Assessing the relationship between toxicity and economic cost of oncological target agents: A systematic review of clinical trials

Francesca Tartari¹, Alessandro Conti², Roy Cerqueti¹*

¹ Department of Economics and Law, University of Macerata. Via Crescimbeni, Macerata, Italy, ² Azienda Ospedaliera dell’Alto Adige, Bressanone/Brisscn Hospital. Via Dante, Bressanone/Brisscn, Italy

* roy.cerqueti@unimc.it

Abstract

Target agents are peculiar oncological drugs which differ from the traditional therapies in their ability of recognizing specific molecules expressed by tumor cells and microenvironment. Thus, their toxicity is generally lower than that associated to chemotherapy, and they represent nowadays a new standard of care in a number of tumors. This paper deals with the relationship between economic costs and toxicity of target agents. At this aim, a cluster analysis-based exploration of the main features of a large collection of them is carried out, with a specific focus on the variables leading to the identification of their toxicity and related costs. The analysis of the toxicity is based on the Severe Adverse Events (SAE) and Discontinuation (D) rates of each target agent considering data published on PubMed from 1965 to 2016 in the phase II and III studies that have led to the approval of these drugs for cancer patients by US Food and Drug Administration. The construction of the dataset represents a key step of the research, and is grounded on the critical analysis of a wide set of clinical studies. In order to capture different evaluation strategies of the toxicity, clustering is performed according to three different criteria (including Voronoi tessellation). Our procedure allows us to identify 5 different groups of target agents pooled by similar SAE and D rates and, at the same time, 3 groups based on target agents’ costs for 1 month and for the median whole duration of therapy. Results highlight several specific regularities for toxicity and costs. This study present several limitations, being realized starting from clinical trials and not from individual patients’ data. However, a macroscopic perspective suggests that costs are rather heterogeneous, and they do not clearly follow the clustering based on SAE and D rates.

Introduction

The present study aims at finding out whether there is a clear connection between the toxicity of novel anticaner drugs and their cost. To this end, we explore the information related to the rate of Severe Adverse Events (SAE) and the discontinuation (D) of a qualified set of oncological drugs. Such rates contribute to the creation of a so-called Toxicity Index (TI). Specifically, we have created a high-quality dataset by investigating the phase III studies in the context of
the approval by the US Food and Drug Administration (FDA) of the target agents and of their introduction in the clinical practice.

The motivations for our study are of economic and social nature. In fact, cancer is one of the most costly health conditions to manage worldwide [1]. Anticancer agents have represented the 43% of new drugs approved by the FDA in the last decade [2]. The increase of drug spending in oncology is mainly due to the recent introduction of new targeted and immunotherapy agents [3], which have improved the outcome of cancer patients in terms of Overall Survival (OS) and Progression-Free Survival (PFS) compared to conventional chemotherapy. Although these agents are generally associated with a lower rate of treatment D due to drug toxicity, their impact on patients’ Quality of Life (QoL) should not be overlooked. Improving patients’ QoL and their compliance to treatments will represent the challenge for cancer researchers in the future years. Indeed, by a purely economic perspective, reducing the toxic effects of these treatments will allow to decrease the abstention from work days and to increase productivity, hence leading to a wider access to cures due to a better economic status [4–8].

This paper can be properly inserted in the frame of pharmacoeconomics, which is a scientific discipline related to the cost and the value of drugs and provides suggestion for the optimal allocation of the health care resources. This conceptualization was proposed by Townsend in 1987 [9], who identified the Pharmacoeconomics as "the description and the analysis of costs of therapeutic approach sustained by the Health System and Society". However, the first definition of Pharmacoeconomics dates back to 1977 when Weinstein and Stason [10] published a paper dealing with economic analysis in health field.

On the current scenario of rapidly rising health care costs, pharmaeconomic techniques are becoming increasingly relevant to analyze the cost-effectiveness and economic sustainability of emerging drugs [11]. Among such techniques, cluster analysis plays a relevant role. In fact, cluster analysis is used to identify groups of similar data based on selected variables and is particularly suitable for their comparison. The versatility of such a statistical technique explains also its popularity in many fields of applied science [12–20]. Indeed, cluster analysis seems to be appropriate for performing a global study of the connection between drug effectiveness, toxicity and cost. In this context, it is worth mentioning Perrier et al [14], who explored the transferability of health cost assessment between Italy and France. The authors constructed a hierarchical structure using cluster analysis and identified four different clusters based on diagnosis, surgery, chemotherapy and follow-up. Their findings showed that a high variability was present between this two countries, suggesting a low transferability of cost evaluations across Italy and France. Two years later, Liao et al. [15] performed an observational study on 18,380 patients with end-stage renal disease who initiated hemodialysis. By using K-means and hierarchical cluster analyses with either flexible beta or Ward’s methods, they identified 4 clusters based on sample sizes and change of cost patterns, finding that higher costs were correlated with more increasing comorbidity scores.

In our study we are different from the quoted papers since we first create a dataset containing clinical and economic information about all the oncological target agents approved in clinical practice. In this respect, it is important to recall that a target agent is a drug that is able to recognize one or more specific molecules expressed by tumor cells, immune cells or, more generally, by tumor microenvironment in cancer patients. The identification procedure has been rather complex - it mirrors the complexity of the faced problem- and represents a relevant step of the research.

Furthermore, we have employed a method based on Voronoi tessellation [21], which represents a potential visualization of the subgroups identified by the cluster analysis. Voronoi diagram is a kind of decomposition of a given metric space based on the distance (which is Euclidean in the original formulation of Voronoi) to specified sites called centroids [21]. Particularly, each centroid recognizes data that are nearer to it than to the other centroids in
accord to the given distance. By applying this technique, we are able to explore the way in which clusters of toxicity and costs overlap, hence giving information on the relationship between drug toxicity and related cost.

