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THE INNOVATIVE, DEMAND-BASED ORGANIZATIONAL DESIGN FOR EFFICIENT ONCOLOGICAL CARE IN POLAND: A VORONOI DIAGRAM ANALYSIS

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Abstract: In this paper, we apply a Voronoi diagram to map the existing design of oncological care in Poland. First, we correlate the actual organization of care with epidemiological data on cancer survival rate and morbidity. On this basis, we build a proxy for localized demand for oncological care. As a further step, we construct a Voronoi diagram to discuss the project of a national network for oncology in Poland based on comprehensive cancer centers and institutes, aiming at improving accessibility and equality in access to specialized oncological care.

Keywords: health economics, Voronoi diagram

INTRODUCTION

Cancers creep toward the top of the list of leading causes of morbidity and mortality worldwide. World Health Organization estimates that there were 14 million of new cases and 8.2 million cancer related deaths in 2012 [World Cancer Report 2014]. The number of new cancer diagnosis is expected to rise by about 70% over the next two decades. Only in Europe the number of cancer-related deaths borders up one million each year. In Poland, cancers are the second cause of mortality with 100 000 fatalities and this number is forecasted to increase rapidly over the next decade and cancer will become the most pestilent illness. Thus, Poland will be shortly facing a real epidemiological crisis associated with cancer incidence.

At the same time, there are significant differences in effectiveness of health care system in Europe. EUROCARE-5 study compares the cancer survival rate across European countries. Although the 5 year survival rate increased from 73 to 83% (the European mean, all cancers) during the 1999-2007 period [De Angelis et al. 2014], there are quite large divergences in regional benchmarking. For instance, the Eastern European countries show the lower survival rate for colon or lung cancer

(compared to Northern and Central European countries). Moreover, Eastern Europe performs poorly with survival rate for breast cancer (Eastern Europe 72% *versus* 82% as European mean). The good news is, however, that the distance in terms of survival outcomes between Eastern Europe and Nordic/Central Europe countries consequently shortens. Sadly, survival rates for rapidly fatal cancers (lung, pancreas, pleura and liver cancer) were impressively high for Austria, Belgium, Croatia, Germany, and Poland.

The efficiency of oncological system can also be evaluated by assessing the accessibility of care. Euro Health Consumer Index 2014 provides the measure of waiting time for oncological treatment (Time to get radiation/chemotherapy after decision). Poland classifies in the middle of the range, with 50-90% of procedures done in less than 21 days[1]. This result, however, is dimmed by the average waiting time for clinic visit. For instance, in some regions, waiting time for hematological clinic visit exceeds 120 days)[2].

There is an extensive knowledge about the risk factors associated with cancers. Since many years public health policy has been focusing on warning populations about the side effects of smoking and alcohol consumption. Information campaigns also embraced recommendations on nutrition habits or sun exposure. While prevention efforts are extremely important in containing cancer disease, experts agree on the fundamental role of screenings, early diagnosis and immediate start of therapy.

In Poland, specialists and policy makers share the opinion that low epidemiological indicators related to cancers are the consequence of late diagnosis. Therefore, the Poland's "Cancer Plan 2015-2014" sets the key-goal of improving morbidity and mortality indicators related to cancer disease, along with raising the quality of life for oncological patients.

Oncologists claim [Warzocha 2013] that achieving this goal is only possible with creating of a national network for oncology based on the comprehensive cancer centers and institutes. Thus, there is a need for redesigning the organization of oncological care based on the concept of reference centers displaying the highest level of competences, ensuring an adequate and rapid treatment. Furthermore, comprehensive oncological centers are of crucial importance for patients suffering from rare cancers and children. As an example, accurately diagnosed sarcoma can be totally cured in case of an early diagnosis using biopsy and molecular biology. However, this can be done only in referral centers[3].

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[1] Survey commissioned by HCP from Patient View 2014. Interviews with healthcare officials, feedback from national agencies. Report available at: http://www.healthpowerhouse.com/files/EHCI_2014/EHCI_2014_report.pdf (accessed on: 2015-05-03)

[2] PWC (2014) Obecny stan zwalczania nowotworów w Polsce. A real-time 'waiting times' for services are available at https://kolejki.nfz.gov.pl/

[3] http://www.rynekzdrowia.pl/Serwis-Onkologia/Nowotwory-rzadkie-brakuje-osrodkow-referencyjnych,128375,1013.html (accessed on: 2015-05-03)

Therefore, the goal of this article is two-fold. First, we aim at analyzing the actual organization of oncological care in Poland. Correlating mortality and morbidity data with demographic characteristics, we construct the proxy of localized demand for oncology care. As a following step, we apply the Voronoi procedure to depict the current design of care. Finally, we discuss the shortcomings of actual design and draw proposals. Thus, the article is structured in three sections, corresponding to the previously announced research objectives.

