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Original article

Digital vs conventional radiography: cost and revenue analysis

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Abstract. The objective of this study was to analyse and compare the operating and investment costs of two radiographic systems, a conventional and a digital one, and to evaluate the cost/revenue ratio of the two systems. The radiological activity over 1 year for chest and skeletal exams was evaluated: 13,401 chest and 7,124 skeletal exams were considered. The following parameters of variable costs were evaluated: the difference between variable proportional costs of the two technologies, the effective variable cost of any size film, including the chemicals, and for different sizes of digital film, variable costs of chest plus skeletal exams performed with the two techniques. Afterwards the economical effect was considered taking into account depreciation during a time of utilization ranging between 8 and 4 years. In the second part of the analysis the total cost and the revenues of the two technologies were determined. The comparison between the digital and conventional systems has shown the following aspects: 1. Digital radiography system has a much higher investment cost in comparison with the conventional one. 2. Operating costs of digital equipment are higher or lower depending on the film size used. Evaluating chest X-ray we reach a breakeven point after 1 year and 10,000 exams only if displayed over 8 × 10-in. film and after 30,000 if displayed over a 11 × 14-in. film. 3. The total cost (variable cost, technology cost, labour cost) of digital technology is lower than that of the conventional system by 20 % on average using 8 × 10-in. film size. 4. Digital technology also allows lesser film waste and lesser film per exam

Key words: Digital radiography – Conventional radiography – Cost and revenue

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Introduction

We analysed operating and investment costs of two radiographic systems, a conventional and a digital one, taking into account radiological activities during 1 year (1996), evaluating chest and skeletal exams.

We studied the costs (evaluated in Liras and then converted to Euro; 1 Euro = 1936.27 Liras on 1 January 1999) according to the Italian National Health Service price list operating at a university hospital; therefore, it must be remembered that the price levels of all the production factors are typical of Italian standards, and directly comparable among Italian hospitals. It is, however, possible to repeat our experience elsewhere, substituting in the calculations the wages of personnel staff, the purchasing costs of equipment and related services, the unitary costs of films, etc.

Inflation was not considered, because in Italy the official (ISTAT) inflation rate had slowed down to 1.4–1.5 % in the previous 2 years.

We focused on the calculation of the average unit total cost per exam. We intended to emphasise the following:

1. The possibility of adopting in a hospital environment, even if, for now, in a very simplified way, the activity-based pricing (ABC) approach
2. The need to monitor the prospective capacity utilization in the investment decisions

If the least costly way of performing a given (budgeted) number of exams has to be calculated, the answer is to choose the way with the lesser average cost, i.e. the way which better exploits the capacity cost.

Digital radiography may allow, in the near future, performance of filmless exams, using magneto-optic storage devices. We do not presently consider this option in our department.

Afterwards we evaluated the cost/revenue ratio of the two systems considering two price tables: one from the National Health Service (SSN) and one from a professional organization, FASI.

Table 1. Chest activity 1996

Conventional radiography Exam (n = 13,401)	Film size (cm)	No. of films (n = 21,945)
Chest (posteroanterior)	36 × 43	13,401
Chest (left lateral)	35 × 35	8544
Digital radiography Exam (n = 13,401)	Film size (in.)	No. of films (n = 15,955)
Chest (posteroanterior)	8 × 10	13,401
Chest (left lateral)	8 × 10	2554

Table 2. Skeletal activity 1996

Conventional radiography Film size (cm)	No. of films (n = 12,875)
36 × 43	1354
20 × 40	1649
30 × 40	2932
24 × 30	6056
18 × 24	854
Digital radiography Film size (in.)	No. of films
8 × 10	7958

N = 7124 exams for each modality

Analysis of investment and operating costs method

The cost object (any entity within the enterprise which can be related with costs by a cause–effect relationship, by means of suitable information [1]) is the product of the radiology department and must be defined and measured. This has included square-metre film, single film or single radiological exam as sum of films. Only the latter choice appeared appropriate, i. e. in accordance with the role of radiology in diagnostic–therapeutic processes which take place within the hospital and in diagnostic procedures for out-patients at the request of general practitioners.

The first item to evaluate is represented by forecasting the number and cause of radiological exam requests coming from wards and general practitioners with regard to diagnostic–therapeutic protocols. With regard to this, we chose a budget assuming a continuous annual exam request and characterization within the Department of Radiology.

The second item is represented by correlation between exam number and films used taking into account possible variations in film size (except for some rare cases) for every type of exam and the number of films to be used, respectively, for conventional and digital radiology, ensuring that diagnostic efficacy remain unchanged or eventually improved.

Then we proceeded by evaluating differential variable costs for every kind of exam: the savings or rise in costs per year was calculated according to the budget of the exams which expected to be done. The economical research was carried out in relation to 13,401 chest exams and over 7124 skeletal exams executed during 1996.

For chest and skeletal radiograms we used Philips equipment. For conventional exams we employed a Lanex-Regular-XLA screen-film system set in a Kodak cassette. For digital exams we used the ADC Agfa-Gevaert system.

With the conventional system we employed for chest exam posteroanterior projection on a 36 × 43-cm film for all 13,401 patients and L-L projection on a 35 × 35-cm film for the 8544 patients who could maintain a standing position (Table 1).

With digital system we employed posteroanterior projection for all 13,401 patients and L-L projection for 2554 patients using a 8 × 10-in. hard copy. Taking into account the good contrast resolution in digital acquisitions, which permits exploration of even opaque areas on conventional radiograms (mediastinum, cardiac area and posterior costodiaphragmatic recesses), we performed L-L projection only for patients showing a mass opacity in the posteroanterior projection, and for those having cardiovascular impairment, in order to be able to study retrocardiac space, resulting in 30% L-L projections performed in a total of 70% of patients who could maintain the upright position.

