INFRASTRUCTURE AND EQUIPMENT FOR RADIATION ONCOLOGY IN THE SPANISH NATIONAL HEALTH SYSTEM: ANALYSIS OF EXTERNAL BEAM RADIOTHERAPY 2015–2020

A.Rodríguez[1], M.Algara[2,3], D.Monge[4], J.López-Torrecilla[5], F.Caballero[4], R.Morera[6], R.Escó[7], H.Pérez-Montero[8], C.Ferrer[9], P.C. Lara[10,11]. On behalf of the Spanish Society of Oncology and Radiotherapy (SEOR) Analysis Group[12]

1.- **Corresponding author**. Department of Radiation Oncology. Hospital Ruber Internacional. Address: Calle de la Masó, 38, 28034 Madrid, Spain. e-mail: arodriguez@ruberinternacional.es

2.- Department of Radiation Oncology, Hospital de la Esperanza, Parc de Salut Mar, Barcelona, Spain.

3.- Universitat Pompeu Fabra. Address: San José de la Montaña 12, 08024 Barcelona, Spain. e-mail: malgara@parcdesalutmar.cat

4.- Facultad de Medicina. Universidad Francisco de Vitoria. Address: Ctra Pozuelo-Majadahonda km 1.800, 28223 Pozuelo de Alarcón, Madrid, Spain. e-mail: dmonge@ufv.es; e-mail: fcaballero@ufv.es

5.- Department of Radiation Oncology, ERESA Hospital General Universitario. Address: Calle de la Casa Misericordia 12, 46014 Valencia, Spain. e-mail: jltorrecilla@eresa.com

6.- Department of Radiation Oncology, Hospital Universitario de La Paz. Address: Paseo de la Castellana 261, 28046 Madrid, Spain. e-mail: rosamaria.morera@salud.madrid.org

7.- Department of Radiation Oncology, Hospital Quirón Zaragoza. Address: Paseo Mariano Renovales 50006, Zaragoza, Spain. e-mail: resco.zar@gmail.com

8.- Department of Radiation Oncology, Hospital Universitario Doce de Octubre. Address: Avda de Córdoba s/n, 28041 Madrid, Spain. e-mail: hectorperezmontero@gmail.com

9.- Department of Radiation Oncology, Consorcio Hospitalario Provincial de Castellón. Address: Avda del Dr Clará 19, 12002 Castellón, Spain. e-mail: ferreralbiach@gmail.com

10.- Department of Radiation Oncology. Hospital Universitario Dr Negrín. Address: Barranco de la Ballena s/n, 35010 Las Palmas de Gran Canaria, Spain. e-mael: plara@dcc.ulpgc.es

11.- Clinical Oncology, Universidad de Las Palmas, Las Palmas, Spain

12.- Members of the Spanish Society of Oncology and Radiotherapy (SEOR) Analysis Group, as authors, can be found, in the online version

ABSTRACT

PURPOSE

Planning for radiation oncology requires reliable estimates of both demand for radiotherapy and availability of technological resources. This study compares radiotherapy resources in the 17 regions of the decentralised Spanish National Health System (SNHS).

MATERIAL AND METHODS

The Sociedad Española de Oncología Radioterápica (SEOR) performed a cross-sectional survey of all Spanish radiation oncology services (ROS) in 2015. We collected data on SNHS radiotherapy units, recording the year of installation, specific features of linear accelerators (LINACs) and other treatment units, and radiotherapeutic techniques implemented by region. Any machine over 10 years old or lacking a multileaf collimator or portal imaging system was considered obsolete.

We performed a k-means clustering analysis using the Hartigan-Wong method to test associations between the gross domestic regional product (GDRP), the number of LINACs per million population and the percentage of LINACs over 10 years old.

RESULTS

The SNHS controls 72 (61%) of the 118 Spanish ROS and has 180 LINACs, or 72.5% of the total public and private resources. The mean rate of LINACs per million population is 3.9 for public ROS, and 42% (n=75) of the public accelerators were obsolete in 2015: 61 due to age and 14 due to technological capability. There was considerable regional variation in terms of the number and technological capacity of radiotherapy units; correlation between GRDP and resource availability was moderate.

CONCLUSION

Despite improvements, new investments are still needed to replace obsolete units and increase access to modern radiotherapy. Regular analysis of ROS in each Spanish region is the only strategy for monitoring progress in radiotherapy capacity.

INTRODUCTION

Planning for radiation oncology requires a reliable estimate of the demand for radiotherapy in a specific population. In Europe, the first attempt [1] to estimate infrastructure and planning needs for radiation oncology services (ROS) across the EU was based on a 2003 study from Australia [2], which concluded that external beam radiotherapy was indicated for about 52.3% of tumours. More recently, a study based on the work of Barton [3] and analyses from Borràs in the ESTRO-HERO (European Society for Radiation Oncology-Health Economics in Radiation Oncology) project [4,5] reported that about 50.5% of new cancer cases in Spain require radiotherapy at least once [6]. Additional demand comes from retreatments, re-radiation, non-melanoma skin cancer and benign pathologies. The same study estimated that 25%–30% of those with an indication for radiotherapy do not receive it due to geographical and transportation-related factors; associated comorbidities; patient preferences; inadequate knowledge of radiotherapy among other specialists; and lack of human and physical resources, which entail wait lists and delays [4-6].

In Spain, the direct costs of cancer stood at EUR 4.82 billion in 2011 – 4.9% of total healthcare expenditure. Radiotherapy cost EUR 248 million, or 5.1% of the total direct costs of cancer and 0.25% of total healthcare expenditure [7]. Because substantial capital investments are necessary to purchase radiation oncology equipment, this specialty is perceived as relatively expensive, prompting intense debate about its necessity. However, the equipment has a long useful life, and the initial layout is balanced by modest costs per patient and service.

Having assessed the demand for radiotherapy in Spain [6], the next step is to analyse the availability of technical resources, identifying deficits and planning for the system's needs. The Spanish health system is based on the National Health Service (NHS) model, with decentralised administration among 17 regional authorities (plus Ceuta and Melilla); these independently administer a common portfolio of health services guaranteed to all citizens, independently of their place of residence. Given the differences between other European countries and Spain in demographics, cancer incidence, and available radiotherapy equipment, together with the pronounced decentralisation of health services administration, comparing the available resources for external beam radiotherapy among the regions – and the factors explaining any differences – is of great interest.

This study aims to describe the current state of radiotherapy in the Spanish National Health System (SNHS) and in its 17 regions in order to identify system needs and propose achievable targets.

MATERIAL AND METHODS

The Infrastructure Commission of the Sociedad Española de Oncologia Radioterapica (SEOR) developed a detailed questionnaire on available radiotherapy resources (linear accelerators (LINACs) and other equipment, personnel and hospital resources) and sent it to all chiefs of both public and private ROS in Spain during the fourth quarter of 2015.

This analysis focuses only on SNHS resources.

The questionnaire contained separate items for treatment units other than LINACs, such as cobalt-60 units, surface therapy, portable accelerators, tomotherapy, Gammaknife and Cyberknife. SEOR established requirements for *minimal acceptability* as a multileaf accelerator with an MV portal imaging system, while the *standard* was a multileaf accelerator with cone-beam computed tomography (CT). We considered any machine over 10 years old or lacking a multileaf collimator or portal imaging system to be obsolete.