CURRENT ORGANIZATION OF ONCOLOGICAL CARE IN POLAND

In Poland, oncological care for adult patients with solid tumors is based on a centralized system, with the major role of the National Institute of Oncology and Hematology (with three branches: in Warsaw, Cracow and Gliwice). In most voivodships there are also regional cancer centers operating as independent units or within multidisciplinary hospitals. An important role in oncological care in Poland is ensured by the clinical hospitals. In some regions oncological care is provided by the smaller cancer centers existing within hospitals of different levels. Patients with blood cancer are treated in hematological centers, whereas patients with cancer of the lymphatic system are treated in regional oncology centers. Childhood cancer care is provided by the regional pediatric cancer centers and some pediatric wards. Surgery treatment is ensured by the Institute of Oncology, oncological surgery wards, general surgery wards and related organ surgery wards of regional cancer centers. Children are treated in pediatric cancer centers and pediatric surgery wards.

Cancer is extremely costly, both in terms of human costs and resources involved to fight cancer. In 2013, Poland total health expenditure (both public and private) accounted for 6,33% of GDP in 2012[4]. This ranks Poland in the tail of OECD countries. In 2013, the National Health Fund signed contracts with providers of oncological care services for the amount of 5,74 PLN billion. Table 1 below presents the detailed information about contracting by category:

Table 1. Contracting in oncology care by service category (2013)

	16 regional cancer centers		Other facilities	
Radiation therapy	70%	580 438 k PLN	30%	253 706 k PLN
Surgery	42%	262 236 k PLN	58%	366 746 k PLN
Chemotherapy	36%	798 718 k PLN	64%	1 428 023 k PLN
Palliative care	2%	6 765 k PLN	98%	333 162 k PLN
Diagnostics	13%	129 005 k PLN	87%	869 405 k PLN
Related treatment services	30%	211 217 k PLN	70%	501 532 k PLN

Source: Authors' calculation based on NHF data (Feb. 2014)

[4] GUS (2014) Health and health care in 2013, Warszawa, p. 127.

Analysis of this table provide us with some important insights. In 2013, 16 regional cancer centers contracted 36,5% of total NHF financial resources directed to cancer care. We can also observe an important dispersion of diagnostics. Furthermore, 70% of resources for radiation therapy was contracted by regional cancer centers, whereas the share of NHF contracting attributed to regional cancer centers was 35,8%.

Information about financial resources must be complemented by the analysis of epidemiological data and the index of resources utilization. This important data is presented in Table 2 below:

Table 2. NHF contracting, cancer morbidity rates and resource utilization index

	National Health Fund cancer contracting (per population mln, in mln PLN, 2012)	All cancer morbidity count (per 105 for males, 2012)	population/megavoltage device ratio (2012)
Dolnośląskie	98.44	269.0	364 572
Kujawsko-Pomorskie	139.26	291.8	299 767
Lubelskie	94.05	256.0	361 976
Lubuskie	97.70	268.7	341 053
Łódzkie	76.33	261.2	422 280
Małopolskie	102.88	274.3	334 680
Mazowieckie	157.87	210.5	310 918
Opolskie	89.19	267.9	337 983
Podkarpackie	79.16	274.9	425 737
Podlaskie	102.81	226.8	300 246
Pomorskie	110.64	313.3	380 583
Śląskie	134.44	254.0	257 020
Świętokrzyskie	128.87	263.5	319 529
Warmińsko-Mazurskie	110.89	275.0	484 199
Wielkopolskie	127.68	290.3	345 548
Zach-pomorskie	107.17	250.0	246 106
min	76.33	210.5	246 106
max	157.87	313.3	484 199
average	109.83	265.4	345 762.30
st. dev.	22.48	24.33	61 831.25

Source: Authors' compilation based on PWC report *Obecny stan zwalczania nowotworów w Polsce*, [Wojciechowska, Didkowska][5] and GUS [2012]