As we will see below, to gain more insights we depart from the original formulation of Voronoi and consider also minimum and maximum distances.

Cluster analysis, with a specific Voronoi diagrams approach, has been recently applied in the economic field [22–25]. In 2009, Liu et al. [22] explored the distribution of rural assessment using this technique. They showed that the distance from highways and rivers were the two factors that majorly influenced the distribution of rural settlements. More recently, Vaz et al. [23] reported a significant difference in term of regional innovation patterns as a consequence of institutional innovation profiles.

As already mentioned above, we here investigate, through a cluster analysis procedure, whether there is a correlation between the cost of molecularly targeted and immnotherapy agents and their toxicity in terms of SAE and D rates.

To the best of our knowledge, this is the first paper dealing with toxicity and cost of target agents in oncology through a cluster analysis. More than this, the construction of the dataset on the basis of an exhaustive literature review is also a novelty in the oncological studies.

The rest of the paper is organized as follows. Section 2 collects the results of the analysis, while Section 3 provides a discussion of them. In Section 4 we present how the used dataset has been constructed and illustrate its main statistical properties. Furthermore, Section 4 contains also the description of the employed methodological tools, with a detailed explanation of the cluster analysis.

Materials and methods

Construction of the dataset

The construction of the dataset has been implemented through a critical analysis of a wide set of clinical studies.

The selection of the relevant researchs has been carried out according to the instructions contained in the PRISMA [26] (S1 File). The scientific literature of interest has been identified from keywords selections on the PubMed database, in a period ranging from 1965 to 2016. Specifically, the research has been conducted by combining the words "cancer", "neoplasm", "solid tumor" and "clinical trial" with the name of each target agent.

As a second step, we have identified the papers dealing with human studies and randomized trials published in English and meeting the following criteria: 1) phase III studies conducted in patients with cancer; 2) random assignment of participants to treatment with a target therapy or a control (standard of care, placebo or best supportive care). In case of several publications related to the same experiment, only the most recent one or the most complete referring to included trial has been considered. Phase I and phase II trials has been excluded because of their variability and the lack of sufficient controls.

For each of the obtained papers we have reported the scientific study, the name of all authors, the name of the journal, the reference year, the number of the volume and the reference pages.

The resulting list of studies on target agents has been explored to assess the variables of interest related to the specific agent, i.e.: number of patients treated with target agents in the clinical studies, PFS (defined as the time from the start of therapy to disease progression or death), rate of all-grade AE and SAE (which leads to the necessity of medical assistance, hospitalization or drug interruption) and the D rate due to drug toxicity.

For the present research, we consider as variables the rate of SAE and the D rate, leaving the other ones for future studies.
Information on the costs of the target agents has been derived directly from their websites. All costs are expressed in American US Dollars.

Cluster analysis

Cluster analysis and Voronoi tessellation were performed by R software version 3.3.0 for Windows (62 megabytes, 32/64 bit). We have compared the clusters of target agents obtained when taking toxicity and when taking costs.

For what concerns toxicity, we have considered SAE and D rates as relevant variables. They are the parameters concurring in our conceptualization of the Toxicity Index (TI, hereafter).

The procedure of centroids selection has been implemented accordingly to clinical and scientific criteria, in order to represent the most meaningful groups of combinations of the two variables. For this analysis, we have reasonably considered five centroids as follows: $\phi_1 = (10,5); \phi_2 = (30,15); \phi_3 = (45,10); \phi_4 = (60,20); \phi_5 = (75,25)$, where the first component is the SAE value while the second one represents the D rate. In particular, centroid $\phi_1$ is associated with low rate of SAE and low D rate, which leads to a low TI; $\phi_2$ has low-medium rate of SAE and medium D rate, which means low-medium TI; $\phi_3$ has medium rate of SAE and low-medium D rate (medium TI); $\phi_4$ represents medium-high rate of SAE and medium-high D rate (medium-high TI); $\phi_5$ identifies a cluster with high rate of SAE and high D rate (high TI).

The cluster obtained by centroid $\phi_h$ will be denoted by $C_h$, for each $h = 1,2,3,4,5$. Moreover, by denoting the observations of SAE and D rates by the variables $x$ and $y$, respectively, we also denote components of the centroid $\phi_h = (\phi_h,x,\phi_h,y)$, for each $h = 1,2,3,4,5$.

Clusters are identified by the nearness of the target agent toxicity with the centroids. At this aim, we apply three different concepts of distance: an Euclidean one–in accord to the original model of Voronoi–, the maximum and the minimum. Formally, for any given target agent $j = 1,2, \ldots ,37$ with SAE rate $x_j$ and D rate $y_j$, we define

$$d_E(j, \phi_h) = \sqrt{(x_j - \phi_{hx})^2 + (y_j - \phi_{hy})^2}$$

$$d_M(j, \phi_h) = max\{|x_j - \phi_{hx}|, |y_j - \phi_{hy}|\}$$

$$d_m(j, \phi_h) = min\{|x_j - \phi_{hx}|, |y_j - \phi_{hy}|\}$$

According to the specific metric selected, we derive the clusters of target agents as follows:

$$C_h^K = \{j = 1, \ldots ,37 | d_E(j, \phi_h) < d_E(j, \phi_h), \forall h \neq h\}, \forall K = E, M, m, \forall h = 1, 2, 3, 4, 5.$$  

For what concerns the costs of the target agents, we have implemented two simple clusterings based on two variables. First, we have grouped the investigated drugs into three groups on the basis of 1-month cost patterns: cost less than 7,000$ (Group A), cost ranging from 7,000 to 11,000$ (Group B) and cost greater than 11,000$ (Group C). In the same way, drugs were grouped according to their costs estimated for the complete treatment for each patient within 3 groups: cost less than 40,000$ (Group D), cost ranging from 40,000$ to 80,000$ (Group E) and cost greater than 80,000$ (Group F).