We recorded the year of installation and specific features for each treatment unit.

To explore associations with resource availability across regions, we performed a k-means clustering analysis using the Hartigan-Wong method, which enables representation of multidimensional data on two axes and definition of the centroid cluster (vector with mean values of each variable). Variables were the gross domestic regional product (GDRP) [8], the number of LINACs per million population and the percentage of LINACs over 10 years old. We used population data from January 2015 for each region from the Spanish Statistical Office (table 1); data from Andalusia includes the population from the semi-autonomous cities of Ceuta and Melilla.

We used SPSS statistical software (version 21) for all analyses.

RESULTS

We achieved a 100% response rate to our survey. Our results show that the SNHS controls 72 (61%) of the 118 Spanish ROS and has 180 LINACs, or 72.5% of the total public and private resources. The number of inhabitants per ROS ranged from 317,053 in La Rioja to 1,104,479 in the Balearic Islands (table 1). The evolution of ROS resources over the past 30 years (1986-2015) is summarised in table 2.

The mean rate of LINACs per million population is 3.9 for public ROS; only seven regions surpass this average, and none meet the recommendation of 7 LINACs per million population (figure 1a). Mean daily operating time was 12.32 hours, with all regions operating longer than the typical eight-hour workday (figure 1b).

Of the 180 LINACs available in public centres, 61 (34%) were older than 10 years. The regions with the oldest machines were Galicia, Cantabria and Castilla La Mancha, while none of the units used in the Balearic Islands, La Rioja and Navarra were deemed obsolete on this criterion (table 1). Of the 119 machines installed within the previous 10 years, 74 (41%) were 6–10 years old, with notable heterogeneity among the regions (table 1).

Services had 1–5 accelerators each, with most (76%) having 1–2. Just three centres (1.7%) in Andalusia, the Canary Islands and Catalonia had five. Regarding the associated technology, 88% (n=159) had a multileaf collimator, 25% (n=45) had a micro-multileaf collimator, and 43% (n=77) had a KV or MV cone-beam CT (supplemental table online).

Considering both age- and technology-related criteria for obsolescence, 42% (n=75) of the public accelerators were obsolete in 2015, and 83% will be in 2020. Fourteen (12%) LINACs were technologically obsolete, while 105 (88%) of the accelerators installed within the previous 10 years were minimally acceptable, and 59.7% (n=71) were standard.

The results for the ‘other units’ category are as follows.

- *Surface therapy*. 12 machines installed from 1975 to 2013 – 4 in Catalonia alone.
- *Tomotherapy*. Available in four public centres in Madrid, Castilla-Leon, Castilla-La Mancha and the Basque Country; installed in 2006 or later.
- *Portable accelerators*. Two machines: one for intraoperative radiotherapy purchased in 2014 (Gregorio Marañón University Hospital, Madrid), and one acquired in 2015 (Hospital Clinic, Barcelona).
- *Intrabeam*. Two units from 2013 (Hospital Negrin, Las Palmas) and one from 2015 (Institut Català d’Oncologia, Barcelona).
- *Cyberknife, Gammaknife, proton beam therapy*. No units identified.

With regard to the **radiotherapeutic techniques implemented** in SNHS centres, 81.9% (n=59 centres) offer intensity modulated radiation therapy (IMRT), and 79.1% (n=57) report using some kind of image-guided radiotherapy (IGRT). Volumetric IMRT is performed in 36.1% (n=26). Other techniques used include: radiosurgery (34.7%, n=25), brain fractionated stereotactic radiotherapy (43%, n=31), craniospinal radiation (72.2%, n=52), stereotactic body radiotherapy (44.4%, n=32), total body irradiation (33.3%, n=24), total skin electron irradiation (6.9%, n=5), intraoperative radiotherapy (9.7%, n=7) and paediatric radiotherapy (44.4%, n=32). The distribution of centres offering these techniques is in table 3.

Other data collected (presented in online supplement) include details for each region regarding LINACs (machine age, technology) and ROS (number of machines per centre, types of IMRT offered), as well as an overall description of the external beam radiation techniques offered in public centres.

The cluster analysis enables graphic representation of the three included variables on the two axes that explain 83.2% of the total variability (figure 2). Spanish regions can be classified in four clusters (table 4). Cluster 1 represents regions with the highest GDRP, highest rates of accelerators per million population and lowest percentage of obsolete units. Cluster 2 regions have a lower – but still substantial – GDRP and a lower rate of LINACs per million population than the (lower GDRP) regions in cluster 3, although more resources in cluster 3 are obsolete. Finally, cluster 4 regions have the lowest GDRP, lowest rate of LINACs per million population and the highest percentage of obsolete machines in operation.

DISCUSSION

We performed this study to identify gaps and plan for future needs within the comprehensive range of SEOR activities implemented over the past 30 years. With full participation from all ROS, we present comparative data on radiotherapy resources for all Spanish regions. These show considerable variability, consistent with the variability in resources observed between European countries during the ESTRO-HERO project [9,10]. This pattern suggests that internal analyses within national borders are just as important as inter-country comparisons.

In Spain, the rise in available resources over the past several decades has been notable. The first white paper with data on oncology services, published in 1986, reported just 50 ROS and 75 megavoltage units [11]. Escó and colleagues [12] also described a situation far from ideal using data from 1999, calling for 44 additional LINACs and the substitution of obsolete cobalt-60 units. This study was the first to record differences between regions; the most disadvantaged were Aragon, Castilla-La Mancha and Murcia, which at the time were still dependent on the central government (decentralisation was not complete until 2002).

Before Palacios and colleagues performed the next national analysis using data from 2004 [13], the results of the ESTRO-QUARTS study were published in the first attempt to estimate the infrastructure and human resources available for radiotherapy across Europe [1,14]. Investigators based their recommendations on objective estimates: 1 LINAC/ 400–450 treatments/year and 1.6–1.9 accelerators/1000 treatments/year. The European average was 5.9 LINACs/million, with stark differences between countries.

Spain did not participate in ESTRO-QUARTS, although a contemporary analysis showed significant growth in infrastructures [13]. The mean number of units per million population was 2.7 in public ROS (59% of the total); despite substantial investments, the 177 existing units fell short of the 266–316 estimated as necessary. In 2004, 98% of the Spanish ROS performed 3D planning; 17.5%, IMRT; 27%, radiosurgery; and 10%, stereotactic body radiotherapy.

The last SEOR white paper [15] estimated the deficit in accelerators at 40–60 in 2008, but there were clear improvements over previous reports, and these have since continued. The SNHS controlled 57% of the operative ROS in 2008, compared to 61% in our study.

The ESTRO-HERO project has provided a snapshot of European radiotherapy. While the results reflect progress in meeting previous recommendations [1], this study and other international analyse [16] show marked between-country heterogeneity [4,5] with limited access to radiotherapy and targeted treatments in some countries.