We used 8 × 10-in. film hard copy after interobserver evaluation with receiver operating characteristics (ROC) analysis and using high-resolution CT (HRCT) as the gold standard which showed the same diagnostic accuracy in comparison with conventional film.

Using both systems, conventional and digital, we performed 7124 exams of the skeleton printed with conventional system on 12,875 films of different size depending on the examined segment, varying between 18 × 24 and 36 × 43 cm; with digital system all exams were printed on 8 × 10-in. hard copy amounting to 7958 films (Table 2).

The lesser number of films used for digital exams was due to the fact that some skeletal segments (cervical and lumbar spine, small segments) were printed on a single film without any diagnostic deterioration.

Evaluation of variable costs

We evaluated the difference between variable proportional costs of the two technologies [or unit level; the activities related to unit level (or volume related) are those with an executing quantity which is determined mainly by quantity (volume) of product (from diagnosis to therapy for each patient)]. All other activity categories were not volume related [1, 2, 3, 4], intended to be compared with the difference among capacity costs (mainly technology and labour costs).

The effective variable cost of any film size resulted in the sum of film cost (at effective purchase price) plus the cost of unusable material equal to 5%, of developing, fixing and of developing exhausted fixing-liquid removal.

We then evaluated effective variable costs for different sizes of digital film using the same method as used

Table 3. Investment costs

	Conventional system	*Digital system*	*Δ*
Developing machine	71,400,000		–71,400,000
Loading system	178,500,000		–178,500,000
Cassettes and screens–plates	28,408,320	54,978,000	+ 26,569,680
Digitizer, workstation, preview Monitor, ID station, laser printer		399,840,000	+ 399,840,000
Total system cost	278,308,320 (143,734.25 Euro)	454,818,000 (234,893.89 Euro)	+ 176,509,689 (91,159.64 Euro)

Prices in Italian Liras

Table 4. Variable (actual) film costs of conventional and digital radiography

Conventional radiography Film size (cm)	Price	Retakes 5%	Developer	Fixer	Eco	Variable cost
18 × 24	941	47	19	37	27	1071 (55 cents)
24 × 30	1566	78	32	61	44	1782 (92 cents)
20 × 40	2596	130	36	68	49	2878 (1.49 Euro)
18 × 43	1672	84	35	66	48	1903 (98 cents)
30 × 40	2596	130	54	102	74	2955 (1.53 Euro)
35 × 35	2745	137	55	104	76	3116 (1.61 Euro)
36 × 43	3335	167	67	128	93	3789 (1.96 Euro)
Digital radiography Film size (in.)	Price	Retakes 2%	Developer	Fixer	Eco	Variable cost
8 × 10	1854	37	23	44	30	1988 (1.03 Euro)
11 × 14	3416	68	44	84	58	3671 (1.89 Euro)
14 × 17	5016	100	69	130	90	5405 (2.79 Euro)

Prices in Italian Liras

for conventional films taking into account, however, costs of unusable material equal to 2% because of the lesser number of retaken exams. Afterwards we compared variable costs of chest plus skeletal exams performed with the two techniques.

For chest exams with digital technique we considered a lesser cost in tube usage, calculating 60 Liras (3 cents) per shot, due to the fact that for 70% of patients only the posteroanterior projection was performed. Moreover, we calculated the cost saving for technical staff identified as the part of labour cost employed proportionally with the number of radiograms performed.

With digital technology we planned a 10-ft. lead time for a chest exam instead of a 12-ft. lead time as applied for conventional technology, because using digital technology 70% of patients undergo only the posteroanterior projection.

The 10-ft. lead time for a chest exam with digital technology also includes the short post-processing time which a technician rarely spends for image optimization. Both the 12- and 10 ft. for every exam are standard times of proved reliability. The savings was equal to 1500 Liras (77 cents) calculating the yearly cost of technician for 250 working days equal to 45,000 Liras (23.24 Euro) per hour. This savings can be interpreted as the measure in financial terms of the production capacity which is set free for doing more exams for patients on waiting lists with a subsequent decrease in total cost per single exam.

Evaluation of economical effect

We evaluated the economical effect taking into account depreciation during time of utilization ranging between 8 and 4 years and other operating costs, particularly for implementation of the technologies.

As shown in Table 3, the total cost of the conventional-system equipment results from the sum of developing machine plus cassette loading system and of cassettes and screens, whereas the cost of digital system results from the cost of cassettes and plates, digitizer, workstation, preview monitor, ID station and laser printer.

For evaluation of equipment depreciation, we considered its annual cost, equal to the total investment cost of the equipment itself divided by the number of considered years (8 and 4 years, respectively).

On the other hand, for cassettes and digital-system plates we considered the hypothesis of a mean yearly usage which obviously depends on the number of exams performed. This depreciation is calculated according to wear and tear, which is an exception in comparison with the most common factor, duration.

We assumed a mean utilization of one plate for 5000 exposures. Then we calculated annual maintenance costs and electrical power use of the two systems. Finally, we calculated the cost-and-revenue ratio.

For costs we took into account only the previously considered factors because all the others (personnel, room space, etc.) were the same for the two systems. Time to report the exams was also the same for both systems, due to the hard-copy reporting for the two systems.

