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ESTRO-HERO survey

Radiotherapy equipment and departments in the European countries: Final results from the ESTRO-HERO survey

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ABSTRACT

Background: Documenting the distribution of radiotherapy departments and the availability of radiotherapy equipment in the European countries is an important part of HERO – the ESTRO Health Economics in Radiation Oncology project. HERO has the overall aim to develop a knowledge base of the provision of radiotherapy in Europe and build a model for health economic evaluation of radiation treatments at the European level. The aim of the current report is to describe the distribution of radiotherapy equipment in European countries.

Methods: An 84-item questionnaire was sent out to European countries, principally through their national societies. The current report includes a detailed analysis of radiotherapy departments and equipment (questionnaire items 26–29), analyzed in relation to the annual number of treatment courses and the socio-economic status of the countries. The analysis is based on validated responses from 28 of the 40 European countries defined by the European Cancer Observatory (ECO).

Results: A large variation between countries was found for most parameters studied. There were 2192 linear accelerators, 96 dedicated stereotactic machines, and 77 cobalt machines reported in the 27 countries where this information was available. A total of 12 countries had at least one cobalt machine in use. There was a median of 0.5 simulator per MV unit (range 0.3–1.5) and 1.4 (range 0.4–4.4) simulators per department. Of the 874 simulators, a total of 654 (75%) were capable of 3D imaging (CT-scanner or CBCT-option). The number of MV machines (cobalt, linear accelerators, and dedicated stereotactic machines) per million inhabitants ranged from 1.4 to 9.5 (median 5.3) and the average number of MV machines per department from 0.9 to 8.2 (median 2.6). The average number of treatment courses per year per MV machine varied from 262 to 1061 (median 419). While 69% of MV units were capable of IMRT only 49% were equipped for image guidance (IGRT). There was a clear relation between socio-economic status, as measured by GNI per capita, and availability of radiotherapy equipment in the countries. In many low income countries in Southern and Central-Eastern Europe there was very limited access to radiotherapy and especially to equipment for IMRT or IGRT.

Conclusions: The European average number of MV machines per million inhabitants and per department is now better in line with QUARTS recommendations from 2005, but the survey also showed a significant heterogeneity in the access to modern radiotherapy equipment in Europe. High income countries especially in Northern-Western Europe are well-served with radiotherapy resources, other countries are facing important shortages of both equipment in general and especially machines capable of delivering high precision conformal treatments (IMRT, IGRT).

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Evidence-based regimens and novel high precision technology have reinforced the important role of radiotherapy in contemporary multimodality management of cancer. Current data estimate that about 50% of all cancer patients would benefit from radiotherapy during the course of their disease, with many of them requiring several courses of treatment [1,2]. Due to significant technical improvements, it is now possible to cure more patients with fewer side effects. This requires, however, access to modern equipment, including intensity modulated radiotherapy (IMRT), image-guided radiotherapy (IGRT), stereotactic radiotherapy and, most recently, particle therapy [3–11]. The European situation is highly diverse with large differences in demographics, cancer incidence and economic resources among countries. From the "Radiation Therapy for Cancer: Quantification of Radiation Therapy Infrastructure and Staffing Needs" (QUARTS) project and more recent analyses, it has been shown that parts of Europe are well-served in radiotherapy resources, whereas others are facing important shortages as well in terms of equipment and infrastructure as of trained personnel [12,13].

The ESTRO initiated HERO-project (Health Economics in Radiation Oncology) has the overall aim to develop a knowledge base and a model for health economic evaluation of radiation treatments at the level of individual European countries [14]. To accomplish these objectives, the HERO project addresses availability, needs, cost and cost-effectiveness of radiotherapy. By providing an updated and validated description of the European radiotherapy landscape in collaboration with the national societies, and through the development of web-based cost and cost-effectiveness models, ESTRO wants to support the European countries and their national radiotherapy societies in benchmarking their position in Europe and computing the cost and cost-effectiveness of radiotherapy in their specific economic context.

This first part of the HERO program is based on a detailed survey providing an inventory of European radiotherapy in terms of resource availability (departments, equipment, and personnel), guidelines and reimbursement. The data will be presented in three simultaneous papers. The two other papers address staffing [15] and guidelines [16], respectively, while the current paper focuses on the distribution of radiotherapy equipment in European countries.

Materials and methods

A web-based questionnaire consisting of 84 questions relating to population and cancer incidence, radiotherapy activity and resources, guidelines and reimbursement was developed and distributed to national scientific and professional radiotherapy societies. The full details of the data collected, the methodological considerations and the practical decisions regarding the data set used for the entire analysis, are described in the Supplementary Documentation.

The current report includes a detailed analysis of radiotherapy departments and equipment (questionnaire items 26–29) in the countries defined by the European Cancer Observatory (ECO), analyzed in relation to the annual number of patients treated in the same countries. Among the 34 ECO countries responding to the questionnaire, 28 countries could be included in the analysis of equipment (Table 1): 24 countries with complete datasets, and 4 countries (Belarus, Germany, Italy and United Kingdom) with partial data. The remaining 12 ECO countries (Romania, Slovakia, Bosnia, Croatia, Cyprus, Latvia, Macedonia, Russia, Serbia, Ukraine, Greece, Republic of Moldova) either provided none or insufficient data, did not submit updates, or did not give their consent to use their previous submission.