In the ESTRO-HERO analysis, Spain (with data from 2011 comprising 112 public and private ROS) has an intermediate rank, with 5.6 LINACs/million population and 2.3 LINACs/ROS, for a total of 220 accelerators (< 50% equipped with IMRT) and five remaining cobalt-60 units. Similarly to the QUARTS project [1] and other more recent analyses [4,5], HERO results showed wide differences between European countries. Our study confirms that within Spain, large variations in available techniques and resources also exist.

Despite investments in the past several years, the situation in Spain is concerning, particularly given the ageing demography that puts Spain on track to become the European country with the oldest population, with implications for rising cancer incidence [18]. Today, even counting LINACs from the private sector backed by public provider agreements, there is an evident gap between evidence-based therapeutic demand and available accelerators [19]. The introduction of techniques like hypofractionation in breast cancer will also have a long-term impact on the total demand, although for now uptake is slow and uneven [20]. More alarming, 42% of the operational stock in 2015 was obsolete. Without new investments, this figure will rise to 83% by 2020 and could reach 100% in six regions.

In practical terms, there are only two options for increasing treatment capacity in ROS: acquire more machines or increase their scheduled use. Extending operating hours often entails problems related to the lack of secondary services or auxiliary staff. Moreover, Spanish ROS already operate for around 12 hours per day, making it difficult to extend hours longer while still respecting staff and patients' family commitments. Adding another LINAC to the ROS has the benefit of averting interruptions by facilitating patients' mobility and relocation if another unit breaks down, especially in the case of twin accelerators. Thus, extending operating hours is not clearly associated with cost savings compared to purchasing new accelerators.

The increase in available accelerators has been accompanied by an increase in ROS following the devolution of healthcare administration that began in the 1990s. Seventy-six per cent of ROS have 1–2 accelerators, reflecting a notable fragmentation and a near absence of subspecialisation (with some exceptions, for example reflected in the high number of centres offering paediatric radiotherapy). In the Netherlands, the number of ROS did not grow in 1998–2010, but the number of accelerators did. Each centre has, on average, 5.7 accelerators [21], enabling greater subspecialisation by pathology among personnel. Moreover, services can replace one or more machines every several years, ensuring the availability of the latest technological developments while still exhausting the useful life of each machine. One measure that has helped avoid fragmentation in service provision in this country has been the implementation of satellite services affiliated with a large centre. This move has allowed an adequate provision of accelerators in sparsely population area without compromising the quality of the service. In Spain, a satellite unit in Tortosa (Tarragona) depends on the ROS in the provincial capital of Reus, enabling care of comparable quality for a sparse and extended population [22], similar to another experience in rural Australia [23]. Given the low-density population in many regions, additional satellite centres can contribute to ensuring equitable and timely access to high-quality radiotherapy for anyone in Spain.

The cluster analysis suggests that the availability of therapeutic resources does not depend on the economic resources of regions but rather on policy. Although the correlation observed between high GDRP, high rate of LINACs/million population and lower percentage of obsolete machines suggests that the availability of economic resources is decisive for ensuring adequate equipment, the cluster analysis reveals that this is not always true. This situation reflects a decentralised model of decison-making, resulting in notable variability with regard to radiotherapy resources.

One limitation of our study, similar to previous analyses [9,10], is that while our data show accelerators' capacity to perform complex techniques, we cannot determine whether the equipment is being used to full capacity.

Ultimately, although we have observed improved availability of LINACs, our results show great heterogeneity between regions in access to modern radiotherapy units. Some regions show deficits in both the number and the technological capacity of their machines. At the same time, the validity of traditional indicators like machine age and technological capacity is waning. The advent of high-precision techniques and daily image guidance entails a greater use of time and resources, limiting the number of treatments per machine, while the generalised use of moderate hypofractionated treatments for the pathologies most frequently treated with radiotherapy shortens treatment course and modifies the capacity of the units. Thus, in the future we will also need to monitor incidence data and treatment activity.

Today, investments should be directed towards replacing units that are obsolete due to age or technology (42% in 2015 and 83% in 2020), increasing the availability of and access to advanced techniques that characterise modern radiotherapy. Regular analysis of both public and private sectors in each Spanish region is the only strategy for monitoring progress in radiotherapy capacity. When calculating future needs, the role of brachytherapy should not be discounted either. Reducing fragmentation in ROS through the pooling of resources and the development of satellite units linked to high-volume services may also be a useful strategy for our country.

ACKNOWLEDGMENTS

We thank Josep M Borrás MD and Ramon Cleries PhD (Universidad de Barcelona) for their valuable advice and assistance in writing the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

INFORMED CONSENT

For this type of study formal consent is not required

APPENDIX A.

Members of the Spanish Society of Oncology and Radiotherapy (SEOR) Analysis Group, as authors, can be found, in the online version.

APPENDIX B. SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version.

REFERENCES

[1] Bentzen SM, Heeren G, Cottier B, Slotman B, Glimelius B, Lievens Y et al. Towards evidence-based guidelines for radiotherapy infrastructure and staffing needs in Europe: The ESTRO QUARTS Project. Radiother Oncol 2005;75:355-65

[2] Delaney G, Jacob S, Featherstone C, Barton MB. The role of radiotherapy in cancer treatment. Estimating optimal utilization from a review of evidence-based clinical guidelines. Cancer 2005;104:1129-37

[3] Barton MB, Jacob S, Shafiq J, Wong K, Thompson SR, Hanna TP et al. Estimating the demand for radiotherapy from the evidence: A review of changes from 2003 to 2012. Radiother Oncol 2014;112:140-44

[4] Borrás JM, Barton M, Grau C, Corral J, Verhoeven R, Lemmens V et al. The impact of cancer incidence and stage on optimal utilization of radiotherapy: methodology of a population based analysis by the ESTRO-HERO project. Radiother Oncol 2015 Jul; 116(1):45-50

[5] Borrás JM, Lievens Y, Duscombe P, Coffey M, Malicki J, Corral J et al. The optimal utilization proportion of external beam radiotherapy in European countries: An ESTRO-HERO analysis. Radiother Oncol 2015 Jul;116(1): 38-44

[6] Rodríguez A, Borrás JM, López-Torrecilla JL, Algara M, Palacios-Eito A, Gómez-Caamaño A et al. Demand for Radiotherapy in Spain. Clin Transl Oncol 2017 Feb;19(2):204-210

[7] "Aproximación al cálculo del coste del abordaje del cáncer en España". Informe SEOM octubre 2013

[8] http://www.datosmacro.com/pib/espana-comunidades-autonomas

[9] Grau C, Defourney N, Malicki J, Dunscombe P, Borras JM, Coffey M, et al. Radiotherapy equipment and departments in the European countries: Final results from the ESTRO- HERO survey. Radiother Oncol 2014;112:155–64.