Results

At the end of text analysis, we have obtained 4,803 studies concerning the use of molecular targeted drugs in cancer patients (the list of drugs is reported in the first column of Table 1).
Table 1. List of target agents employed in oncological patients. Their characteristics are related to drug efficacy in terms of median Progression-Free Survival (PFS) and drug toxicity in terms of rate of all-grade, severe adverse events and discontinuation rate. BCC = Basal-cell Carcinoma; GIST = Gastrointestinal Stromal Tumor; NSCLC = Non Small Cell Lung Cancer; RCC = Renal Cell Carcinoma.

| Target Agent                                    | First Authors, Year | Reference | Cancer Type | Number of Patients | Median PFS (Months) | All grade Adverse Events (%) | Severe Adverse Events (%) | D Rate (%) |
|-------------------------------------------------|---------------------|-----------|-------------|--------------------|---------------------|----------------------------|--------------------------|------------|
| Abiraterone acetate (first line therapy)        | Charles JR, 2013    | 27        | Prostate    | 546                | 16.5                | 99                         | 48                       | 10         |
| Abiraterone acetate (successive line-therapy)   | de Bono S, 2011     | 28        | Prostate    | 797                | 5.6                 | 23                         | 7                        | 19         |
| Afatinib                                        | Sequist LV, 2013    | 29        | NSCLC       | 230                | 11.1                | NA                         | 49                       | 8          |
| Bevacizumab                                     | Friedmann HS, 2009  | 30        | Glioblastoma| 82                 | 5.6                 | 100                        | 65.8                     | 17.7       |
| Bevacizumab                                     | Escudier B, 2007    | 31        | RCC         | 327                | 10.2                | 97                         | 29                       | 28         |
| Bevacizumab (first line therapy)                | Hurwitz H, 2004     | 32        | Colorectal  | 411                | 10.6                | NA                         | 84.9                     | 8.4        |
| Bevacizumab (successive line-therapy)           | Bennouna J, 2013    | 33        | Colorectal  | 409                | 5.7                 | 98                         | 64                       | 16         |
| Cabozantinib                                    | Eisei R, 2013       | 34        | Thyroid     | 219                | 11.2                | NA                         | 69                       | 16         |
| Cetuximab                                       | Vermorken JB, 2008  | 35        | Head and Neck| 222               | 5.5                 | NA                         | 82                       | 20         |
| Cobimetinib + Vemurafenib                       | Larkin J, 2014      | 36        | Melanoma    | 247                | 9.9                 | 95                         | 62                       | 12         |
| Crizotinib                                      | Shaw AT, 2013       | 37        | NSCLC       | 173                | 7.7                 | NA                         | 33                       | 6          |
| Enzalutamid (first line therapy)                | Beer TM, 2015       | 38        | Prostate    | 800                | 8.3                 | 34                         | 28                       | 8          |
| Enzalutamid (successive line-therapy)           | Scher HI, 2012      | 39        | Prostate    | 872                | 5.7                 | 97                         | 43                       | 6          |
| Erlotinib                                       | Moore MJ, 2007      | 40        | Pancreas    | 282                | 3.8                 | 100                        | 61                       | 10         |
| Erlotinib (first line therapy)                  | Rosell R, 2012      | 41        | NSCLC       | 86                 | 9.7                 | 98                         | 45                       | 13         |
| Erlotinib (maintenance therapy)                 | Cappuzzo F, 2010    | 42        | NSCLC       | 438                | 2.9                 | NA                         | 11                       | 16         |
| Everolimus                                      | Baselga J, 2012     | 43        | Breast      | 482                | 7.8                 | NA                         | 23                       | 19         |
| Lenvatinib                                      | Schlumberger M, 2015| 44       | Thyroid     | 261                | 14.7                | 97.3                       | 75.9                     | 14.2       |
| Nivolumab                                       | Brahmer J, 2015     | 45        | Squamous NSCLC| 135               | 3.5                 | 58                         | 7                        | 3          |
| Nivolumab (Non-Squamous NSCLC)                  | Borghaei H, 2015    | 46        | Non-Squamous NSCLC| 292             | 2.3                 | 69                         | 10                       | 5          |
| Nivolumab                                       | Robert C, 2015      | 47        | Melanoma    | 210                | 5.1                 | 74.3                       | 11.7                     | 2.4        |
| Nivolumab                                       | Motzer RJ, 2015     | 48        | RCC         | 410                | 4.6                 | 79                         | 19                       | 8          |
| Palbociclib (+letrozole)                        | Finn RS, 2015       | 49        | Breast      | 84                 | 20.2                | 99                         | 76                       | 33         |
| Palbociclib (+fulvestrant)                      | Turner NC, 2015     | 50        | Breast      | 347                | 9.2                 | 97.7                       | 69.3                     | 2.6        |
| Pembrolizumab                                   | Robert C, 2015      | 51        | Melanoma    | 277                | 4.1                 | 72.9                       | 75                       | 6.9        |
| Ramucirumab                                     | Fuchs CS, 2014      | 52        | Gastric     | 238                | 2.1                 | 94                         | 57                       | 11         |
| Ramucirumab                                     | Garon EB, 2014      | 53        | NSCLC       | 628                | 4.5                 | 98                         | 79                       | 15         |
| Ramucirumab                                     | Tabernero J, 2015   | 54        | Colorectal  | 536                | 5.7                 | 83                         | 36                       | 11         |
| Regorafenib                                     | Grothey A, 2013     | 55        | Colorectal  | 505                | 1.9                 | 93                         | 54                       | 44.8       |
| Sonidegib                                       | Midgen MR, 2015     | 56        | BCC         | 79                 | 13.1                | 95                         | 31                       | 22         |
| Sorafenib                                       | Escudier B, 2007    | 57        | RCC         | 451                | 5.5                 | NA                         | 34                       | 10         |
| Sunitinib                                       | Motzer RJ, 2009     | 58        | RCC         | 375                | 11                  | NA                         | 7                        | 38         |
Toxicity and cost of oncological target agents