Table 5. Variable costs of chest-exam analyses (n = 13,401)

Variable costs with conventional radiography				
Exam	Film size (cm)	No. of films	Variable cost	Total variable cost[a]
Chest (posteroanterior)	36 × 43	13,401	3789	50,776,389
Chest (left lateral)	35 × 35	8544	3116	26,623,104
Variable costs with digital radiography				
Exam	Film size (cm)	No. of films	Variable cost	Total variable cost[b]
Chest (posteroanterior)	8 × 10	13,401	1988	26,641,188
Chest (left lateral)	8 × 10	2554	1988	5,077,352
Savings on variable costs (films) with digital radiography				
				Total savings
				45,680, 953 (23,592.24 Euro)[c]
Global savings with digital radiography				
	Per unit	Total exams		
Savings on film	3409	45,680,953		
Savings on tube consumption	60	357,480		
Saving 2 ft. on technician	1000	13,401,000		
Total savings	4469 (2.31 Euro)	59,439,433 (30,697.91 Euro)		

Prices in Italian Liras
[a]Total variable cost for both exams with conventional radiography: 77,399,493 (39,973.50 Euro); average cost per exam 5776 (2.98 Euro)
[b]Total variable cost for both exams with digital radiography: 31,718,540 (16,381.26 Euro); average cost per exam 2367 (1.22 Euro)
[c]Average cost savings per exam: 3409 (1.76 Euro)

Table 6. Variable costs of skeletal-exam analyses (n = 7124)

Variable costs with conventional radiography			
Film size (cm)	No. of films	Variable cost	Total variable cost[a]
36 × 43	1354	3789	5,130,306
20 × 40	1649	2878	4,745,822
30 × 40	2932	2955	8,664,060
24 × 30	6056	1782	10,791,792
18 × 24	884	1071	946,764
Variable costs with digital radiography			
Film size (in.)	No. of films	Variable cost	Total variable cost[b]
8 × 10	7958	1988	15,820,504 (8170.61 Euro)
Savings on variable costs with digital radiography			
			Total savings
			14,458,240 (7467.06 Euro)[c]

Prices in Italian Liras
[a]Total variable cost for all exams with conventional radiography: 30,278,744 (15,637.67 Euro); average cost per exam: 4250 (2.19 Euro)
[b]Total variable cost for all exams with digital radiography: 15,820,504 (8170.61 Euro); average cost per exam: 2221 (1.15 Euro)
[c]Average cost savings per exam: 2029 (1.05 Euro)

For revenues we considered two price lists, one from SSN and the other from the professional organization FASI.

Results

Purchase and operating costs

Table 4 shows variable (effective) costs for every film size both for conventional and digital systems. The comparison of operating costs of the two systems for 13,401 chest exams revealed a savings with the digital system of 45,680,953 Liras (23,592.24 Euro) for films, 13,401,000 Liras (6,921.04 Euro) for lesser technician labour time and 357,480 Liras for lesser tube usage, equal to a total of 59,439,433 Liras (30,697.91 Euro; Table 5).

The comparison for the 7124 skeletal exams revealed a savings with the digital system related only to films and equal to 14,458,240 Liras (7,467.06 Euro; Table 6).

Economical effect

In Table 7 we report technology costs as equipment depreciation and operating costs, calculating a useful life of 8 and 4 years, respectively. Regarding the digital plates, we optimized their use for 5000 exposures and

Table 7. Depreciation and other operating costs (technology costs)

	Conventional system	*Digital system*	*Δ*
At 8 years			
System cost/year			
(8 years of depreciation)	31,237,500	49,980,000	18,742,500
Cassettes and screens			
(8 years of depreciation)	3,551,040		
Plates and cassettes			
(cost 210/exposure × 20.525 ex.)[a]		5,280,000	1,728,960
Yearly maintenance	33,396,998	40,000,000	6,603,002
Electric power			
kW/day	30	40	
kW cost	150	150	
Days	250	250	
Total	1,125,000	1,500,000	375,000
Total yearly cost	69,310,968 (35,796.13 Euro)	96,760,440 (49,972.60 Euro)	27,449,472
Total cost at 8 years	554,487,744 (286,369.02 Euro)	774,083,520 (399,780.77 Euro)	219,595,776 (113,411.75 Euro)
At 4 years			
System cost/year			
(4 years of depreciation)	62,475,000	99,960,000	37,485,000
Cassettes and screens			
(4 years of depreciation)	7102,080		
Plates and cassettes			
(cost 210/exposure × 20.525 ex.)[a]		5,280,000	–1,822,080
Yearly maintenance	33,396,998	40,000,000	6,603,002
Electric power			
kW/day	30	40	
kW cost	150	150	
Days	250	250	
Total	1,125,000	1,500,000	
Total yearly cost	104,099,508 (53,762.91 Euro)	146,740,440 (75,785.11 Euro)	42,640,932 (22,022.20 Euro)
Total cost at 4 years	416,398,032 (215,051.64 Euro)	586,961,760 (303,140.45 Euro)	170,563,728 (88,081.81 Euro)

Prices in Italian Liras
[a]Corresponds to 13,401 chest and 7124 skeletal examinations

thereby achieved a cost of approximately 260 Liras (13 cents) for every exposure of the plate.

It is fundamental to quantify the annual average consumption. We based this upon 20,525 chest plus skeletal exams performed in our department during 1 year. Comparing the annual cost of the two systems, there was a higher cost of the digital system equal to 27,449,472 Liras (14,176.47 Euro) with depreciation in 8 years and 42,640,932 Liras (22,022.20 Euro) with depreciation in 4 years.