[10] Lievens Y, Defourny N, Coffey M, Borras JM, Dunscombe P, Slotman B, et al. Radiotherapy staffing in the European countries: Final results from the ESTRO-HERO survey. Radiother Oncol 2014;112:178–86

[11] Comisión de las Sociedades Oncológicas para la Planificación Oncológica en España. Libro Blanco de la Oncología en España. Informe para la Planificación Global de la Oncología. Ed. Jims, Barcelona; 1988

[12] Escó R, Palacios A, Pardo J, Biete A, Carceller JA, Veiras C et al. Infrastructure of radiotherapy in Spain: a minimal standard of radiotherapy resources. Int J Radiat Oncol Biol Phys 2003; 56(2): 319-327

[13] Palacios A, Espinosa M, Mañas A, de Las Heras M. Radiation Oncology: Future needs and equipment. Current situation in Spain. Clin Transl Oncol 2008; 10:478-485

[14] Slotman BJ, Cottier B, Bentzen SM, Heeren G, Lievens Y, van den Bogaert W. Overview of national guidelines for infrastructure and staffing of radiotherapy. ESTRO-QUARTS: Work package 1. Radiotherapy and Oncology. 2005;75(3):349-54

[15] Ismael Herruzo Cabrera, María Espinosa Calvo, José López Torrecilla, Miquel Maciá, Amalia Palacios Eito, Jose Antonio Sánchez Calzado et al. Cálculo de necesidades e infraestructura en España. Cap 4.2 en Libro Blanco SEOR XXI. ISBN 978-84-7714-344-4. 2010. Pag 65-85

[16] Rosenblatt E, Izewska J, Anacak Y, Pynda Y, Scaillet P, Boniol M. Radiotherapy capacity in European countries: an analysis of the Directory of Radiotherapy Centres (DIRAC) database. Lancet Oncology. 2013;14(2):e79-E86.

[17] Fernández J.L., Parapar C., Ruiz M. El envejecimiento de la población, Lychnos 2, Cuadernos de la Fundación general CSIC. ISSN 2174-5102. 2015

[18] Borrás JM, Lievens Y, Barton M, Corral J, Ferlay J, Bray F et al. How many new cancer patients in Europe will require radiotherapy by 2025? an ESTRO-HERO analysis. Radiotherapy and Oncology 2016;119(1):5–11.

[19] Datta NR, Samiei M, Bodis S. Radiotherapy infrastructure and human resources in Europe- Present status and its implications for 2020. Eur J Cancer 2014;50:2735-43

[20] Prades J, Algara M, Espinàs JA, Farrus B, Arenas M, Reyes V et al. Understanding variations in the use of hypofractionated radiotherapy and its specific indications for breast cancer. A mixed-methods study. Radiotherapy and Oncology 2017;123 (1):22-28.

[21] Slotman BJ, Vos PH. Planning of radiotherapy capacity and productivity. Radiotherapy and Oncology 2013;106:266–270

[22] Meritxell Arenas, David Gómez, Sebastià Sabater, Angeles Rovirosa, Albert Biete, Jordi Colomer. Decentralisation of radiation therapy. Is it possible and beneficial to patients? Experience of the first 5 years of a satellite radiotherapy unit in the province of Tarragona, Spain. Rep Pract Oncol Radiother 2014 Nov 8;20(2):141-4.

[23] Shakespeare TP, Turner M, Chapman A. Is rural radiation oncology practice quality as good as the big smoke? Results of the Australian radiotherapy

single machine unit trial. Australas Radiol 2007;51:381–5.

