput assumption 2). Another way of assessing the plausibility of the necessary QALY gains is to compare them with those estimated for other diagnostic tests based on firmer evidence. In many situations the health gains from changes in diagnostic technologies tend to be relatively small as only a proportion of patients have their diagnoses altered as a result, a smaller proportion still experience a therapeutic change, and a yet smaller group actually have a change in outcomes. For example, in evaluating different diagnostic strategies for coronary artery disease in patients of 55 years of age, Garber and Solomon found differences in lifetime QALYs of between 0.001 and 0.025 across six diagnostic strategies [22].

On the basis of the evidence and analysis presented here, the NICE Diagnostic Advisory Committee concluded that EOS® is unlikely to represent a cost-effective use of NHS resources. The Committee considered the evidence available on the benefits of EOS®, but concluded that, for EOS® to be cost-effective, these benefits need to translate into health improvements for patients and called for further research to establish whether EOS® can achieve health benefits over and above those associated with lower radiation exposure [2]. These additional health benefits would result from better clinical decision making achieved with the improved imaging provided by EOS®. Until further evidence is available, and given the cost of EOS®, the size of the benefits associated with radiation and the patient throughput required, EOS® cannot be considered cost-effective.

The scenario and threshold analyses attempted to address the limitations of the model where evidence was not available or of poor quality, in particular on the reduction in radiation dose achieved with EOS, the additional health benefits other than those from reduced radiation exposure and patient throughput. The evidence on clinical effectiveness is of limited quality because the studies were based on entrance surface dose measurements, rather than effective doses, which are dependent on the X-ray spectrum used, and used CR and film rather than the more efficient DR systems. This required the assumptions that reductions in entrance surface dose are equivalent to reductions in effective dose and that CR systems result in the same exposure to radiation as DR, both of which are unlikely to be the case. Nonetheless, the scenario analyses showed that these assumptions have little impact on the cost-effectiveness of EOS®. This is because the health losses resulting from X-ray induced cancers are small, and greater reductions in radiation dose such as those tested in scenario 1 fail to make EOS® appear cost-effective.

Other potential limitations include the inability to fully explore uncertainty in the model input parameters due to a lack of reporting of standard deviations or confidence intervals in the published

clinical effectiveness literature and having to rely on expert opinion due to the limited published evidence relating to monitoring patterns. Also cancers can be heterogeneous in nature, therefore the costs and QALYs used for the four cancers assessed may not fully reflect the costs and QALYs associated with all cancers.

5. Conclusions

In conclusion, the evidence available on the potential benefits of EOS® is limited to a reduction in radiation dose. This translates into lower lifetime risk of cancer but since the risk of radiation-induced cancer associated with X-ray exposure is small (of the order of 1 in 100,000), the reduction in radiation dose with EOS® translates into small improvements in QALYs lost due to cancer. Unless EOS® can generate additional health benefits from the nature and quality of the image, comparative patient throughput with standard X-ray will be the major determinant of its cost-effectiveness.

Acknowledgements

The authors gratefully acknowledge the contribution of the clinical expert advisors appointed to contribute to the National Institute for Health and Clinical Excellence (NICE) Diagnostic Advisory Committee. We would also like to thank Lisa Stirk, Nigel Gummerson, Peter Millner, Paul Shrimpton, Erika Denton, Sally MacLachlan, Maxine Clarke, Peter Howells and Paul Tappenden for providing information and advice. This project was funded by the National Institute for Health Research Health Technology Assessment (NIHR HTA) Programme on behalf of the NICE. The views expressed are those of the authors and not necessarily those of the NIHR HTA Programme. Any errors are the responsibility of the authors.

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