Table 1. (Continued)

| Target Agent          | First Authors, Year | Reference | Cancer Type | Number of Patients | Median PFS (Months) | All grade Adverse Events (%) | Severe Adverse Events (%) | D Rate (%) |
|-----------------------|---------------------|-----------|-------------|--------------------|----------------------|-----------------------------|---------------------------|------------|
| Sunitinib             | Demetri GD, 2006    | 59        | GIST        | 207                | 6.4                  | 83                          | 20                        | 9          |
| T-DM1                 | Verma S, 2012       | 60        | Breast      | 495                | 9.6                  | 95.9                        | 15.5                      | 5          |
| Temsirolimus          | Hudes G, 2007       | 61        | RCC         | 209                | 3.8                  | NA                          | 11                        | 7          |
| Trametinib + Dabrafenib| Long GV, 2014       | 62        | Melanoma    | 211                | 9.3                  | 95                          | 32                        | 9          |
| Ziv-Aflibercept       | Van Cutsem E, 2012  | 63        | Colorectal  | 612                | 6.9                  | 99.2                        | 83.5                      | 26.8       |

https://doi.org/10.1371/journal.pone.0183639.t001

Fig 1. Study selection according to PRISMA statement.

https://doi.org/10.1371/journal.pone.0183639.g001
Therefore, 2,914 of the 4,083 original papers have been excluded because of phase I studies, observational, in vitro, reviews or letters about targeted therapies. Of the 1,889 remained studies, 1,852 were excluded because dealing with phase II or because not containing data on the SAE and D rates.

As a result, we have found 23 target agents that are used in 37 different therapeutic settings [27–63] (Table 1).

Table 2 contains the main statistical indicators of the dataset. The mean/std. dev. ratio allows additional considerations about the heterogeneity within the clusters, which is low, supporting that each cluster includes similar drugs both in terms of SAE and D rates.

Concerning skewness, it is relevant to note that only the rate of all grade adverse events is negative (-2.06) with a curve of distribution characterized by a longer left tail with a median of patients developing at least an adverse event (95%) that overcross the mean of patients (86%). Further information can be added by observing the leptokurtic distribution of all grade adverse events (curtosis is 3.95), while the distribution of SAE is platykurtic (curtosis is -1.38).

It is also important to observe the response rates reported by target agents, which range from 1% to 80% (Table 2). Such a result underlines the extreme variety of actions of these new generation agents that can improve patient survival without reducing tumour sizes.

Fig 2A, 2B and 2C show the clusters based on Euclidean distance, maximum distance and minimum distance, respectively. A spatial representation of the dynamic fields related to cluster analysis by Euclidean distance has been obtained by Voronoi diagram as reported in Fig 3.

The results of cluster analysis with Euclidean distance show a major similarity with the findings obtained by the maximum distance. In particular, such clustering criteria place in two different clusters only two drugs (Regorafenib, charaterized by SAE and D rates of 54 and 44.8, respectively, and Pembrolizumab, with SAE and D rates of 75 and 6.9, respectively. They belong to cluster 4 based on Euclidean distance and to cluster 5 according to the maximum distance). Differently, the clusters based on minimum distance are markedly different from both the other analyses.

It is interesting to note that the highest cost for a month and per PFS are represented by the combination of Cobimetinib and Vemurafenib and the lowest by Erlotinib (when used for patients with pancreatic cancer). The mean and median montly costs are 9,366 $ and 8,627 $.

Table 2. Main statistical indicators of the dataset.

| Number of patients | DRUG EFFECTIVENESS | DRUG TOXICITY |
|--------------------|--------------------|---------------|
|                    | Median PFS (months) | All grade adverse events (%) | Severe adverse events (%) | Discontinuation rate (%) |
| Mean               | 356                | 7.60          | 86            | 44             | 14              |
| Std. Dev.          | 205                | 4.14          | 20            | 26             | 10              |
| Mean/Std. Dev.     | 1.73               | 1.84          | 4.30          | 1.68           | 1.42            |
| Min                | 79                 | 1.9           | 23            | 7              | 2.4             |
| Max                | 872                | 20.2          | 100           | 84.9           | 45              |
| Median             | 292                | 6.4           | 95            | 43             | 11              |
| Skewness           | 0.83               | 1.03          | -2.06         | 0.10           | 1.48            |
| Kurtosis           | 0.23               | 1.21          | 3.95          | -1.38          | 2.19            |
| Q1                 | 211                | 4.6           | 81            | 20             | 8               |
| Q3                 | 482                | 9.9           | 98            | 65.8           | 17.7            |

https://doi.org/10.1371/journal.pone.0183639.t002
respectively. On the other hand, the mean and median costs per PFS are 73,154 $ and 49,500 $, respectively (Table 3).