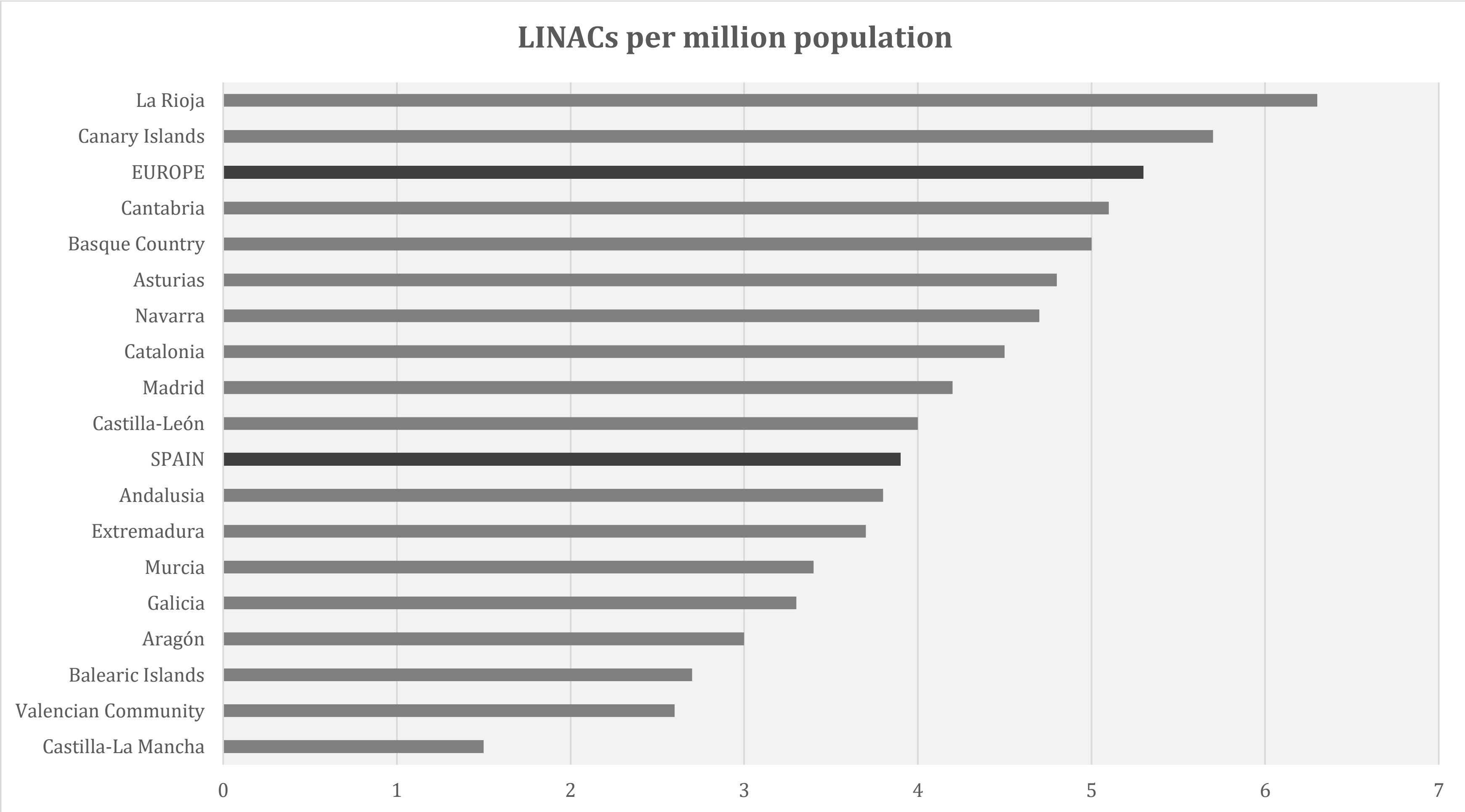

Figure 1a. LINACs per million population and region

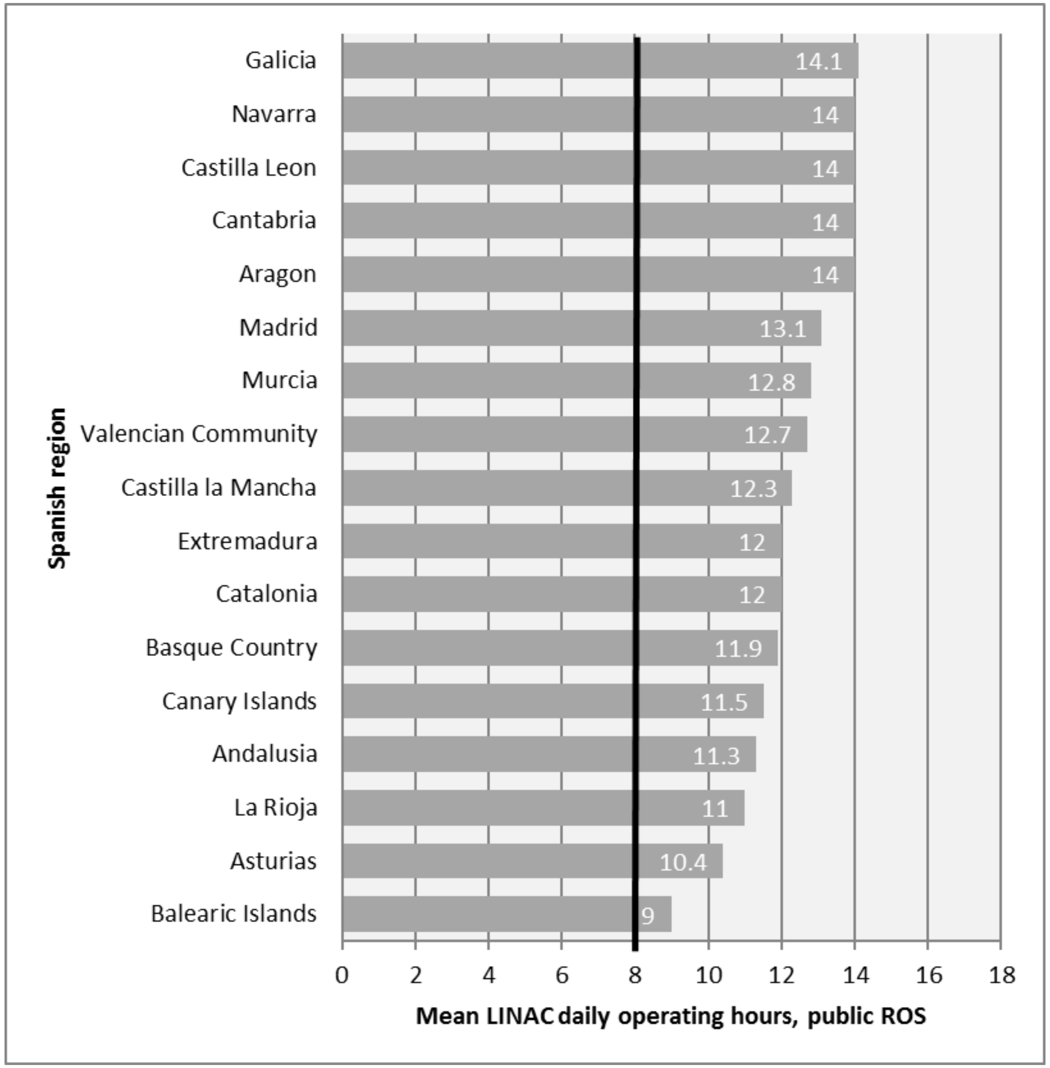

Figure 1b.- LINAC daily operating hours in public ROS

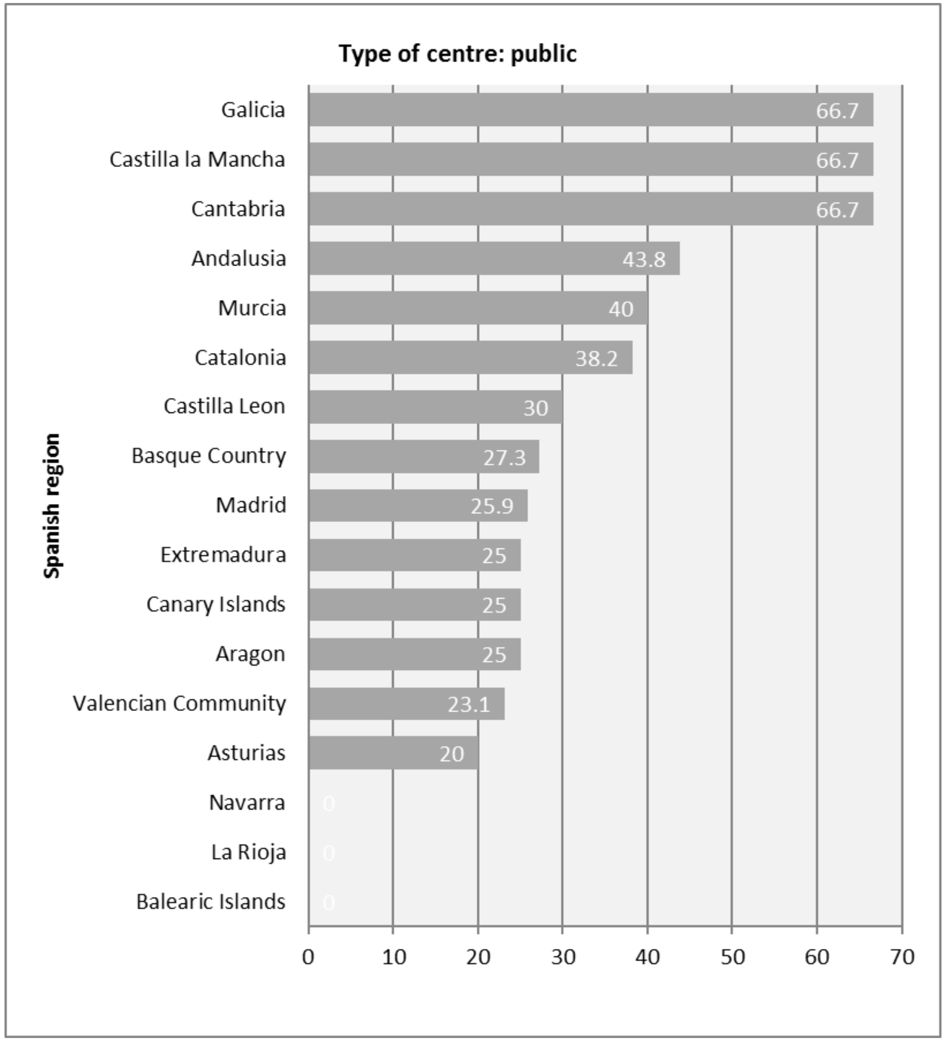

Figure 1c.Percentage of public LINACs over 10 years old (2015 data)