In Table 7 we also report total costs over an 8-year useful life span of the two technologies for 8 and 4 years of depreciation: the result was a higher cost of the digital equipment in 8 years of 219,595,776 Liras (113,411.75 Euro) and in 4 years of 170,563,688 Liras (88,088.81 Euro).

In Fig. 1 we compare the trend of the differential depreciation costs for digital technology with operating-costs savings in 8 and 4 years for 20,525 exams of chest and skeleton. An overall savings both for 8 and 4 years resulted of 371,585,608 Liras (191,907.95 Euro) and 125,026,964 Liras (64,571.04 Euro), respectively. Once the analysis of investment and operating costs (films and maintenance) has been determined together with the savings obtained during our annual radiological skeletal and chest activity, we will present the results for chest exams related to the thousands of performed exams.

In Fig. 2 we report the trend of annual costs for 8 years of conventional and digital techniques, considering for the latter the use of two formats: 8 × 10 and 11 × 14 in., respectively, for 10,000 and 30,000 chest exams.

For 10,000 exams an immediate savings results starting from the first year reaching 53,124,224 Liras (27,436.37 Euro) in the eighth year using 8 × 10-in. film. On the other hand, using 11 × 14-in. film there is a higher cost equal to 107,115,776 Liras (55,320.68 Euro).

It is necessary to perform 30,000 exams in order to reach a savings also with the 11 × 14-in. film, equal to 117,844,224 Liras (60,861.46 Euro), whereas using the 8 × 10-in. film the savings amounts to 598,564,224 Liras (309,132.62 Euro). It is clear therefore that with this number of chest exams digital technology shows also a good economical benefit.

Analysis of full-cost-and-revenue method

Evaluation of total cost

We evaluated the total cost only for the chest X-ray exam performed both with digital and conventional technique. Usually, the total cost is defined as variable cost plus fixed cost, where the former is the volume-related cost and the latter is the sum of all non-volume-re-

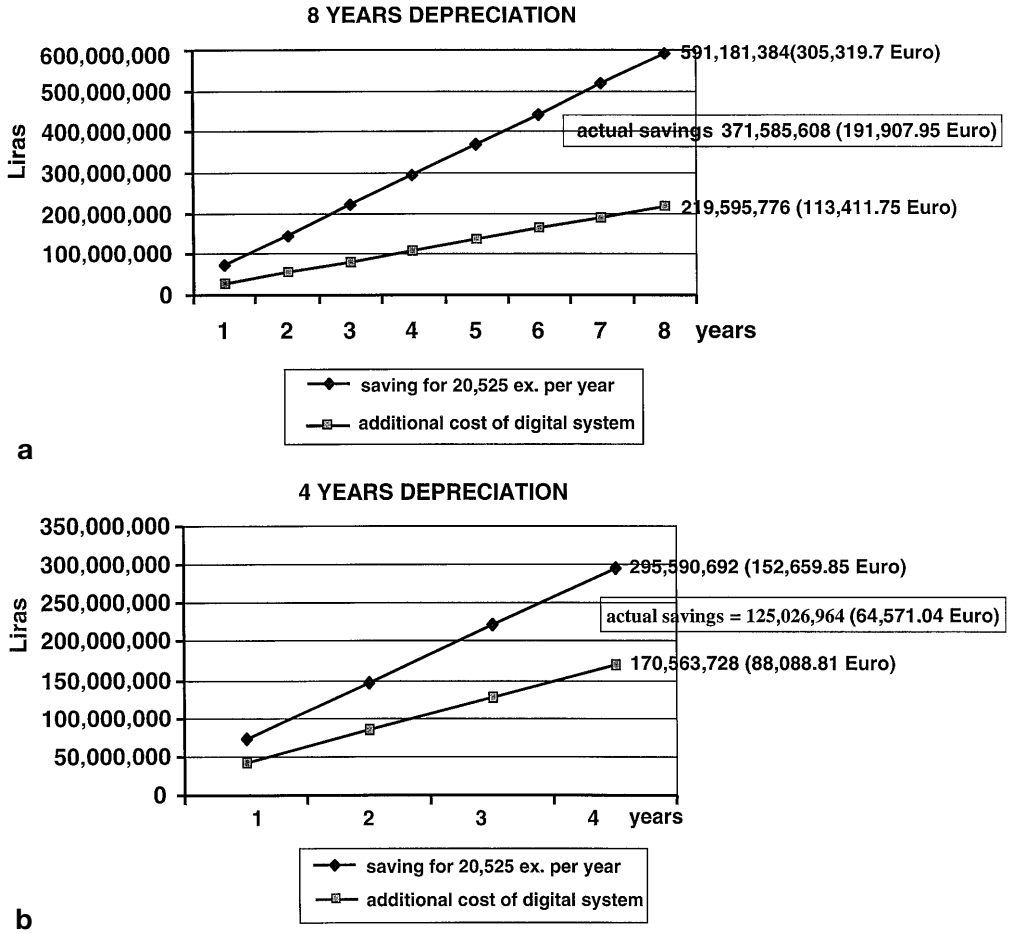

Fig. 1 a, b. Costs and savings of digital vs conventional radiography

lated costs. If activity-based costing is adopted, the total cost incurred during an accounting period is, as usual, the cost of all the resources used in the period, whereas the total cost of a unit of product is obtained taking into account that the use of resources is the effect of different causes, not only the production volume (variable cost) or "other" causes (fixed or more precisely "non-variable" cost).