![Cluster analysis based on Toxicity Index (TI) considering Euclidean distance (A), maximum distance (B) and minimum distance (C). The “+” represent the centroids.](https://doi.org/10.1371/journal.pone.0183639.g002)
Both Fig 4A and 4B show that heterogeneous cost distribution that doesn’t clearly follow the cluster division based on TI. However, some illustrations of the relationship between toxicity and costs can be carried out at the single clusters level. For instance, as for the 1-month cost, the higher rate of drugs from Group C belongs to Cluster 5, whilst the higher percentage of drugs from Group A are included in Cluster 3. Concerning the total cost estimated for a single patient for the whole treatment, the higher rate of drugs belonging to Group D belongs to Cluster 4, whilst the higher percentage of drugs from Group F are in Cluster 5. The complete distribution of costs within the 5 clusters is reported in Table 4 and Fig 5.

**Discussion**

Our paper concerns the study of the relationship between the toxicity and cost of newly approved target agents in the Oncology field. All the drugs approved by FDA have been considered. Variables related to SAE and D rates have been collected from published phase III studies.

Cluster analysis has been employed to explore such a relationship. Specifically, three different clustering criteria based on the Euclidean distance—in accord to the standard Voronoi tesselation definition—and maximum and minimum distances have been considered.

To interpret the outcomes of the analysis, we need to provide an intuitive description of the clustering criteria.

The minimum distance is the one that underestimate the toxicity level, in that it may place a drug in a low-toxicity cluster even if some related parameters are of remarkable high level.

Differently, the maximum distance is more “cautious” and overestimates the level of toxicity, since it may insert an agent into a high-toxicity cluster even when some toxicity parameters exhibit a low value.

The “fair” situation is captured by the Euclidean distance, which is the one used in the original Voronoi model. The comparison among the results of the clustering procedures suggests that taking a definition of toxicity that may imply its overestimation is closer to fairness than dealing with an understimation criterion.

It is important to note that the toxicity associated with oncological drugs implicates a high-cost management. In this regard, previous studies have tried to quantify this amount. For example, Roncato et al. [64] evaluated the economic burden of Irinotecan-related toxicity in patients with metastatic colorectal cancer, revealing that the mean predicted cost per patient...
was 4,886 €. On the other hand, Arondekar et al. [65] investigated the costs of AEs in 2,621 patients with metastatic melanoma by employing multivariate generalized linear models (GLMs) with a log-link function and gamma distribution. They reported a 30-day incremental cost of over 9,000 $ for metabolic AEs, 8,450 $ for hematologic, 6,476 $ for cardiovascular and 6,338 $ for gastrointestinal AEs [65].

Similarly, Bilir et al. [66] studied the economic burden of toxicities associated with treating metastatic melanoma in the United States. They registered that the highest mean in patient costs for an AE were associated with acute myocardial infarction, sepsis, and coma, ranging

| Target Agent | Cancer Type     | Monthly cost ($) | Cost per PFS ($) |
|--------------|-----------------|------------------|------------------|
| Abiraterone acetate (first line therapy) | Prostate | 8,627 | 142,346 |
| Abiraterone acetate (successive line-therapy) | Prostate | 8,627 | 48,311 |
| Afatinib | NSCLC | 6,970 | 77,367 |
| Bevacizumab | Glioblastoma | 4,400 | 24,640 |
| Bevacizumab | RCC | 4,400 | 44,880 |
| Bevacizumab (first line therapy) | Colorectal | 2,680 | 28,408 |
| Bevacizumab (successive line-therapy) | Colorectal | 2,680 | 15,276 |
| Cabozantinib | Thyroid | 14,300 | 160,160 |
| Cetuximab | Head and Neck | 7,000 | 38,500 |
| Cobimetinib + Vemurafenib | Melanoma | 26,300 | 260,370 |
| Crizotinib | NSCLC | 11,500 | 88,550 |
| Enzalutamide (first line therapy) | Prostate | 7,450 | 61,835 |
| Enzalutamide (successive line-therapy) | Prostate | 7,450 | 42,465 |
| Erlotinib | Pancreas | 2,450 | 9,310 |
| Erlotinib (first line therapy) | NSCLC | 3,000 | 29,100 |
| Erlotinib (maintenance therapy) | NSCLC | 3,000 | 8,700 |
| Everolimus | Breast | 7,000 | 54,600 |
| Lenvatinib | Thyroid | 13,945 | 204,992 |
| Nivolumab | Squamous NSCLC | 12,600 | 44,100 |
| Nivolumab | Non-Squamous NSCLC | 12,600 | 28,980 |
| Nivolumab | Melanoma | 12,600 | 64,260 |
| Nivolumab | RCC | 6,984 | 32,126 |
| Palbociclib (+letrozole) | Breast | 9,850 | 198,970 |
| Palbociclib (+fulvestrant) | Breast | 9,850 | 90,620 |
| Pembrolizumab | Melanoma | 23,017 | 94,370 |
| Ramucirumab | Gastric | 13,000 | 27,300 |
| Ramucirumab | NSCLC | 11,000 | 49,500 |
| Ramucirumab | Colorectal | 13,000 | 74,100 |
| Regorafenib | Colorectal | 7,600 | 14,440 |
| Sonidegib | BCC | 12,000 | 157,200 |
| Sorafenib | RCC | 6,600 | 36,300 |
| Sunitinib | RCC | 7,000 | 77,000 |
| Sunitinib | GIST | 7,000 | 44,800 |
| T-DM1 | Breast | 9,800 | 94,080 |
| Temsirolimus | RCC | 2,960 | 11,248 |
| Trametinib + Dabrafenib | Melanoma | 16,300 | 151,590 |
| Ziv-Aflibercept | Colorectal | 11,000 | 75,900 |

https://doi.org/10.1371/journal.pone.0183639.t003
from 31,682 $ to 47,069 $. In addition, the mean cost for hospitalization due to other AEs ranged from 19,122 $ to 26,861 $ [66].