From the questionnaire, the number of megavoltage (MV) units was calculated as the sum of linear accelerators (including helical tomotherapy), cobalt-60 and dedicated stereotactic machines. Simulators for radiotherapy imaging and treatment planning were classified as conventional simulators (2D), CT simulators or simulators with a cone-beam CT option (CBCT).

The number of radiotherapy treatment courses, being primary treatments, palliative treatments or retreatments, was recorded in the questionnaire. For the countries where the information about retreatments was unavailable, the primary treatment figures were augmented with 25% [12].

The economic status of the countries was expressed as gross national income per capita (GNI/n) using the Atlas method [17]. In order to identify relatively homogeneous groups of countries based on selected characteristics such as the percentage with IMRT technology, megavoltage machine units per million inhabitants and GNI/n, we used the k-means clustering via principal components analysis using the Hartigan and Wong method [18]. With this method, multidimensional data can be represented on two axes and the cluster centroids (vector of mean values of each variable) could be defined. Germany and Italy were excluded from this part of the analysis since the data related to IMRT capability were not available. The statistical software R was used to perform this analysis [19].

Results

The validated data on number of radiation treatments, departments and equipment in the 28 ECO countries form the basis of the present analysis (Table 1).

Equipment

A total of 3024 photon therapy units (2705 MV and 319 kV machines) and 7 proton facilities were recorded in the 28 countries. One country did not supply detailed information about MV unit type; in the remaining 27 countries there were 2192 linear accelerators, 96 stereotactic machines and 77 cobalt machines reported. Twelve countries (43%) had at least one cobalt machine in use. Information about equipment for IMRT and IGRT was available for 26 countries; a total of 1327 out of 1915 MV units in 26 countries with this information availble were equipped for IMRT (69%). IGRT equipment was available in 930 of 1915 MV units (49%). In seven countries (Albania, Belarus, Bulgaria, Hungary, Ireland, Lithuania, Spain) less than half of the MV machines were equipped for delivering IMRT, and in 13 countries (Albania, Montenegro, Hungary, Bulgaria, Belarus, Spain, Lithuania, Switzerland, Czech Republic, Ireland, United Kingdom, Slovenia, Portugal) less than half of the MV units were equipped for IGRT. There was a total of 96 dedicated stereotactic radiotherapy units in 13 countries; the remaining 15 countries did not have such equipment ($n = 12$) or did not report ($n = 3$). Simulators for treatment planning were either 2D kilovoltage (kV; $n = 220$), CT-simulators ($n = 592$) or 2D kV units with 3D option (CBCT) ($n = 62$). Overall, 75% of all simulators had 3D capability. In three countries (Czech Republic, Hungary, Lithuania) less than half of the simulators had 3D capability.

Department infrastructure

A total of 872 facilities were recorded in 27 countries, distributed as 814 departments (93%) and 58 satellites (7%). The highest number of facilities was in France ($n = 176$) followed by Italy ($n = 165$), Spain ($n = 112$), and the United Kingdom ($n = 77$); the remaining countries had between 1 and 48 centers each. The

Table 1
Data on demographics, average number of treatment machines, simulators and departments in 28 European countries included in the HERO database.