In evaluating technology costs the importance of reliability in calculating prices of equipment is emphasized (it can be greatly influenced by significant discounts) and congruous choices are also emphasized concerning the depreciation calculation. The depreciation was calculated employing the simplest method, according to useful life, with the straight-line method in all cases in which a verifiable measurement was not available for evaluating physical wearing out (which happened only for imaging plates in the digital system).

The duration of the economically useful life of the radiological equipment was evaluated ranging between a technological minimum of 4 years (time of obsolescence of scientific instruments) and a maximum of 8 years (time of diagnostic effectiveness of instruments).

Briefly, we did not factor in the possible financial effects in our hospital annual report, due to the fact that savings are subsequent to equipment purchase, whereas cost increases occur partly afterwards and partly immediately upon equipment purchasing.

Technology costs are calculated on time-of-usage basis, instead of number-of-exam basis. Interest expense was not significant in our case, because the hospital did not have to get a loan to buy the equipment.

Afterwards we evaluated also technician, radiologist and auxiliary personnel costs, thereby bringing calculation of total cost very close to reality. In calculating total cost we restricted our evaluation to technical action (or technical procedure), and we ignored the hospital facility costs. In fact, this could potentially involve the services of all personnel in the radiology department and other cost centres belonging to the hospital, and, for inpatients, also the role of radiological exams upon therapy.

The aim of our evaluation was instead the calculation of the cost of chest exam as accurately as possible, including most of the costs of the radiology department. In this way it is possible to make comparison along time (in comparison with the budget aims) and space (in comparison with other hospitals: hospital trusts, hospitals with independent accounting or otherwise private hospitals).

Technology costs and technician labour costs seem to us the only costs which correspond to a production capacity utilized in every exam (unit level). Concerning medical personnel costs, partly for technicians and partly for auxiliary staff, we took account of the fact that their capacity is exploited at batch level (activities which

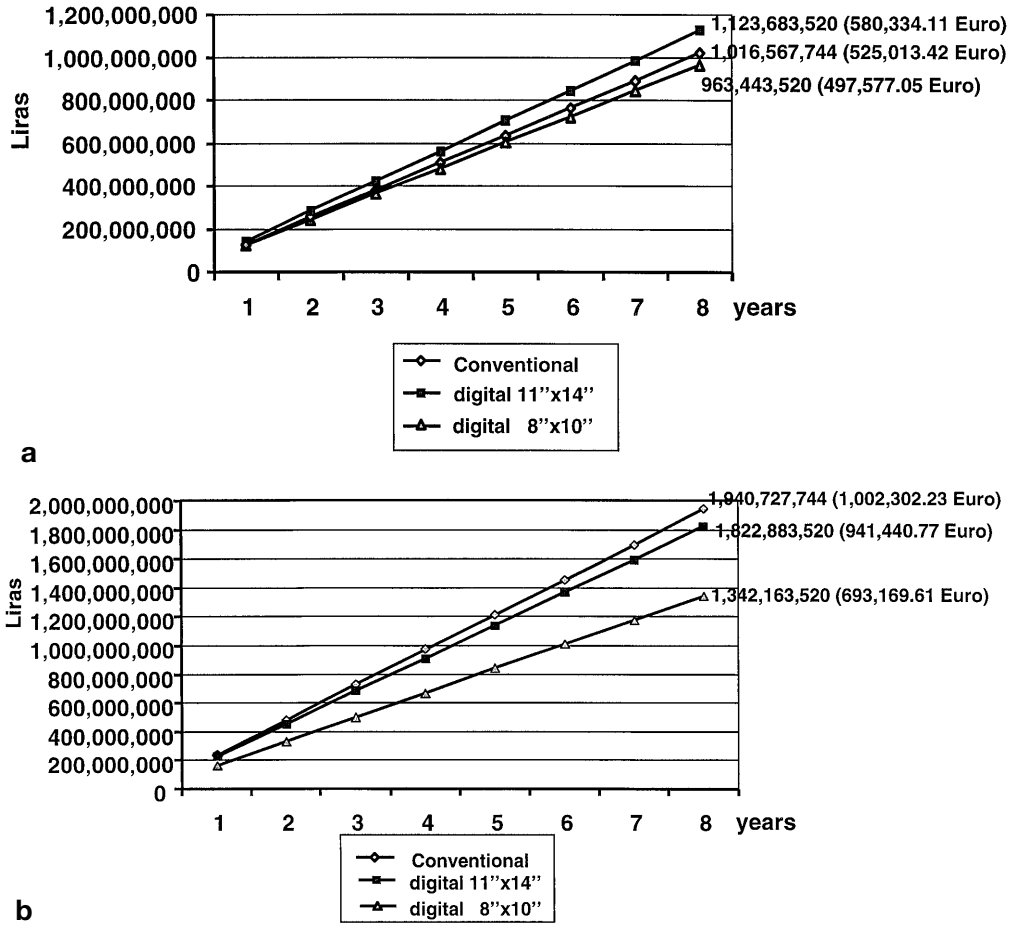

Fig. 2. **a** Operating costs of 10,000 chest exams; **b** operating costs of 30,000 chest exams

can be executed in a quantity which can be ascertained, mainly by lots in which products are set or other cost objects; from diagnosis to therapy given to more patients as a whole, or elaborating exams within groups [1]) or at process level (support activities for processes or process-sustaining level are those with an executing quantity which can be valued, due mainly to the number of processes within an organizational unit (by equipment groups or operative units of the UO) [1], or, lastly, by the complexity of the radiology department's facility level or product level. (Activities related to production sites or facility level are those with an executing quantity which can be ascertained, due mainly to the number of organizational units in which the cost centre is divided (by ward or department fragmentation or, in a more modern manner, by a department fragmentation into different facilities, wards, physical areas, buildings, etc.). Product-sustaining-level activities are those for which executing quantity can be valued, due mainly to the number of products which are regularly manufactured (by different DRG treated or different exams) [1, 5, 6].