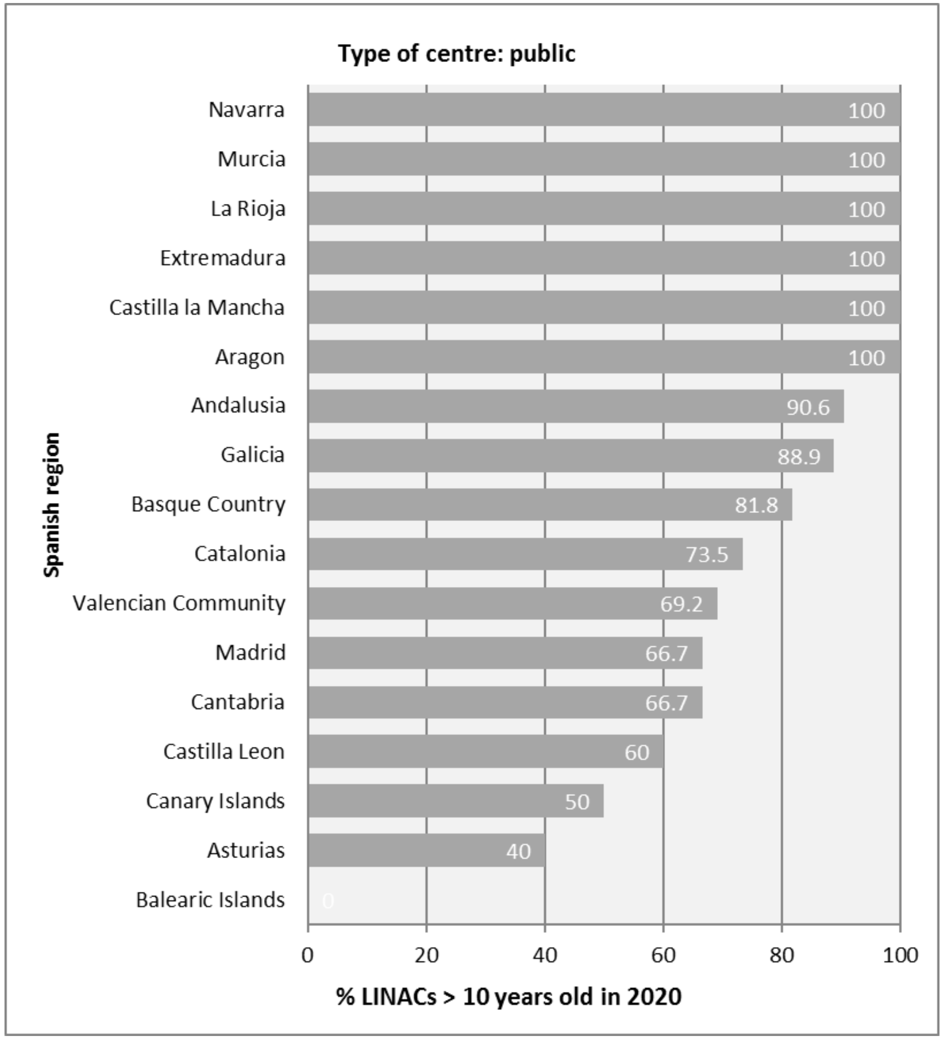

Figure 1d. Percentage of public sector LINACs, obsolete in 2020 due to ag

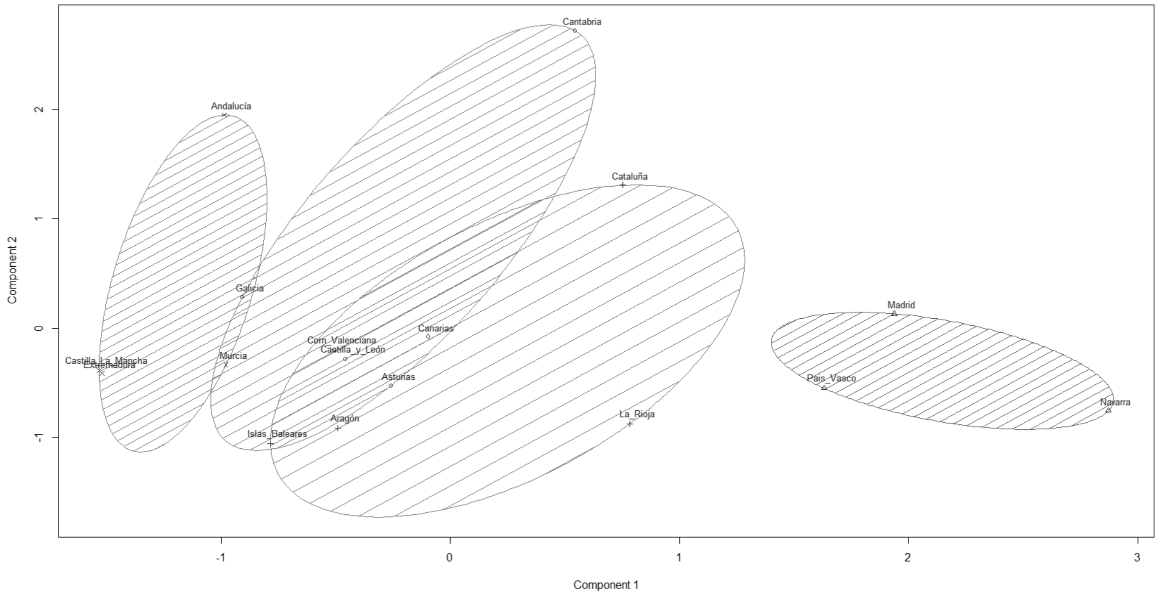

Figure 2. Clusters identified in k-means analysis

Table 1. - Radiation oncology service (ROS) and linear accelerators in the public sector, by region and population

Region	ROS	Population/ROS	Linear accelerators	Linear accelerators ≤10 years		Linear accelerators >10 years	
				n	% col	N	**N**% col
Andalusia	13	659,145	32	18	15.1%	14	23.0%
Aragon	2	658,923	4	3	2.5%	1	1.6%
Asturias	2	525,614	5	4	3.4%	1	1.6%
Balearic Islands	1	1,104,479	3	3	2.5%	0	0.0%
Basque Country	4	547,314	11	8	6.7%	3	4.9%
Canary Islands	3	700,102	12	9	7.6%	3	4.9%
Cantabria	1	585,179	3	1	0.8%	2	3.3%
Castilla la Mancha	2	1,029,595	3	1	0.8%	2	3.3%
Castilla Leon	5	494,410	10	7	5.9%	3	4.9%
Catalonia	11	682,555	34	21	17.6%	13	21.3%
Extremadura	3	364,332	4	3	2.5%	1	1.6%
Galicia	3	910,782	9	3	2.5%	6	9.8%
La Rioja	1	317,053	2	2	1.7%	0	0.0%
Madrid	12	536,416	27	20	16.8%	7	11.5%
Murcia	2	733,644	5	3	2.5%	2	3.3%
Navarra	1	640,476	3	3	2.5%	0	0.0%
Valencian Community	6	830,115	13	10	8.4%	3	4.9%
Total	**72**		**180**	**119**	**100.0%**	**61**	**100.0%**

Table 2. - Evolution of radiation oncology services in Spain, 1986–2015

Year	1986	1999	2003	2009	2011	2015
Study	1st white paper [9]	Escó et al[10]	Palacios et al [12]	López Torrecilla et al [15]	ESTRO-HERO [16]	
ROS	50	84	97	109 (62 public)	112	118 (72 public)
LINAC	18	90	132	213	220	248
Cobalt-60	57	67	45	23	5	2
LINAC/mil pop.			2.7* 4†			3.9‡ 5.3§