In the second column of this table, we present the values of the NHF regional contracting for the entire spectrum of oncological services (including palliative care

[5] Available at http://onkologia.org.pl/raporty/ (accessed on 2015-05-03)

and health programs). For each region, the value of contracts has been scaled to population ratio. As a further step, we have proceed with calculation of Pearson correlation coefficients between: contracting and morbidity count ($r_{c,m}$) and resource utilization index and morbidity count ($r_{r,m}$). Because of the fact that the correlation coefficient is sensitive to outliers, we have omitted Mazowieckie and Łódzkie for $r_{c,m}$ calculation and Mazowieckie, Pomorskie, Warmińsko-Mazurskie and Zachodniopomorskie for $r_{r,m}$ calculation. The value for $r_{c,m}$ (.20) suggests that increasing only spending is inefficient in reducing cancer mortality. However, this must be interpreted with caution, as we do not control for the quality of care. Similarly, the value of $r_{r,m}$ (.40) would suggest there is an inefficiency component associated with cancer screening procedure. One should remember, however, that there is likely a temporality problem associated with static approach. Moreover, analysis of the accessibility indicator (population/magevoltage device ratio) highlights quite large odds that may create additional waiting time for radiation treatment that is not associated with limited NHF contracting.

VORONOI DIAGRAM FOR THE CURRENT SYSTEM OF ONCOLOGICAL CARE IN POLAND

In the light of previous remarks on accessibility of oncology care in a current design, we have applied a Voronoi diagram in order to depict the map of existing facilities for adults and children. Before, in the subsequent sections, we present the theoretical foundation of the concept along with applied examples.

Theoretical background

The Voronoi diagram is the nearest-neighbor map for a set of points. Each region contains those points that are nearer one input site than any other input site. We start with describing the principles of calculation and elementary properties of Voronoi diagrams.

Let χ be a finite set of k points, which belongs to the Euclidean space S. The elements of the set χ we call centres. The Voronoi region (Voronoi cell) which is adherent to the element p of the set χ we call the set of points which are closer to the point p than any other element of this set [Aurenhammer 2000]

$$\chi(p) = \{x \in S | \forall q \in S, d(x,p) \leq d(x, q)\} \quad (1)$$

where d is the distance between two points described by:

$$d(a,b) = d(b,a) = \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2 + \cdots + (a_n - b_n)^2}$$
$$= \sqrt{\sum_{i=1}^{n}(a_i - b_i)^2} \quad (2)$$

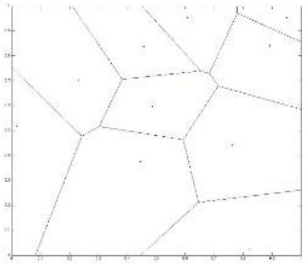
For any pair of points which belong to the space χ $(a, b \in \chi)$ in the 2-dimension space, there is a set $\Pi(a, b)$ of points which are in the same distance from both points a, b. This set is called the perpendicular bisector. This ideal line is also the limit between the set of points which are less remote from b than a.

To describe the Voronoi cell, we need to describe first the set of points half-plane which is limited by the ideal line *Π(a, b)* in which the point *a* is included. This half-plane is an area which contains every point that is closer to the point *a* than *b*.

$$H(a, b) = \{x \in S | d(x,a) \leq d(x, b)\} \quad (3)$$

The Voronoi cell, Voronoi region which is assigned to the point *a* is the part of the common of every half planes where *b* may replace each point from the set $S-\{a\}$. The Voronoi cells are the convex polygon. The set of those polygons separates the 2-dimensional Euclidean space and represents the Voronoi diagram, which corresponds to the set of points *S*.
An example of a Voronoi diagram is presented in Figure 1.

Figure 1. The example of Voronoi diagram based on the set of random points



Source: Authors' computation in Matlab

Based on the Voronoi diagram, we have also made calculation/computation of triangulation. We have used the Delaunay triangulation. The Delaunay triangulation is based on the Voronoi diagram through the principle of duality.[6]

Let *P* be a finite set of points in a sub-domain Ω^n of the n-dimensional space R^n. Two points p_i and p_j are connected by a Delaunay edge *e* if and only if there exists a location $\chi \in \Omega^n$ which is equally close to p_i and p_j and closer to p_i, p_j than to any other $p_k \in P$. The location *x* is the center of an n-dimensional sphere which passes through the points p_i, p_j and which contains no other points p_k of *P* [Fleishmann 1999].