The quantification of the economic impact related to the toxicity of target agents will represent a major step forward in the phases of drug approval and cost establishment, representing a fundamental parameter that must be considered during these processes.

In the last years, several techniques of drug reimbursement have been introduced in the pharmacoeconomic scenario and are currently employed in the oncological field. These modalities include: (1) payment by results, which consists in the total refund by the manufacturer for non-responding patients; (2) risk sharing, which provides for a partial refund for
non-responding patients after a clinical/radiological evaluation; (3) cost sharing, which sets an initial discount for all treated patients. These techniques have become even more fundamental after the introduction of immunotherapy in the therapeutic armamentarium of cancer patients. In fact, these agents are characterized by both relevant cost and high efficacy, supporting the research for new tools aimed to optimize the use of economic resources in the health system. In this respect, Russi et al. [67] proposed a new cost-containment strategy for the use of immunotherapeutic agent ipilimumab for patients with melanoma in Italy. This model included, by one side, drug-day and centralization of compounding (accounting for a reduction of -11.1% of drug cost) and, by the other side, payback systems designed by AIFA (resulting in additional -6.2%) [67].

Our study presents several limitations. First of all it is a systematic review realized starting from clinical trials and not from individual patients’ data. Thus, data on drug toxicity might be influenced by confounding factors such as the presence of different tumors, patients’ comorbidities or simultaneous treatments. Furthermore, patients eligible for clinical trials mostly show fair organ functions, leading to a potential underestimation of drug toxicity compared to clinical practice. Finally, we are aware that the various toxicities considered in our analysis may have a different impact on patient QoL, and a wide range of clinical consequences, although we considered only SAEs that lead to patient hospitalization and/or medical interventions and the D rate.

In the face of these limitations, at a macroscopic level, our analysis highlights that there is not a straightforward relationship between the toxicity of target agents and their relative costs for 1-month or the whole treatment duration. However, we can notice that the number of target agents with high costs results more relevant in the clusters associated with the worst drug-tolerability (high SAE and D rates), although they belong also to the cluster characterized by better safety (low SAE and D rates).

Table 4. Distribution of costs within the 5 clusters based on TI.

|               | 1-month treatment cost | Total cost for a single patient (estimated by PFS) |
|---------------|------------------------|--------------------------------------------------|
|               | Group A (%)            | Group B (%) | Group C (%) | Group D (%) | Group E (%) | Group F (%) |
| Cluster 1     | 33                     | 33          | 34          | 44          | 44          | 12          |
| Cluster 2     | 22                     | 34          | 44          | 11          | 56          | 33          |
| Cluster 3     | 50                     | 50          | 0           | 25          | 50          | 25          |
| Cluster 4     | 38                     | 24          | 38          | 63          | 0           | 37          |
| Cluster 5     | 14                     | 28          | 58          | 29          | 29          | 42          |

https://doi.org/10.1371/journal.pone.0183639.t004

Fig 5. The distribution of different clusters into the three cost categories related to the amount for median Progression-Free Survival (PFS).

https://doi.org/10.1371/journal.pone.0183639.g005
Interestingly, data on kurtosis and skewness underline that a high percentage of cancer patients treated with molecularly target agents do experience at least one all grade adverse event. The toxicity of these drugs, although lower than that associated with chemotherapy, suggest that the costs of management of adverse events must be considered during the phases of approval and price negotiation.

To sum up, the relationship between the cost and the efficacy and toxicity of new generation drugs does not follow a regular path. However, the constructed database and the findings here obtained can be efficiently used for the development of a unified theory on the cost management of treating cancer patients and on the study of the impact of these agents on their QoL.

Supporting information
S1 File. PRISMA 2009 checklist. List of the indications provided by the “PRISMA statement” for the realization of meta-analyses and systematic review.

Acknowledgments
We thank Dr. Matteo Santoni for his support in the revision of the oncological data employed in this analysis.

Author Contributions
Conceptualization: Francesca Tartari, Roy Cerqueti.

Data curation: Francesca Tartari, Alessandro Conti.

Formal analysis: Alessandro Conti, Roy Cerqueti.

Investigation: Francesca Tartari, Roy Cerqueti.

Methodology: Francesca Tartari, Roy Cerqueti.

Writing – original draft: Francesca Tartari, Roy Cerqueti.

Writing – review & editing: Francesca Tartari, Roy Cerqueti.