Countries	Demographics				Treatment units						Other machines			Simulators				Departments		
	Population (2011, WB)	GNI/n 2011 (USD)	RT Courses	Ref. year equipment	Total MV units	Linear accelerators	Linacs with IMRT	Linacs with IGRT	Dedicated SRS	Cobalt units	Ortho-voltage machines	Proton facilities	Carbon ion facilities	Total simulators	2D sim	2D sim with CT option	CT sim	Total facilities	Departments	Satellites
Albania	2,829,337	4,050	2,195	2010	4	2	0	0	0	2	1	0	0	2	0	0	2	2	2	0
Austria	8,406,187	48,170	21,481	2010	43	42	35	26	1	0	7	0	0	21	8	1	12	14	14	0
Belarus	9,473,000	6,270		2009	30	8	5	4	0	22	18	0	0	20	9	7	4	23	20	3
Belgium	11,047,744	45,840	34,672	2013	91	87	71	57	3	1	8	0	0	29	8	7	14	36	25	11
Bulgaria	7,348,328	6,640	13,794	2012	13	5	2	1	0	8	10	0	0	6	1	1	4	14	14	0
Czech Republic	10,496,088	18,720	32,630	2009	57	43	29	17	4	10	39	1	0	28	18	0	10	48	36	12
Denmark	5,570,572	60,160	17,680	2010	53	53	50	47	0	0	6	0	0	14	0	0	14	9	7	2
Estonia	1,327,439	15,260	2,122	2012	4	4	4	4	0	0	0	0	0	3	1	0	2	2	2	0
Finland	5,388,272	47,740	13,994	2010	43	41	41	41	2	0	0	0	0	17	2	2	13	13	12	1
France	65,343,588	42,690	187,172	2012	449	421	412	238	28	0	11	2	0	165	26		139	176	172	4
Germany	81,797,673	44,230		2010	450	434				16	103									
Hungary	9,971,727	12,840	19,951	2011	36	26	6	2	1	9	4	0	0	19	12	0	7	12	12	0
Iceland	319,014	35,260	595	2010	2	2	2	1	0		1	0	0	1	0	1	0	1	1	0
Ireland	4,576,794	38,960	8,373	2009	32	31	10	10	0	1	2	0	0	12	3	0	9	12	12	0
Italy	59,379,449	35,350		2011	340													165	162	3
Lithuania	3,028,115	13,000	6,268	2011	10	10	3	2	0	0	5	0	0	5	4	0	1	5	4	1
Luxembourg	518,347	77,380	1,180	2010	2	2	2	1	0	0	0	0	0	2	1	0	1	1	1	0
Malta	416,268	19,760	535	2014	2	2	1	1	0	0	1	0	0	1	0	0	1	1	1	0
Montenegro	620,644	6,810	1,500	2011	2	2	0	0	0	0	0	0	0	3	1	1	1	1	1	0
The Netherlands	16,693,074	49,660	55,683	2012	132	132	125	125		0	8	0	0	38	8	0	30	29	21	8
Norway	4,953,088	88,500	13,483	2011	41	40	40	40	1	0	6	0	0	22	11	0	11	9	5	4
Poland	38,534,157	12,340	73,500	2010	120	115	109	77	4	1	5	1	0	76	24	16	36	35	35	0
Portugal	10,557,560	21,420	17,957	2010/12	44	41	30	18	3	0	0	0	0	20	3	5	12	17	17	0
Slovenia	2,052,843	23,940	6,023	2012	8	8	5	3	0	0	1	0	0	3	1	0	2	1	1	0
Spain	46,742,697	30,930	98,525	2011	261	220	56	50	36	5	18	0	0	167	35		132	112	112	0
Sweden	9,449,213	53,530	22,678	2012	63	62	51	44	1	0	4	0	0	21	6	0	15	16	15	1
Switzerland	7,912,398	76,350	19,000	2013	59	52	52	12	6	1	11	2		39	13		26	41	37	4
United Kingdom	63,258,918	37,840		2010/11	314	307	186	109	6	1	50	1	0	140	25	21	94	77	73	4
England	53,012,456	n.a.	121,289	2010	268	261	146	86	6	1	46	1	0	117	19	18	80	68	64	4
Scotland	5,295,000	n.a.		2011	25	25	23	16	0	0	1	0	0	13	4	1	8	5	5	0
Wales	3,063,456	n.a.	6,445	2011	13	13	9	7	0	0	3	0	0	7	2	1	4	3	3	0
Northern Ireland	1,810,863	n.a.	4,180	2010	8	8	8	0	0	0	0	0	0	3	0	1	2	1	1	0
No. entries	28	28	24	26	28	27	26	26	25	26	27	26	25	26	26	23	26	27	27	27
Total	488,012,534	973,640	670,991		2705	2192	1327	930	96	77	319	7	0	874	220	62	592	872	814	58
Median	8,159,293	35,305	15,837	2011	43	41	30	15	1	0	5	0	0	20	5	0	11	14	14	0
Min	319,014	4,050	535	2009	2	2	0	0	0	0	0	0	0	1	0	0	0	1	1	0
Max	81,797,673	88,500	187,172	2014	450	434	412	238	36	22	103	2	0	167	35	21	139	176	172	12

Table 2
Calculated indicators for availability of radiotherapy equipment in 28 European countries included in the HERO database.