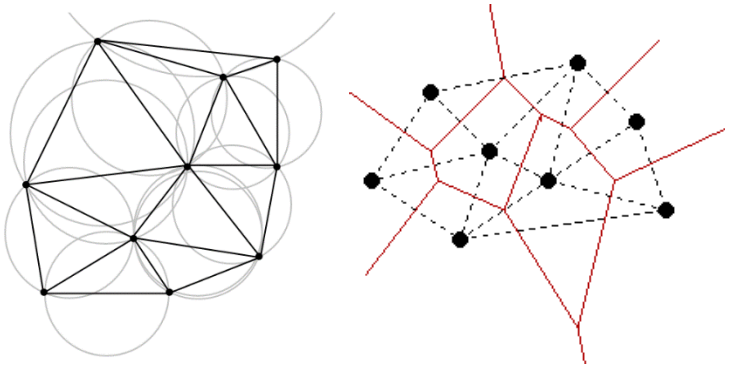
$$\begin{gathered} e_{Delaunay}(p_i, p_j) \Leftrightarrow \exists x \\ x \in \Omega^n \wedge \\ \| \| x - p_i \| = \| x - p_j \| \wedge \\ \forall k \neq i, j ; \quad \| x - p_i \| < \| x - p_k \| \end{gathered} \quad (4)$$

[6]

[6] The equation and definition from: Fleischmann P. (1999) Dissertation: Mesh Generation for Technology CAD in Three Dimensions, Vienna.

Combining this criterion for the three edges of a triangle and furthermore for the four triangles of a tetrahedron leads to the following criteria for Delaunay simplices. A Delaunay triangle is thereby the dual of a Voronoi edge.

Figure 2. Dealunay triangulation and Voronoi diagram



Source: compgeom.com, geom.uiuc.edu

On the left we present the Delaunay triangulation based on the circumscribed triangles, whereas the right picture shows the combination of Delaunay triangulation (black dotted line) and the Voronoi diagram (solid line).
So defined diagram have many applications in robotics (path planning in the presence of obstacles)[Drysdale 1993], biology (area potentially available to a tree), [Okabe 2009, Drysdale 1993, astrophysics (identifying clusters of stars and galaxies)[Qiang et al.1999] or in business retail stores market area) [Kalcsics et al. 1999, Clarkson 1985].

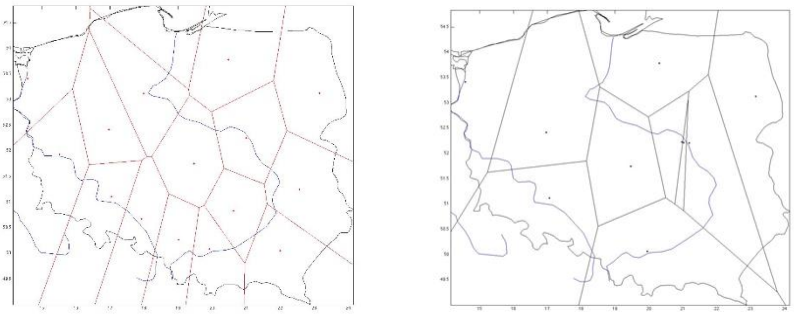
Data and procedure

Following the publicly available information about the location of cancer centers in Poland, we have constructed a related database, distinguishing adults and children facilities. That database enabled us to create maps of Poland with marked centers on it.
As a further step, we have proceeded with creating a Voronoi diagram, which divide the map for 16 regions in case of reference centers for adults and into 10 regions in case of reference centers for children (see Figure 3).

Results

Our map (depicted on Figure 3) shows the division of territory into zones that belong to each reference center. In the ideal situation, each cell should have the same area and should have the reference center in the middle of the Voronoi region.