References
1. Soni A. Trends in the Five Most Costly Conditions among the U.S. Civilian Institutionalized Population, 2002 and 2012. Statistical Brief 470. Rockville, Md: Agency for Healthcare Research and Quality; 2015.
2. http://www.fda.gov; accessed on December 10th, 2016
3. Bradley CJ, Yabroff KR, Warren JL, Zeruto C, Chawla N, Lamont EB. Trends in the Treatment of Metastatic Colon and Rectal Cancer in Elderly Patients. Med Care. 2016; 54: 490–497. https://doi.org/10.1097/MLR.0000000000000510 PMID: 26900634
4. Shih YC, Smieliauskas F, Gevysisman DM, Kelly RJ, Smith TJ. Trends in the Cost and Use of Targeted Cancer Therapies for the Privately Insured Nonelderly: 2001 to 2011. J Clin Oncol. 2015; 33: 2190–2196. https://doi.org/10.1200/JCO.2014.58.2320 PMID: 25987701
5. Ekwueume DU, Yabroff KR, Guy GP Jr, Banegas MP, de Moor JS, Li C, et al. Medical costs and productivity losses of cancer survivors United States, 2008–2011. MMWR Morb Mortal Wkly Rep. 2014; 63: 505–510. PMID: 24918485
6. Guy GP Jr, Ekwueume DU, Yabroff KR, Dowling EC, Li C, Rodriguez JL, et al. Economic burden of cancer survivorship among adults in the United States. J Clin Oncol. 2013; 31: 3749–3757. https://doi.org/10.1200/JCO.2013.49.1241 PMID: 24043731
7. Guy GP Jr, Yabroff KR, Ekhueme DU, Smith AW, Dowling EC, Rechis R, et al. Estimating the health and economic burden of cancer among those diagnosed as adolescents and young adults. Health Aff (Millwood). 2014; 33: 1024–1031. https://doi.org/10.1016/j.healthaff.2015.09.002 PMID: 26590644

8. Guy GP Jr, Yabroff KR, Ekhueme DU, Virgo KS, Han X, Banegas MP, et al. Healthcare Expenditure Burden Among Non-elderly Cancer Survivors. 2008–2012. Am J Prev Med. 2015; 49: S489–497. https://doi.org/10.1016/j.amepre.2015.09.002 PMID: 26590644

9. Townsend RJ. Post-marketing drug research and development. Drug Intell Clin Pharm. 1987; 21: 134–136. PMID: 3816576

10. Weinstein MC, Stason WB. Foundations of cost-effectiveness analysis for health and medical practices. N Engl J Med. 1977; 296: 716–721. https://doi.org/10.1056/NEJM197703312961304 PMID: 402576

11. Zanfina A, Hansoo K, Ella Z, Christopher MR, Bruce H, Danny L. Overview of pharmacoeconomic modelling methods. Br J Clin Pharmacol. 2013; 75: 944–950. https://doi.org/10.1111/bcpr.12125 PMID: 2399725

12. Řezanková Hana. Cluster Analysis of Economic Data. STATISTIKA 94(1); 2014.

13. Eisen MB, Spellman PT, Brown PO, Botstein D. Genetics Cluster analysis and display of genome-wide expression patterns. Proc Natl Acad Sci USA. pp.14863–14868; 1998. PMID: 9843981

14. Lionel P, Alessandra B, Giuseppe M, Patrick SB, Françoise D, Petrus JP, et al. Transferability of health cost evaluation across locations in oncology: cluster and principal component analysis as an explorative tool. BMC Health Serv Res. 2014; 14: 537. https://doi.org/10.1186/s12913-014-0537-x PMID: 25399725

15. Liao M, Li Y, Kianifard F, Obi E, Arcona S. Cluster analysis and its application to healthcare claims data: a study of end-stage renal disease patients who initiated hemodialysis. BMC Nephrol. 2016; 17: 25. https://doi.org/10.1186/s12882-016-0238-2 PMID: 26936756

16. Requia WJ, Koutrakis P, Roig HL, Adams MD, Santos CM. Association between vehicular emissions and cardiorespiratory disease risk in Brazil and its variation by spatial clustering of socio-economic factors. Environ Res. 2016; 150: 452–460. https://doi.org/10.1016/j.envres.2016.06.027 PMID: 27393825

17. Blanco MR, Martin JS, Kahlscheuer ML, Krishnan R, Abelsohn J, Laederach A, et al. Single Molecule Cluster Analysis dissects splicing pathway conformational dynamics. Nat Methods. 2015; 12: 1077–1084. https://doi.org/10.1038/nmeth.3602 PMID: 26414013

18. Gerber S, Horenko I. Improving clustering by imposing network information. Sci Adv. 2015; 1: e1500163. https://doi.org/10.1126/sciadv.1500163 PMID: 26601225

19. Bailly S, Destors M, Grillet Y, Richard P, Stach B, Vivodtzev I, et al. scientific council and investigators of the French national sleep apnea registry (OSFP). Obstructive Sleep Apnea: A Cluster Analysis at Time of Diagnosis. PLoS One. 2016; 11: e0157318. https://doi.org/10.1371/journal.pone.0157318 PMID: 27314230

20. Wong NS, Huang S, Chen L, Zhao P, Tucker JD, Yang LG, et al. Spatiotemporal clusters of primary and secondary syphilis cases in south China: an observational study. Lancet. 2016; 388 Suppl 1: S90.

21. Voronoi GF. Nouvelles applications des paramètres continus à la théorie de formes quadratiques, Journal fûr die reine und angewandte Mathematik. 1908; 134: 198–287.

22. Liu XT, Zheng XQ, Li DB. Voronoi Diagram-Based Research on Spatial Distribution Characteristics of Rural Settlements and Its Affecting FactorsA Case Study of Changing District, Beijing. Journal of Ecology and Rural Environment 2,007; 2009.

23. Vaz E, de Noronha Vaz T, Galindo PV, Nijkamp P. Modelling innovation support systems for regional developmentanalyses of cluster structures in innovation in Portugal, Entrepreneurship and Regional Development. 2014; 26: 23–46. https://howmuch.net/articles/us-economy-summarized-in-one-diagram; accessed on December 10th, 2016

24. http://www.relativelyinteresting.com/world-economy-visualized-one-brilliant-diagram; accessed on December 10th, 2016

25. Moher D, Liberati A, Tetzlaff J, Altman DG for the PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009; 339: 25–35.