Countries	Indicators									
	Departments/mil inh	MV units/mil inh	MV units/dep	MV units with IMRT	MV units with IGRT	Sim/dep	Sim/MV unit	Sim with 3D	Courses/dep	Courses/MV
Albania	0.7	1.4	2.0	0%	0%	1.0	0.5	100%	1098	549
Austria	1.7	5.1	3.1	81%	60%	1.5	0.5	62%	1534	500
Belarus	2.1	3.2	1.5	17%	13%	1.0	0.7	55%		
Belgium	2.3	8.2	3.6	78%	63%	1.2	0.3	72%	1387	381
Bulgaria	1.9	1.8	0.9	15%	8%	0.4	0.5	83%	985	1061
Czech Republic	3.4	5.4	1.6	51%	30%	0.8	0.5	36%	906	572
Denmark	1.3	9.5	7.6	94%	89%	2.0	0.3	100%	2526	334
Estonia	1.5	3.0	2.0	100%	100%	1.5	0.8	67%	1061	531
Finland	2.2	8.0	3.6	95%	95%	1.4	0.4	88%	1166	325
France	2.6	6.9	2.6	92%	53%	1.0	0.4	84%	1088	417
Germany		5.5								
Hungary	1.2	3.6	3.0	17%	6%	1.6	0.5	37%	1663	554
Iceland	3.1	6.3	2.0	100%	50%	1.0	0.5	100%	595	298
Ireland	2.6	7.0	2.7	31%	31%	1.0	0.4	75%	698	262
Italy	2.7	5.7	2.1							
Lithuania	1.3	3.3	2.5	30%	20%	1.3	0.5	20%	1567	627
Luxembourg	1.9	3.9	2.0	100%	50%	2.0	1.0	50%	1180	590
Malta	2.4	4.8	2.0	50%	50%	1.0	0.5	100%	535	268
Montenegro	1.6	3.2	2.0	0%	0%	3.0	1.5	67%	1500	750
The Netherlands	1.3	7.9	6.3	95%	95%	1.8	0.3	79%	2652	422
Norway	1.0	8.3	8.2	98%	98%	4.4	0.5	50%	2697	329
Poland	0.9	3.1	3.4	91%	64%	2.2	0.6	68%	2100	613
Portugal	1.6	4.2	2.6	68%	41%	1.2	0.5	85%	1056	408
Slovenia	0.5	3.9	8.0	63%	38%	3.0	0.4	67%	6023	753
Spain	2.4	5.6	2.3	21%	19%	1.5	0.6	79%	880	377
Sweden	1.6	6.7	4.2	81%	70%	1.4	0.3	71%	1512	360
Switzerland	4.7	7.5	1.6	88%	20%	1.1	0.7	67%	514	322
United Kingdom	1.2	5.0	4.3	59%	35%	1.9	0.4	82%		
England	1.2	5.1	4.2	54%	32%	1.8	0.4	84%	1895	453
Scotland	0.9	4.7	5.0	92%	64%	2.6	0.5	69%		
Wales	1.0	4.2	4.3	69%	54%	2.3	0.5	71%	2148	496
Northern Ireland	0.6	4.4	8.0	100%	0%	3.0	0.4	100%	4180	523
No. entries	27	28	27	26	26	26	26	26	24	24
Total										
Median	1.7	5.3	2.6	73%	45%	1.4	0.5	72%	1173	419
Min	0.5	1.4	0.9	0%	0%	0.4	0.3	20%	514	262
Max	4.7	9.5	8.2	100%	100%	4.4	1.5	100%	6023	1061

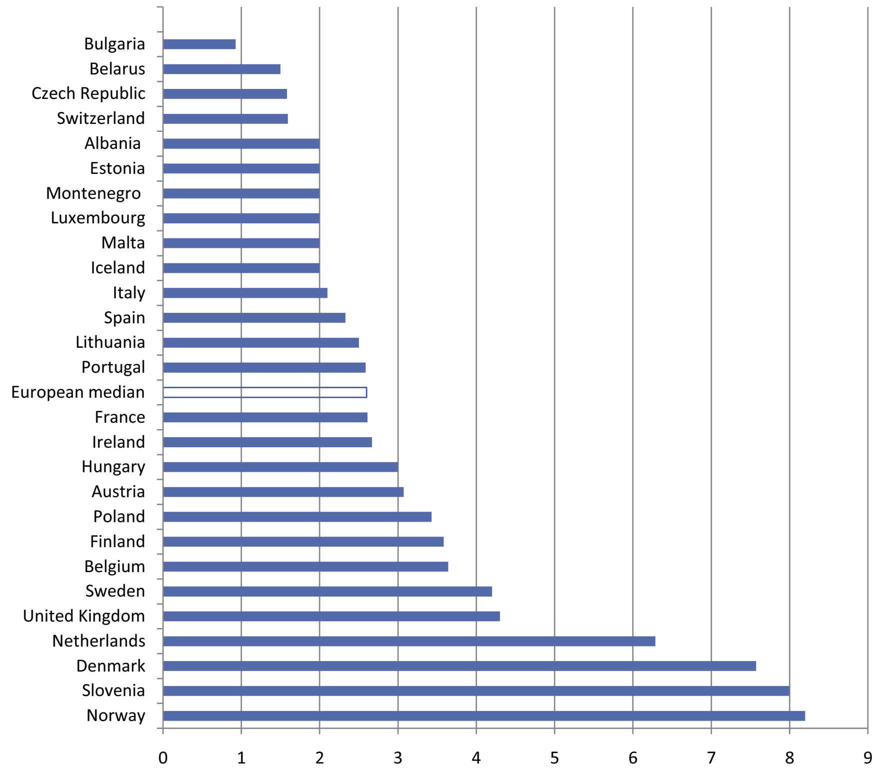

Fig. 1. Histogram showing the average number of radiotherapy treatment machines (MV units) per department in 27 European countries.

average number of MV units per department ranged from fewer than two (Belarus, Bulgaria, Czech Republic, Switzerland) to more than six (Denmark, The Netherlands, Norway, Slovenia); the median being 2.6 MV units per department (Table 2 and Fig. 1). There was a median of 1.4 simulators per department (range 0.4–4.4) and 0.5 simulators per MV unit (range 0.3–1.5).