We now analyse in detail our evaluation of total cost of the chest exam performed both with digital and conventional technique with the method used in our department as previously described. We considered eight components of the total cost and more specifically the following:

1. Variable costs of digital and conventional technologies (materials and related services)
2. Chest radiology unit costs (depreciation and maintenance)
3. Digital equipment costs (depreciation)
4. Exposure costs (wearing out of plates, depreciation)
5. Cassettes, screens and developing machine costs
6. Technician staff costs
7. Radiologist staff costs
8. Auxiliary staff costs
9. Department overheads

Results

Digital technology

Variable costs for digital technology

Considering that we performed two projections only in 30% of examined patients in standing position, 121 8×10-in. films were used for 100 exams [100 + (30% of 70)]. The variable cost of 2367 Liras (1.22 Euro) comes out as previously analysed (Table 5).

Chest radiology unit costs

We considered the present cost of chest-dedicated unit with a wall bucky stand. The average cost evaluated was 100,000,000 Liras (51,645.69 Euro) + IVA (19 %) = 119,000,000 Liras (61,458.37 Euro; note that starting 1 January 1998 the IVA is at 20 %).

An annual cost of 14,875,000 Liras (7,682.30 Euro) results with an 8-year depreciation. We must add to this amount the reasonable necessary costs for maintenance and spare parts over 8 years, amounting, according to our evaluation, to 5,000,000 Liras/per year (2,582.28 Euro).

The sum of the annual depreciation (14,875,000 Liras = 7,682.30 Euro) plus the annual costs for maintenance and spare parts gives therefore an annual cost of the radiological unit equal to 19,875,000 Liras (10,264.58 Euro). Calculating 250 working days, the daily cost is 79,500 Liras (41.06 Euro).

As already shown, our RIS provides one exam every 10 ft. Therefore, the 38 chest exams are performed during one shift scheduled considering that one technician takes approximately 20 ft. at the beginning and another 20 ft. at the end of his shift (7.30–14.30) to set up and dismantle the unit.

Dividing the daily cost of the unit (79,500 Liras = 41.06 Euro) by the number of exams, we calculated that the cost of the unit during one shift for every radiological exam is on average 2,092 Liras (1.08 Euro).

Digital equipment costs

As shown in Table 7, the total annual cost of digital equipment (considering an 8-year depreciation) is 91,480,440 Liras (47,245.70 Euro) (equipment costs + maintenance + electrical power consumption). We did not consider additional investment in the equipment, because the demographic trend of the population served by the hospital is very stable.

Dividing it by the operating hours per year (250 days/year multiplied by 6 h plus 30 ft./day = 1.750 h of functioning), we obtain a cost per hour equal to 52,274 which is 871 Liras/min (45 cents).

As mentioned previously, since we expose 121 films for 100 patients, and since our evaluations show that a chest cassette keeps the equipment busy for 2 min, we considered 2 ft. plus 21 % = = > 2.5 h of digital equipment cost equal to 2,177 Liras (1.12 Euro).

Exposure costs (wearing out of plate)

The cost of plates and cassettes 36 × 43 cm (purchasing price + IVA 19 %–45 % discount) is 1,296,565 Liras (669.62 Euro) each. Considering their utilization for 5000 exposures, a cost of 264 Liras (14 cents) resulted (259 Liras per shot plus 5 Liras equal to 2 % of retakes) to which we must add 52 Liras (3 cents) for the cost of plate and cassette 35 × 35 cm (which is 1,210,825 Liras = 625.34 Euro): 5000 exposures plus 2 % retakes = 247 Liras (13 cents) which is, however, shown only in 21 % of patients with an L-L projection indicated. The result is the cost of plate usage per exam: 316 Liras (16 cents).

Costs for cassettes, screens and developing do not appear in a digital system.

Technician staff costs

The annual cost of a technician is 45,000,000 Liras (23,240.56 Euro). We also considered effective working hours. We calculated time of leave, i. e. holidays, illnesses, leaves, accidents (mean 30 %) for which we can consider the effective presence of technicians equal to 35 weeks/year: the total weekly cost of the technician is 1,285,714 Liras (664.01 Euro). Therefore, considering 190 chest exams performed weekly, the staff cost for each exam is equal to 6,766 Liras (3.49 Euro).

Radiologist staff costs

As already stated, the radiologist duty was considered at exam batch level. We consider incorrect dividing the fixed radiologist cost by the total number of exams performed. In our department, chest exams are reported by two radiologists and their daily duty amounts to 2 h each for a total of 4 h of daily medical duty.

Evaluating the annual cost of a radiologist (100,000,000 Liras = 51,645.69 Euro) and deducting ordinary, extraordinary and sickness leaves from the total annual hours (mean 30 %), we obtain a daily radiologist cost of 571,429 Liras (295.12 Euro) and 84,033 Liras (43.40 Euro) per hour. Therefore, the daily cost of chest reports is equal to 336,134 Liras (173.60 Euro) which is 8,845 Liras (4.57 Euro) per exam.

Auxiliary personnel staff costs

We considered all professional employees we did not mention previously (except for nursing staff not involved in chest exams). We counted one technician supervisor, five auxiliary staff, seven archiving staff and seven administrative employees.