*2.7 public MV units (includes LINAC + Co)
†4 public and private MV units (includes LINAC + Co)
‡3.9 public sector LINACs per million population
§5.3 public and private sector LINACs per million population

Table 3. External beam radiation techniques available in public sector radiation oncology services, by Spanish region

	Radiosurgery	Brain FSRT	Craniospinal radiation	SBRT	TBI	TSEI	IOR	Paediatric radiotherapy
Region	N	N	N	N	N	n	N	N
Andalusia	2	3	7	4	4	0	1	4
Aragon	1	1	1	0	0	0	0	1
Asturias	0	0	1	0	1	0	0	1
Balearic Islands	0	0	1	0	1	0	0	1
Basque Country	1	1	2	0	0	0	0	2
Canary Islands	3	2	3	2	2	1	1	3
Cantabria	1	1	1	1	1	0	0	1
Castilla la Mancha	2	2	2	1	0	0	0	2
Castilla Leon	1	2	4	2	2	1	0	2
Catalonia	2	3	9	6	5	1	0	3
Extremadura	0	0	1	0	0	0	0	1
Galicia	2	2	2	1	2	0	1	2
La Rioja	0	0	1	0	0	0	0	0
Madrid	6	8	9	8	3	1	3	4
Murcia	2	2	2	2	1	0	0	1
Navarra	1	1	1	1	1	0	0	1
Valencian Community	1	3	5	4	1	1	1	3
Total	25	31	52	32	24	5	7	32

FSRT: fractionated stereotactic radiotherapy; IOR: intraoperative radiotherapy; SBRT: stereotactic body radiotherapy; TBI: total body irradiation; TSEI: total skin electron irradiation

Table 4. Centroids of clusters identified in k-means analysis by means of principal components.

	Cluster	GDRP (Euro)*	Rate LINAC†	Rate LINAC > 10 years (%)
1	Madrid, Navarra, Basque Country	30.3	7.4	5.4
2	Aragon, Catalonia, Balearic Islands, La Rioja	25.8	4.8	5.7
3	Asturias, Canary Islands, Cantabria, Castilla y León, Valencian Community, Galicia	20.7	5.5	9.4
4	Andalusia, Castilla la Mancha, Extremadura, Murcia	17.7	4.6	7.8

GDRP: gross domestic regional product.
*per 1000.
†per million population.

Table 1. Distribution of LINACs, by machine age and region

	0-5years		6-10years		11-15years		16-20years		>20years		
Comunidad Autónoma	n	% row	n	%row	n	%row	n	%row	n	%row	total
Andalusia	3	9.4%	15	46.9%	10	31.3%	3	9.4%	1	3.1%	32
Aragon	0	0.0%	3	75.0%	0	0.0%	1	25.0%	0	0.0%	4
Asturias	3	60.0%	1	20.0%	1	20.0%	0	0.0%	0	0.0%	5
BalearicIslands	3	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3
Basque Country	2	18.2%	6	54.5%	3	27.3%	0	0.0%	0	0.0%	11
CanaryIslands	6	50.0%	3	25.0%	3	25.0%	0	0.0%	0	0.0%	12
Cantabria	1	33.3%	0	0.0%	2	66.7%	0	0.0%	0	0.0%	3
Castilla la Mancha	0	0.0%	1	33.3%	2	66.7%	0	0.0%	0	0.0%	3
Castilla León	4	40.0%	3	30.0%	1	10.0%	2	20.0%	0	0.0%	10
Catalonia	9	26.5%	12	35.3%	8	23.5%	5	14.7%	0	0.0%	34
Extremadura	0	0.0%	3	75.0%	1	25.0%	0	0.0%	0	0.0%	4
Galicia	1	11.1%	2	22.2%	5	55.6%	1	11.1%	0	0.0%	9
La Rioja	0	0.0%	2	100.0%	0	0.0%	0	0.0%	0	0.0%	2
Madrid	9	33.3%	11	40.7%	4	14.8%	2	7.4%	1	3.7%	27
Murcia	0	0.0%	3	60.0%	0	0.0%	2	40.0%	0	0.0%	5
Navarra	0	0.0%	3	100.0%	0	0.0%	0	0.0%	0	0.0%	3
ValencianCommunity	4	30.8%	6	46.2%	2	15.4%	1	7.7%	0	0.0%	13
TotalpublicLINACs	45		74		42		17		2		180

Table 2.Distribution of radiation oncology services (ROS), by number of LINACs (overall and by region)

Comunidad Autónoma	Number of LINACs										n ROS
	1		2		3		4		5		n
	n	% row	n	% row	n	% row	n	% row	n	% row	
Andalusia	13	40.63%	13	40.63%	4	12.50%	1	3.13%	1	3.13%	32
Aragon	2	50.00%	2	50.00%	0	0.00%	0	0.00%	0	0.00%	4
Asturias	2	40.00%	2	40.00%	1	20.00%	0	0.00%	0	0.00%	5
BalearicIslands	1	33.33%	1	33.33%	1	33.33%	0	0.00%	0	0.00%	3
Basque Country	4	36.36%	4	36.36%	2	18.18%	1	9.09%	0	0.00%	11
CanaryIslands	3	25.00%	3	25.00%	3	25.00%	2	16.67%	1	8.33%	12
Cantabria	1	33.33%	1	33.33%	1	33.33%	0	0.00%	0	0.00%	3
Castilla la Mancha	2	66.67%	1	33.33%	0	0.00%	0	0.00%	0	0.00%	3
Castilla León	5	50.00%	3	30.00%	2	20.00%	0	0.00%	0	0.00%	10
Catalonia	11	32.35%	11	32.35%	7	20.59%	4	11.76%	1	2.94%	34
Extremadura	3	75.00%	1	25.00%	0	0.00%	0	0.00%	0	0.00%	4
Galicia	3	33.33%	3	33.33%	2	22.22%	1	11.11%	0	0.00%	9
La Rioja	1	50.00%	1	50.00%	0	0.00%	0	0.00%	0	0.00%	2
Madrid	12	44.44%	9	33.33%	4	14.81%	2	7.41%	0	0.00%	27
Murcia	2	40.00%	2	40.00%	1	20.00%	0	0.00%	0	0.00%	5
Navarra	1	33.33%	1	33.33%	1	33.33%	0	0.00%	0	0.00%	3
ValencianCommunity	6	46.15%	6	46.15%	1	7.69%	0	0.00%	0	0.00%	13
Total	72		64		30		11		3		180