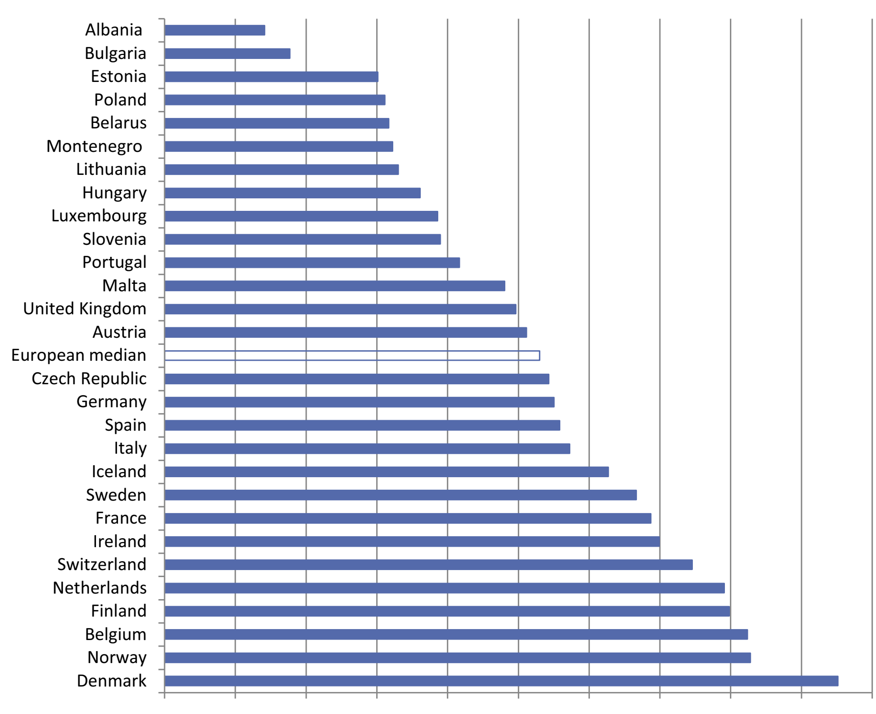

Fig. 2. Histogram showing the average number of radiotherapy treatment machines (MV units) per million inhabitants in 28 European countries.

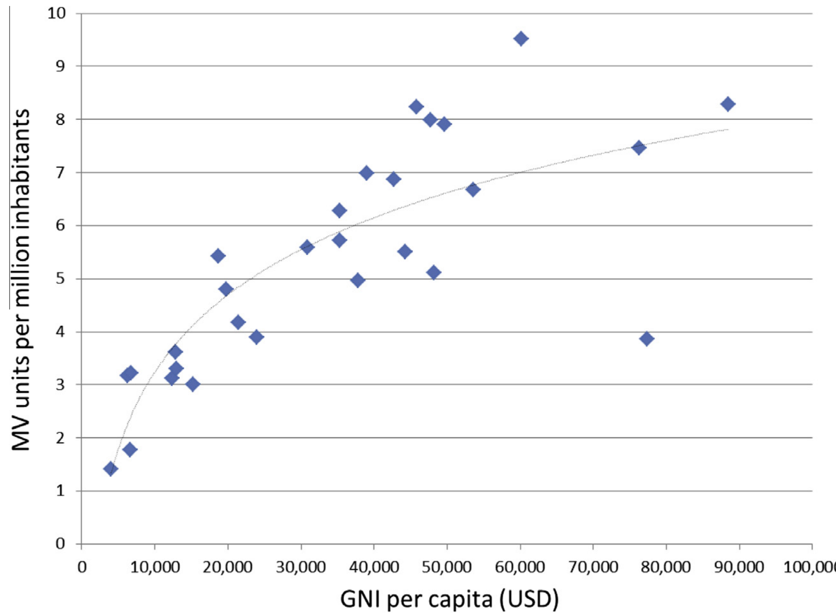

Fig. 3. Diagram showing the relationship between economic status (GNI per capita) and the average number of radiotherapy treatment machines (MV units) per million inhabitants in 26 European countries.