Overall this auxiliary staff works together to operate the department as a whole (batch, process, facility level). We consider their jobs not influenced by the kind of exams, and therefore their total cost was divided by the total number of exams performed in the Department of Radiology. During 1996 this total number of exams was 112,953 and this determined [considering a 40,000,000 Liras (20,658.28 Euro) annual cost pro capita] an average auxiliary staff cost of 7,083 Liras (3.66 Euro) per exam.

Department overheads

It is presently very difficult to evaluate accurately the effective department overhead costs. These costs can be

Table 8. Chest radiology unit full cost

	Conventional system	Digital system	Δ
Variable costs	5776	2367	+ 3409
Chest radiology unit costs	2092	2092	–
Digital equipment costs	–	2177	–2177
Exposure costs (wearing out of plates)	–	316	–316
Cassettes, screens, developing machine costs	3376	–	+ 3376
Technician staff costs	9919	6766	+ 3153
Radiologist staff costs	8845	8845	–
Auxiliary staff costs	7083	7083	–‘
Department overheads	2184	2184	–

divided into (a) indirect costs for technology, and (b) indirect costs for staff. Under the first category we included various items (computers, printers, recorders, electric and network equipment, cleaning materials), and the result was a total cost of 1,000 Liras based on our management analysis. Under the second category we included the technicians not directly involved with X-ray exams: six technicians are regularly dedicated to support activity (exam planning, PACS, RIS, equipment and warehouse management, enveloping and delivery of radiograms with report). This is a great amount of work force [6 of 34 (17.5 %) in which facility level, batch and process are included]. Therefore, we consider this as the 17.5 % of the technician staff cost which is 1,184 Liras (61 cents). The result is a total indirect cost of 2,184 Liras (1.13 Euro).

At the end of this analysis we determined the total cost of chest exam performed with digital technology (Table 8). There was a clear difference between total cost of chest X-ray exam and the regional price list (30,000 Liras = 15.50 Euro). In fact, it is noteworthy that our evaluation considered only one X-ray procedure (8 × 10 in. and L-L in 21 % of patients) which leads to maximum savings.

The total cost increases by enlarging film size or by performing routine L-L projection. Moreover, we evaluated only total cost referred to the radiology department because it was difficult to obtain a valid overview of complete cost of a radiological exam performed in the hospital. Therefore, we conclude that a chest X-ray exam priced by the Italian national price list and/or the regional list is a service performed at a loss by the hospital.

Finally, we point out that the FASI price list represents an acceptable index for single radiological exams and, more specifically, for a chest X-ray. The revenue of a chest X-ray exam in the FASI price list is 75,000 Liras (38.73 Euro), and therefore it agrees with paid prices in comparison with the high producing costs. It is certain, however, that calculating the complete exam cost and including in it a percentage which evaluates costs for other functions within the hospital (without which, by the way, a radiology department would not be able to function) would produce a higher total cost and, therefore, also the FASI price list, as the pricing instrument of a professional organization, would barely be able to yield a profit margin for the hospital.

Conventional technology

We evaluated total cost for chest X-ray performed by using conventional technology, considering the same subgroups we had evaluated previously:

Variable costs for conventional technology

The variable costs for conventional technology were 5,776 Liras (2.98 Euro) in our experience (Δ: + 3,409 Liras = 1.76 Euro). A 36 × 43-cm film is needed for all patients and a 35 × 35-cm film for L-L projection is needed for those patients (70 %) who can maintain a standing position.

Chest unit costs

Chest unit costs are obviously the same.

Digital equipment costs

Digital equipment costs are not included in conventional imaging (Δ: –2,177 Liras = 1.12 Euro).

Exposure costs

The usage costs obviously do not exist for traditional radiology (Δ: –316 Liras = 16 cents)

Cassettes, screens and developing costs

In the functioning of a conventional system the depreciation costs for the developing machine and charging system for cassettes and screens must be evaluated. As shown in Table 7, the total yearly cost is of 69,310,968 Liras (35,796.13 Euro). Therefore, the system seems to be used not only for chest activities but also for skeletal exams, so we divided the cost by the total number of exams (20,525) and obtained a cost of 3,376 Liras/per exam (1.74 Euro; Δ: + 3,376 Liras = 1.74 Euro).

Technician staff costs

Technician staff costs vary because of the two additional minutes required by the conventional system (13 vs 11 ft. considering also support activity) and give therefore a cost of 9,919 Liras (5.12 Euro; Δ: + 3,153 Liras = 1.63 Euro).

We consider the last subgroups, radiologist staff costs, auxiliary staff costs and department overheads as unchanging. As a result, a chest radiogram performed with conventional technology requires an additional cost of 7,445 Liras (3.85 Euro) and therefore a total cost of 39,275 Liras (20.28 Euro).

Discussion

The acquisition of radiological equipment using photostimulated plates has allowed us, after 1 year of activity with the chest and skeletal units, to evaluate, first of all, the investment and operating costs of the new system and to make a cost–revenue analysis for the digital system compared with the conventional system.

The evaluation of total costs for the two technologies with an 8-year and 4-year depreciation revealed a greater cost for the digital technique of approximately 219,595,776 Liras (113,411.75 Euro) and 170,563,728 Liras (88,088.81 Euro), respectively (Table 7).

Comparing the depreciation of higher differential costs for digital technology with the operating-cost savings over 8 and 4 years for 13,401 chest exams and 7124 skeletal exams, a total savings of 371,585,608 Liras (191,907.95 Euro) and 125,026,964 Liras (64,571.04 Euro), respectively, resulted (Fig. 1). This savings resulted mainly from the use of reduced film sizes (8 × 10 in.) in all cases and from the elimination of L-L projection for chest, except for mass-opacity cases in frontal view and in patients with cardiovascular problems.