Figure 3. The Voronoi Diagram of reference centers for adults (left) and for Children (right)

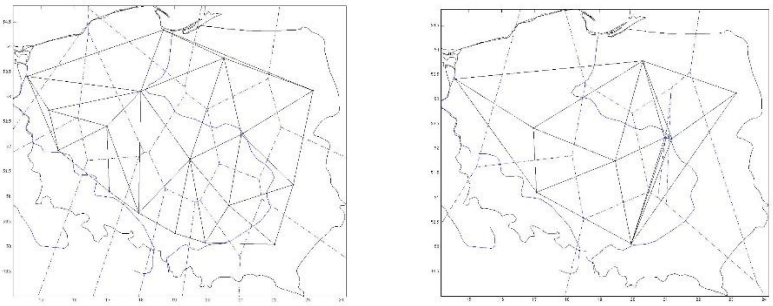


Source: Authors' computation in Matlab

As can be seen on both maps, for adults and for children, the cells have different areas and, in most cases, the reference center is not even close the center of a region. In case of the map, which represents the location of centers for adults, we see that there are centers in each region's capital city, but when we take a look at the map representing the locations of facilities for children the outcome is significantly worse. There is a substantial regional gap that is supposed to create inequalities in access to care.

In the ideal situation we should see that the map divided into a similar sized areas, which cover the entire surface of the country. If in addition to the map we add a triangulation based on the points corresponding to the reference centers (see Figure 4), we see that only the central area of Poland is covered by the graph. Once again, this can be interpreted in terms of limited accessibility of care and, partly elucidate the unsatisfactory health outcomes related to oncological care

Figure 4. Delaunay Triangulation based on the position of reference centers in Poland, for adults (left) and children (right)



Source: Authors' computation in Matlab

DISCUSSION

Our analysis confirms the partial inefficiency of current organization of oncology care in Poland. We have proved that there is an important, territorial barrier in accessibility of care. Moreover, limited resources (rationing of NHF contracting, limited medical devices) may partly explain unsatisfactory cancer survival rates in Poland. Polish *Cancer Plan* aims at containing the spread of cancer by implementing, among others, early detection and diagnosis for cervical, breast, prostate, bladder, stomach, esophagus, colorectal, and melanoma cancers, i.e. those diseases which recognition in Poland is much delayed compared to opportunities arising from the current state of practical knowledge. The plan also targets the improvement in the quality of diagnostic tests and the availability of effective treatments for malignant tumors. Furthermore, Poland intends to widen cancer screening programs (based on quality of epidemiological data), improve the accessibility of coordinated treatment, as well as raise the quality and scope of palliative cancer care. Fulfillment of these goals is only possible with the implementation of the latest science achievements. In turn, this is conditional of clinical and research excellence.

It appears, however, that this can be accomplished by rethinking the existing networks of cancer centers, following the idea of efficient and patient-oriented *Comprehensive Cancer Centers* (CCCs).

Towards Comprehensive Cancer Centers

The success factors in countries having the best outcomes in cancer diagnosis and treatment embrace, among others, the organization of care system based on the concept of reference centers under the label of *Comprehensive Cancer Centers* (CCCs). These centers share a series of distinctive features. First, they should be patient-centered and based on a coordinated mechanism of multidisciplinary treatment. Moreover, the Comprehensive Cancer Centers are supposed to be efficient in terms of resources and health outcomes. The centers' activity should rely on reducing waiting time for procedures, monitoring the effects of treatments and applying therapeutic guidelines based on best practices. Among others, there is also a competence requirement for the medical staff (continuous training, research activities). Finally, the network of comprehensive cancer centers should initiate and oversee the screening programs nationwide. The successful networks of CCCs exist in the U.S. (with 41 facilities nationwide), the Netherlands (7 facilities) and France (20 facilities)[7]. It is worth mentioning that the activities of American, Dutch and French CCCs are coordinated and overseen by the National Cancer Institutes.

In order to evaluate the potential to become CCCs for cancer centers in Poland, we apply the assessment criteria developed by the Organization of European Cancer

7 http://www.unicancer.fr/en/healthcare-professionals/innovative-oncology-model (accessed on: 2015-06-15)

Institutes (OECI)[8]. In 2008, the OECI launched its Accreditation and Designation Program aiming at certifying the quality of oncology care and designating the various types of cancer structures, including CCCs. We have chosen to evaluate Centrum Onkologii-Instytut Marii Skłodowskiej-Curie (COI) in Warsaw, Gliwice and Cracow The certification criteria along with their assessment are presented in Table 3 below.