Table 3. Technology in public LINACs

Region	Multileafcollimator		Micro-multileafcollimator		Cone-Beam (KV or MV)		Megavoltageportal imaging		Kilovoltage portal imaging		Exac-Trac		Vision-RT		RT4D orGating	
	n	% col	n	% col	n	% col	n	% col	n	% col	n	% col	n	% col	n	% col
	23	14.50%	9	20.00%	8	10.40%	12	9.00%	8	11.30%	0	0.00%	1	4.30%	2	6.90%
Aragon	4	2.50%	1	2.20%	3	3.90%	3	2.30%	1	1.40%	0	0.00%	0	0.00%	0	0.00%
Asturias	5	3.10%	2	4.40%	3	3.90%	5	3.80%	5	7.00%	2	25.00%	2	8.70%	2	6.90%
BalearicIslands	3	1.90%	0	0.00%	0	0.00%	3	2.30%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Basque Country	11	6.90%	4	8.90%	8	10.40%	8	6.00%	3	4.20%	0	0.00%	4	17.40%	3	10.30%
CanaryIslands	11	6.90%	3	6.70%	8	10.40%	10	7.50%	6	8.50%	0	0.00%	0	0.00%	2	6.90%
Cantabria	3	1.90%	1	2.20%	1	1.30%	2	1.50%	1	1.40%	1	12.50%	3	13.00%	1	3.40%
Castilla la Mancha	3	1.90%	1	2.20%	0	0.00%	3	2.30%	0	0.00%	1	12.50%	0	0.00%	1	3.40%
Castilla León	10	6.30%	2	4.40%	6	7.80%	10	7.50%	6	8.50%	0	0.00%	2	8.70%	0	0.00%
Catalonia	30	18.90%	6	13.30%	15	19.50%	28	21.10%	16	22.50%	0	0.00%	1	4.30%	9	31.00%
Extremadura	4	2.50%	0	0.00%	0	0.00%	4	3.00%	1	1.40%	0	0.00%	0	0.00%	0	0.00%
Galicia	8	5.00%	4	8.90%	2	2.60%	9	6.80%	2	2.80%	1	12.50%	0	0.00%	0	0.00%
La Rioja	2	1.30%	0	0.00%	1	1.30%	2	1.50%	1	1.40%	0	0.00%	0	0.00%	0	0.00%
Madrid	23	14.50%	5	11.10%	13	16.90%	16	12.00%	11	15.50%	2	25.00%	9	39.10%	4	13.80%
Murcia	5	3.10%	4	8.90%	3	3.90%	4	3.00%	3	4.20%	0	0.00%	0	0.00%	0	0.00%
Navarra	3	1.90%	0	0.00%	1	1.30%	3	2.30%	1	1.40%	0	0.00%	0	0.00%	3	10.30%
ValencianCommunity	11	6.90%	3	6.70%	5	6.50%	11	8.30%	6	8.50%	1	12.50%	1	4.30%	2	6.90%
Total	159	100.00%	45	100.00%	77	100.00%	133	100.00%	71	100.00%	8	100.00%	23	100.00%	29	100.00%

Table 4.Available IMRT and IGRT in public radiation oncology services, by region

Region	IMRT	IGRT	StaticIMRT	DynamicIMRT	Volumetric IMRT
	n	n	n	n	n
Andalusia	9	10	6	6	4
Aragon	2	2	1	1	0
Asturias	1	1	1	1	1
BalearicIslands	1	1	1	1	1
Basque Country	3	3	3	0	0
CanaryIslands	3	3	3	2	2
Cantabria	1	1	1	1	1
Castilla la Mancha	2	2	2	1	0
Castilla Leon	3	4	2	3	2
Catalonia	11	9	9	9	5
Galicia	2	1	2	1	0
La Rioja	1	1	1	1	0
Madrid	12	11	10	9	8
Murcia	2	2	2	2	1
Navarra	1	1	1	1	0
ValencianCommunity	5	5	5	2	1
Total	59	57	50	41	26

IGRT: image-guided radiotherapy; IMRT: intensity-modulated radiation therapy.

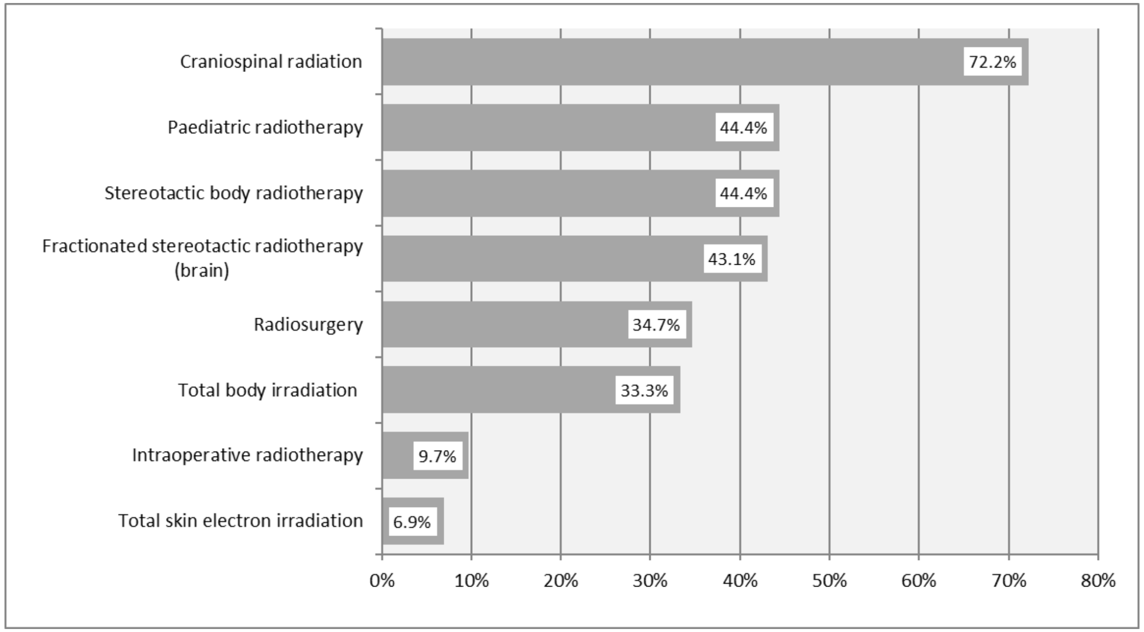

Figure 1. External beam radiation techniques offered in 72 public radiation oncology services

Table 5.Techniques available in Spanish radiation oncology services, by region

Region	Radiosurgery	Brain FSRT	Craniospinalradiation	SBRT	TBI	TSEI	IOR	Paediatricradiotherapy
	n	n	n	n	n	n	n	n
Andalusia	2	3	7	4	4	0	1	4
Aragon	1	1	1	0	0	0	0	1
Asturias	0	0	1	0	1	0	0	1
BalearicIslands	0	0	1	0	1	0	0	1
Basque Country	1	1	2	0	0	0	0	2
CanaryIslands	3	2	3	2	2	1	1	3
Cantabria	1	1	1	1	1	0	0	1
Castilla la Mancha	2	2	2	1	0	0	0	2
Castilla Leon	1	2	4	2	2	1	0	2
Catalonia	2	3	9	6	5	1	0	3
Extremadura	0	0	1	0	0	0	0	1
Galicia	2	2	2	1	2	0	1	2
La Rioja	0	0	1	0	0	0	0	0
Madrid	6	8	9	8	3	1	3	4
Murcia	2	2	2	2	1	0	0	1
Navarra	1	1	1	1	1	0	0	1
ValencianCommunity	1	3	5	4	1	1	1	3
Total	25	31	52	32	24	5	7	32

FSRT: fractionated stereotactic radiotherapy; IOR: intraoperative radiotherapy; SBRT: stereotactic body radiotherapy; TBI: total body irradiation; TSEI: total skin electron irradiation