The use of 8 × 10-in. film was important primarily for a cost savings management. Its employment for chest radiograms has been acknowledged by interobserver evaluation with ROC analysis concerning the accuracy of this format in digital technique as compared with the 36 × 43-cm film size in conventional technique.

The employment of 8 × 10-in. film size leads to a breakeven point in 1 year with 10,000 chest exams. In order to obtain the same breakeven point with 11 × 14-in. film size, 30,000 chest exams are needed.

For skeletal exams, in which there is not elimination of projections but only reduction in film size, the breakeven point in 1 year, using 8 × 10-in. film size, is reached with 20,000 exams performed.

Utilization of a smaller film size leads the radiologist into some initial difficulties: in our experience, we reached it gradually after getting familiar with the 11 × 14-in. film.

Regarding the small film size, the main difficulty with the orthopaedics which accepted the new size was with skeletal segments which were to be replaced by protheses (hip and knee), for which we used conventional technology.

On chest X-ray imaging, moreover, using digital technology, part of the production capacity is saved; in particular, there is a lesser wearing out of the radiological tube and a lead time per exam of 2 min less due to the equipment and technician staff employment. This last aspect is interesting because it permits performance of more chest exams which are done otherwise by other operating units, spending only variable cost.

As a result, the total cost per exam would be reduced, and this reduction would improve the efficiency of the hospital. The analysis of the total cost with the two technologies and the unitary revenue analysis was very interesting.

The total cost for digital technology was 31,830 Liras (16.44 Euro), whereas for conventional technology it was 39,275 Liras (20.52 Euro), resulting in a loss if compared with the National Health Service Price of 30,000 Liras (15.50 Euro). Moreover, the cost of the hospital structure in which our department operates was not included in the total cost. Introducing radiographic equipment using photostimulated plates is therefore justified from an economical point of view, and its depreciation time is determined both by film size and number of performed exams.

In the literature two groups have evaluated the digital system using photostimulated plates compared with the conventional system from an economical point of view. In contrast to Braunschweig et al. [7], we tried not to classify the different production factors into two traditional categories, fixed and variable costs according to volume. We instead tried to evaluate, for every production factor, the main variability causes.

On the other hand, we agreed on the digital system's convenience as long as a sufficient number of exams is performed and a small-size hard copy is used. In our evaluation the lesser cost was obtained using the 8 × 10-in. smaller format, and in addition, we discontinued use of L-L projection for 70 % patients.

In contrast to Ferrari et al. [8], we acted more cautiously in estimating the savings in wasted films obtained with digital equipment: approximately 50 % compared with 9–10 % cited in the literature; on the other hand, authors are more cautious in estimating time savings: half if compared with our estimation of 2 min.

These differences may, however, be explained as being part of different operating environments of analysed units. Moreover, we preferred to measure radiological activity always as number of exams, even if this was not a great difference, instead of adopting film number occasionally and square metres of film occasionally.

There seems to be significant agreement concerning the total cost content. It must be acknowledged, however, that the variable cost calculation in the two systems seems comparable with the one of cited in the literature. At the same time, even taking into account the fact that they use a weighted exam as cost object, according to the system adopted in the Emilia Romagna Region, the total cost is calculated only as total period cost divided by total number of exams.

This method is very much approximate. We employed it only for the items of lesser importance. For

the most important items, i.e. medical and technician staff costs, depreciation costs and electrical power costs, we proceeded by direct and specific calculation in considering true cost elements for these production factors.

It is astonishing to see authors report about "money saving" when considering "room capacity utilization" reduction. In fact, this had just been correctly shown as a productivity increase, without an overview of change to obtain annual or monthly savings for labour or other factor costs. All of this seems to be an improbability within a National Health Service hospital. Moreover, a possible place for this productivity improvement has not been explained (typically, it would be more exams yearly).

Finally, we point out not only the economical advantages of digital equipment, but also the clinical advantages which are: (a) homogeneous image quality with significant lower number of retaken films; (b) chance to manipulate imaging; and (c) almost complete disappearance of blind areas in chest radiograms.

In case of digitalization of the department, digital technology offers even more economical and operative advantages such as: (a) monitor image viewing and therefore no more need for film use and storage; (b) PACS use and therefore long distance image transferring; and (c) connection with RIS and HIS.

Conclusion

In conclusion, the comparison between digital and conventional radiography systems emphasized the following aspects:

1. Digital Radiography system has a much higher investment cost in comparison with the conventional system.
2. Operating costs of digital equipment may be higher or lower depending on film size. Evaluating chest X-ray, we reach a breakeven point after 1 year and 10,000 exams only if displayed on 8 × 10-in. film and after 30,000 if displayed on a 11 × 14-in. film.
3. Using the 8 × 10-in. film size, the total cost (variable cost, technology cost, labour cost) of digital technology is lower than the cost of conventional technology by 20% on average.
4. Digital technology allows: (a) lesser film waste; (b) lesser film per exam; and (c) advantages due to image post-processing, long-distance transfer and, possibly, the use of a monitor only for report, eliminating the film.

It is advisable to invest in digital technology to obtain the lower average cost per exam in the hospital, given two conditions: (a) the agreement of radiologists and physicians to choose the 8 × 10-in. film size; and (b) a budgeted yearly workload equal to or more than that of breakeven between the two alternatives.

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