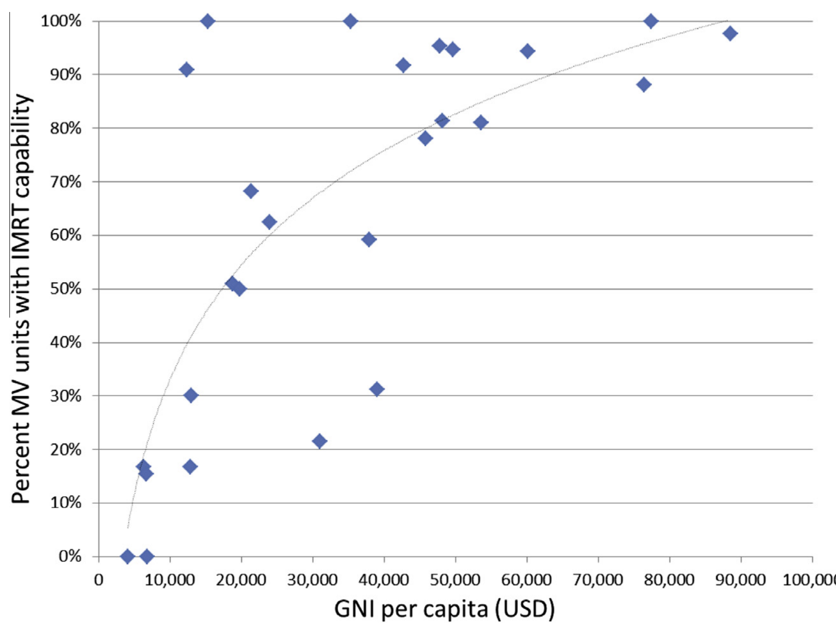

Fig. 4. Diagram showing the relationship between economic status (GNI per capita) and the percentage of radiotherapy treatment machines (MV units) capable of delivering IMRT in 27 European countries.

Demographic and economic indicators

The availability of radiotherapy services in relation to key demographic and economic parameters is presented in Table 2. The average number of departments per million inhabitants ranged from 0.5 to 4.7 (median 1.7). This variation was to some extent reflected in a similarly large variation in the average size of the departments, as shown in Fig. 1.

Fig. 2 shows the average number of MV units per million inhabitants; the median number was 5.3. There was a sevenfold variation in this parameter, ranging from very low availability of less than 2 MV units per million in Albania and Bulgaria to more than 8 MV units per million in Belgium, Denmark and Norway.

There was a significant influence of national economic status on the availability of radiotherapy services in the 28 European countries. Fig. 3 shows the correlation between GNI per capita and the number of MV units per million inhabitants. High-income countries had more machines per million than countries with lower GNI per capita. Countries with GNI per capita above USD

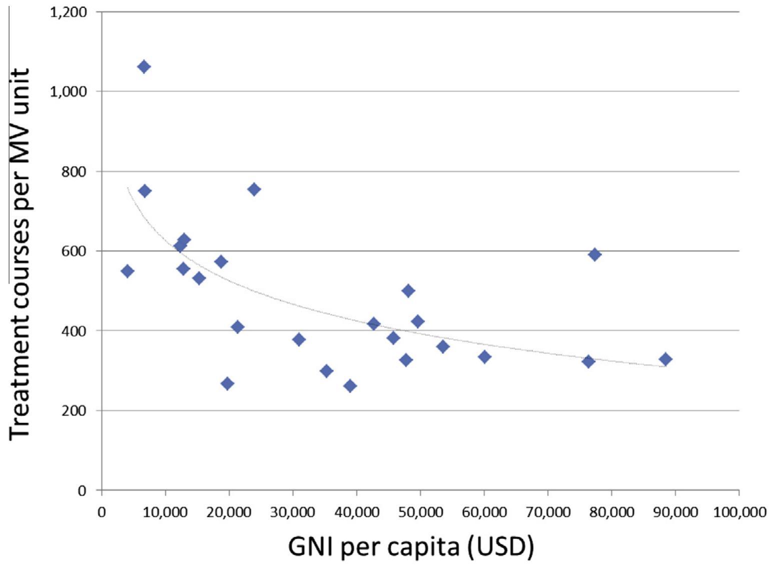

Fig. 5. Diagram showing the relationship between economic status (GNI per capita) and the average number of treatment courses per radiotherapy treatment machines (MV units) in 27 European countries.

Table 3
Correlation between variables included in the k-means clustering via principal components analysis.

	IMRT (%)	GNI/n	MV units/mil inh
IMRT (%)	1	0.68	0.59
GNI/n	0.68	1	0.76
MV units/mil inh	0.59	0.76	1

30,000 in general had more than 4 MV units per million inhabitants, the only exception being Luxembourg (3.9 MV/mil). The eight countries with GNI per capita below USD 16,000 all had less than four MV units per million inhabitants.

The economic status also influenced access to machines with the ability to deliver highly conformal treatments (IMRT). Fig. 4 shows the relationship between GNI per capita and percentage of MV units capable of IMRT. As can be seen, more than 75% of machines could deliver IMRT in countries with GNI/n above USD 40,000, compared to less than 25% in the four lowest income countries. Poland and Estonia were exceptions, having a high percentage of IMRT capability despite a relatively low GNI per capita.

The average number of treatment courses delivered per year per department varied from fewer than 700 (Switzerland, Ireland, Iceland, Malta) to more than 2000 (Poland, Denmark, The Netherlands, Norway, Slovenia); the median number was 1173 treatment courses. The median number of treatment courses per MV unit in 24 countries was 419, with a large variation from fewer than 300 courses per MV in Ireland, Iceland and Malta to more than 700 in Bulgaria, Montenegro and Slovenia. There was a clear correlation with the socio-economic status, with more treatments delivered per machine in the countries with the lowest GNI per capita (Fig. 5).