Table 3. Assets assessment for Centrum Onkologii – Instytut Marii Skłodowskiej-Curie

Designation criteria for Comprehensive Cancer Center (OECI)	Warsaw, Gliwice and Cracow (situation as of 2013, except clinical trials)
budget for care: > 5000 k€	Yes, 863 680.70k PLN (205 638.26k €) [source: annual report]
budget for research: > 3000 k€	Yes, 64 237.40k PLN (15 294.62k €) [source: annual report]
no. of beds and ambulatory day care beds: > 100	Yes, 1.443 [source: annual report]
active clinical trials: > 50	Yes, 76 [source: ClinicalTrials.gov]
no. of scientific publications: >30	Yes, 407 [source: annual report]
no. of scientific publications with IF over 10: > 17	Yes, 23 [source: annual report and Web of Science™]

Source: Author's simulation based on Saghatchian M. (2014) and COI (2014) annual report

Our simulation confirms that COI meets the CCC's accreditation criteria. Therefore, it already constitutes an important nexus and example to follow for transforming remaining regional cancer centers into CCCs. Of course, this organizational design should be complemented by the study of effectiveness of administrated care. However, such a study remains beyond the competences of economists. We can only claim its necessity. Finally, we think that Polish cancer centers should undergo the independent accreditation procedure and the general paths of their activities and development should be initiated overseen by the Ministry of Health.

Developing economically efficient quality and inclusive oncology care is a quite challenging task. Nevertheless, it is possible once we allow to be innovative in financing (e.g. new models of financing with fair remuneration of providers with value-based pricing), organization (e.g. Comprehensive Cancer Centers) and treatment (e.g. proton therapy, personalized medicines).

[8] The OECI is a non-government, non-profit Organisations founded in Vienna in 1979 with the primary goal of strengthening cooperation between oncological institutions in the EU. The OECI promotes the concept of Comprehensiveness in treatment, as well as encourages improvement in the quality of cancer care, research and education. For more information see http://www.oeci.eu/About_OECI.aspx

REFERENCES

Aurenhammer F., Klein R. (2000) Voronoi diagrams, Handbook of computational geometry 5, 201-290.

Björnberg A. (2014) Euro Health Consumer Index 2014 Report, Health Consumer Powerhouse Ltd.

Clarkson K. (1985) A probabilistic algorithm for the post office problem, Proceedings of the seventeenth annual ACM symposium on Theory of computing, ACM.

COI (2014) Sprawozdanie dyrektora z działalności Centrum Onkologii w 2013 r.

De Angelis et al. (2014) Cancer survival in Europe 1999–2007 by country and age: results of EUROCARE-5—a population-based study, Lancet Oncology, 15, 23–34.

Drysdale S. (1993) Voronoi diagrams: Applications from archeology to zoology, Technical Report, Regional Geometry Institute, Smith College.

Fleischmann P. (1999) Dissertation: Mesh Generation for Technology CAD in Three Dimensions, Vienna.

GUS (2012) Area and population in the territorial profile in 2012, Warszawa.

GUS (2014) Health and health care in 2013, Warszawa.

Kalcsics J. et al. (1999) Facility location decisions in supply chain management, Operations Research Proceedings, Springer Berlin Heidelberg.

Lee D.-T., Schachter B. J. (1980) Two algorithms for constructing a Delaunay triangulation, International Journal of Computer & Information Sciences 9.3, 219-242.

Okabe A. et al. (2009) Spatial tessellations: concepts and applications of Voronoi diagrams, Vol. 501, John Wiley & Sons.

PWC (2014) Obecny stan zwalczania nowotworów w Polsce (available at: http://www.pto.med.pl/, accessed on: 2015-06-10).

PWC (2014) Strategia walki z rakiem w Polsce 2015-2024 (available at: http://www.pto.med.pl/, accessed on: 2015-06-10).

Qiang D. et al. (1999) Centroidal Voronoi tessellations: applications and algorithms, SIAM review 41.4, 637-676.

Saghatchian M. (2014) Pioneering quality assessment in European cancer centers: a data analysis of the organization for the European Cancer Institutes accreditation and designation program, Journal of Oncology Practice, Vol.10 (5), 342-349.

Stewart B.W., Wild Ch. P. (2014) World Cancer Report 2014, International Agency for Research on Cancer.

Warzocha K. (2013) National Institute of Oncology and Hematology, Hematologia, 4. 3, 185–196.

Wojciechowska U., Didkowska J. (2014) Zachorowania i zgony na nowotwory złośliwe w Polsce. Krajowy Rejestr Nowotworów, Centrum Onkologii - Instytut im. Marii Skłodowskiej – Curie.