Cluster analysis

Table 3 shows correlations between the three variables (%IMRT, MV units/mil, GNI/n) used in the clustering analysis. GNI was

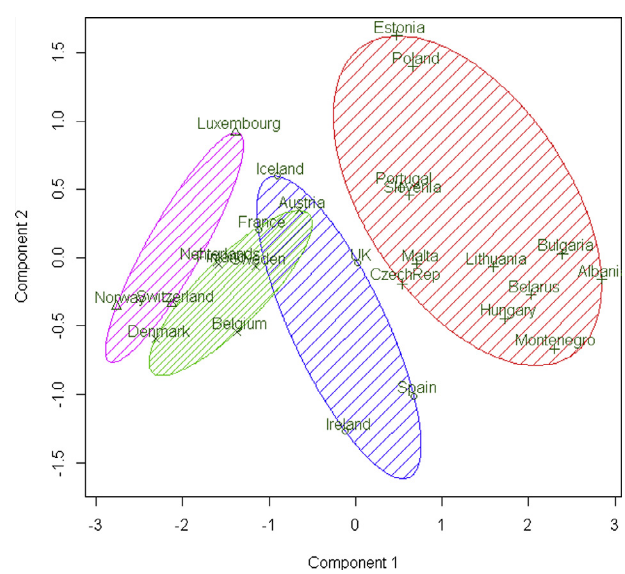

Fig. 6. The four clusters found through the k-means clustering via principal components analysis.

highly correlated with the percentage of IMRT capability ($r = 0.68$) and MV machines per million inhabitants ($r = 0.76$), however these last two variables showed a slightly lower correlation between them ($r = 0.59$). In the subsequent clustering analysis it was found that these three variables could be graphically depicted using two axes which represented 92.7% of the total variability. Using these two components, we found 4 clusters of countries (Fig. 6 and Table 4). Cluster 1 defined by Luxembourg, Norway and Switzerland showed high equipment inventories per million inhabitants and the highest GNI/n. Countries in cluster 2 (Austria, Belgium, Denmark, Finland, The Netherlands) had lower GNI/n but higher equipment inventories per million inhabitants than that of cluster 1. Cluster 3, formed by France, Iceland, Ireland, Spain and

Table 4
Centroids of the clusters identified in the k-means clustering via principal components analysis.

	Cluster	IMRT (%)	GNI/n	MV units/mil inh
1	Luxembourg, Norway, Switzerland	95.3	80.7	6.6
2	Austria, Belgium, Denmark, Finland, The Netherlands, Sweden	87.3	50.8	7.6
3	France, Iceland, Ireland, Spain, UK	60.6	37.1	6.2
4	Albania, Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Lithuania, Malta, Montenegro, Poland, Portugal, Slovenia	41.8	13.4	3.4

UK showed centroid values lower than those of cluster 2. Cluster 4 was formed by former Eastern European countries, Malta, and Portugal, presented the lowest GNI/n, equipment and IMRT technology.

Discussion

This is the initial report on the outcome of the ESTRO-HERO database, based on validated national data, collected in collaboration with the national radiotherapy societies. The main findings confirm a large variation between countries for all types of equipment and availability indicators studied.

The first parts of the HERO project build on the experience of the QUARTS-project, the first real attempt to arrive at estimates for the appropriate level of radiotherapy infrastructure and staffing in Europe [12,20]. The two main equipment indicators from QUARTS were MV units per million inhabitants and number of treatments per MV unit. Official guidelines for the number of linear accelerators and personnel were available in about 40% of the countries in the QUARTS analysis. For accelerators, the analysis of guidelines came to a recommendation of an average of 5.5 MV units/million in the high, 3.5 MV units/million in the medium and 2.0 MV units/million in the low resource countries [20]. These numbers have not changed significantly over the last decade, as illustrated in the update of guidelines survey performed as part of the HERO project [16]. In the second part of the QUARTS analysis [12], the best available evidence on radiotherapy indications in 23 main cancer types was combined with epidemiological data from all 25 EU countries at that time and with published benchmarks for accelerator throughput. A large variation in crude cancer incidence observed within the analyzed EU countries translated into a similarly large variation in the estimated number of required linear accelerators per million inhabitants (between 4.0 and 8.1 linear accelerators/million inhabitants), hovering around a European average of 5.9. In the current HERO data set, the actual number was 5.3 MV units/million, meaning that the overall European average is now close to the QUARTS guideline standard for high income countries, albeit with a significant sevenfold difference from the highest to the lowest coverage. The lowest income countries all have less than 4 MV units per million inhabitants, and the highest income countries have close to 10 MV units per million. This socioeconomic disparity was also highlighted in the recent IAEA DIRAC study [13]. Despite some discussion about potential problems with the DIRAC data previously addressed [21,22], the two studies thus reach the same overall conclusions about the heterogeneity in radiotherapy equipment availability between European countries. Whether the actual need is still 5.9 MV units/million will be refined in the ongoing HERO project by calculating the needs based on actual cancer incidence in the individual countries and using evidence-based indications for radiotherapy.

Although the high correlations observed between GNI and MV units per million inhabitants and the percentage with IMRT could suggest the conclusion that economic resources available at country level are the main determinants of the radiotherapy equipment, the cluster analysis showed that the situation is not so straight forward. The countries included in the cluster with the highest GNI (Luxemburg, Norway, and Switzerland) do not have the highest number of MV per million, although they have the most technological updated equipment. From this perspective, it could be suggested that health policy decisions at country level matters.

The number of patients treated per MV unit is often used as a measure of machine productivity. From the guidelines, QUARTS estimated a European benchmark of 450 patients per machine per year, with an estimate of 400–450 patients per year accounting for increasing complexity. The recent HERO update of available guidelines showed no major change in this recommendation over the last decade [16]. In the current analysis of actually available equipment, the benchmark is reached, as the median number of treatment courses was 419 per MV unit. As shown in Fig. 5 there was a striking variation in machine throughput, which seemed to be related to the socio-economic status of the country, with high values in low income countries. In many of these low income countries, the equipment is being utilized for extended hours. In e.g. Slovenia, where the average throughput is over 700 patients per linear accelerator, all machines are used in two shifts per day. It can be seen from Table 2 that these countries also have the least advanced technology available, i.e. fewer linear accelerators capable of IMRT and IGRT, and relatively more cobalt units. The throughput is also dependent upon other factors, including referral base, complexity of treatment and the age of the equipment. Increasing use of high quality advanced conformal treatments and daily imaging will in many situations be more time-consuming and thus put a limit to how many treatments a machine can deliver. This is further discussed in the HERO staffing paper [15].

The type of radiotherapy equipment available in the European countries differed significantly. In total, 69% of all MV units were equipped for IMRT and 49% for IGRT, with much higher rates in high income countries. A number of Eastern European countries still have cobalt machines, which are not able to deliver modern conformal treatments. This skewed distribution was also noted in the DIRAC study [13].

The size of radiotherapy departments is an indicator of the organizational infrastructure. In the Nordic countries, Poland, The Netherlands and Slovenia, radiotherapy services are centralized in departments treating on average more than 1600 patients per year. Such large departments enable subspecialization of the staff. In the Dutch model, each radiation oncologist has 2–3 areas of expertise; to cover all tumor sites it is necessary to have at least eight specialists, which again require 1600–2000 patients per year to be efficient [23]. In most other European countries, however, facilities are small with only one or two machines. An average of fewer than 1,000 courses per year per department, as seen in eight countries (Malta, Switzerland, Iceland, Ireland, Spain, Czech Republic and Bulgaria), may indicate a fragmentation of radiotherapy services, which potentially influence treatment quality and might have negative effect on productivity. The major cost components of radiotherapy are buildings, equipment and staff. Due to the economics of scaling, the average cost per patient decreases with increasing department size and optimal utilization of resources. Earlier studies concluded that the costs per patient substantially decrease when a department is treating more than 1000 patients annually [24] or 1000–1200 annually [25]. Similar calculations have been done for Canada [26], finding a threshold about 1600 patients annually.

This HERO study has several limitations. We used national averages of institutional data, collected by individuals in the national societies over several years. This will inevitably introduce bias and variation in the data. Although we have tried to validate the data by repeated updates and comparison to other sources, and exclusion of the least reliable datasets, there will be some uncertainty in the presented data. This uncertainty specifically applies to data on complexity of the equipment (IMRT, IGRT, SRS), which are also sensitive to the time of data collection, since the field is quickly evolving. The survey also collected equipment capability only and did not collect data to understand if the equipment was actually being used to its full capability. This is important as equipment can be operational without the new technologies actually being implemented, e.g. due to limited workforce availability and constraints related to skills or resources. Finally, the interpretation in the various countries of specific entities such as 'dedicated stereotactic equipment' and 'intra-operative linacs' may have been different in different countries. Since these units are only a very small fraction of the total machines, such variations will have little impact on the overall conclusions.

Collecting and validating the data has been a huge task for many of the representatives from the national societies. It is our hope that the experience obtained and the collegial network established through this project will be valuable not only for future updates of the HERO database but also forming the basis for more qualified discussions within the national societies[21]. The next step in the HERO framework is to benchmark the data to the equipment needs in the individual countries, based on cancer incidence and stage mix and performed in cooperation with the Collaboration for Cancer Outcomes, Research and Evaluation (CCORE) in Australia. The data will also be used in developing the HERO costing model for European countries, in order to provide budgetary estimates of the radiotherapy optimization process in various jurisdictions.

In conclusion, the results of this survey document a significant heterogeneity in the access to modern radiotherapy equipment in Europe. Although the European average number of MV machines per million inhabitants and per department is now better in line with QUARTS recommendations from 2005, there is still a significant heterogeneity in the access to radiotherapy equipment in Europe. While high income countries especially in Northern–Western Europe are well-served with radiotherapy resources, other countries are facing important shortages of both equipment in general and especially machines capable of delivering high precision conformal treatments (IMRT, IGRT).

Conflict of interest

The authors have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.radonc.2014.08.029.

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