26. Ryan CJ, Smith MR, de Bono JS, Molina A, Logothetis CJ, de Souza P, et al. Abiraterone in metastatic prostate cancer without previous chemotherapy. N Engl J Med. 2013; 368: 138–48. https://doi.org/10.1056/NEJMoia1209096 PMID: 23228172

27. de Bono JS, Logothetis CJ, Molina A, Fizazi K, North S, Chu L, et al. Abiraterone and increased survival in metastatic prostate cancer. N Engl J Med. 2011; 364: 1995–2005. https://doi.org/10.1056/NEJMoia1014618 PMID: 21612468
29. Sequist LV, Yang JC, Yamamoto N, O’Byrne K, Hirsh V, Mok T, et al. Phase III study of afatinib or cisplatin plus pemetrexed in patients with metastatic lung adenocarcinoma with EGFR mutations. J Clin Oncol. 2013; 31: 3327–3334. https://doi.org/10.1200/JCO.2012.44.2806 PMID: 23816960

30. Friedman HS, Prados MD, Wen PY, Mikkelsen T, Schiff D, Abrey LE, et al. Bevacizumab alone and in combination with irinotecan in current glioblastoma. J Clin Oncol. 2009; 27: 473–4740.

31. Escudier B, Pluzanska A, Koralewski P, Ravaud A, Bracarda S, Szczylar C, et al. Bevacizumab plus interferon alfa-2a for treatment of metastatic renal cell carcinoma: a randomised, double-blind phase III trial. Lancet. 2007; 370: 2103–2111. https://doi.org/10.1016/S0140-6736(07)61904-7 PMID: 18156031

32. Hurwitz H, Fehrenbacher L, Novotny W, Cartwright T, Hainsworth J, Heim W, et al. Bevacizumab in previously untreated metastatic colorectal cancer. N Engl J Med. 2004; 350: 2335–2342. https://doi.org/10.1056/NEJMoa032691 PMID: 15175435

33. Bennouna J, Sastre J, Arnold D, Österlund P, Greil R, Van Cutsem E, et al. Continuation of bevacizumab after first progression in metastatic colorectal cancer (ML18147): a randomised phase 3 trial. Lancet Oncol. 2013; 14: 29–37. https://doi.org/10.1016/S1470-2045(12)70477-1 PMID: 23168366

34. Elisei R, Schlumberger MJ, Müller SP, Schöffski P, Brose MS, Shah MH, et al. Cabozantinib in progressive medullary thyroid cancer. J Clin Oncol. 2013 (29):3639–3646. https://doi.org/10.1200/JCO.2012.48.4659 PMID: 24002501

35. Vermorken JB, Mesia R, Rivera F, Remenar E, Kawecki A, Rottey S, et al. Platinum-based chemotherapy plus cetuximab in head and neck cancer. N Engl J Med. 2008; 359: 1116–1127. https://doi.org/10.1056/NEJMoa0802656 PMID: 18784101

36. Larkin J, Ascierto PA, Dréno B, Atkinson V, Liszkay G, Maio M, et al. Combined vemurafenib and cobimetinib in BRAF-mutated melanoma. N Engl J Med. 2014; 371: 1867–1876. https://doi.org/10.1056/NEJMoa1408868 PMID: 25265494

37. Shaw AT, Kim DW, Nakagawa K, Seto T, Crinó L, Ahn MJ, et al. Crizotinib versus chemotherapy in advanced ALK-positive lung cancer. N Engl J Med. 2013; 368: 2385–2394. https://doi.org/10.1056/NEJMoa1214886 PMID: 23724913

38. Beer TM, Armstrong AJ, Rathkopf DE, Loriot Y, Higano CS, et al. Enzalutamide in metastatic prostate cancer before chemotherapy. N Engl J Med. 2014; 371: 424–33. https://doi.org/10.1056/NEJMoa1405095 PMID: 24881730

39. Scher HI, Fizazi K, Saad F, Taplin ME, Sternberg CN, Miller K, et al. Increased survival with enzalutamide in prostate cancer after chemotherapy. N Engl J Med. 2012; 367: 1187–1197. https://doi.org/10.1056/NEJMoa1207506 PMID: 22894553

40. Moore MJ, Goldstein D, Hamm J, Figer A, Hecht JR, Gallinger S, et al. Erlotinib plus gemcitabine compared with gemcitabine alone in patients with advanced pancreatic cancer: a phase III trial of the National Cancer Institute of Canada Clinical Trials Group. J Clin Oncol. 2007; 25: 1960–1966. https://doi.org/10.1200/JCO.2006.07.9525 PMID: 17452677

41. Rosell R, Carcereny E, Gervais A, Verger-Nogués A, Massuti B, Felip E, et al. Erlotinib versus standard chemotherapy as first-line treatment for European patients with advanced EGFR mutation-positive non-small-cell lung cancer (EURTAC): a multicentre, open-label, randomised phase 3 trial. Lancet Oncol. 2012; 13: 239–246. https://doi.org/10.1016/S1470-2045(11)70393-X PMID: 22285168

42. Capuzzo F, Ciuleanu T, Stelmakh L, Cicanas S, Szczesna A, Juhasz E, et al. Erlotinib as maintenance treatment in advanced non-small-cell lung cancer: a multicentre, randomised, placebo-controlled phase 3 study. Lancet Oncol. 2010; 11: 521–529. https://doi.org/10.1016/S1470-2045(10)70112-1 PMID: 20493771

43. Baselga J, Campone M, Piccart M, Burris HA 3rd, Rugo HS, Sahmoud T, et al. Everolimus in postmenopausal hormone receptor-positive advanced breast cancer. N Engl J Med. 2012; 366: 520–529. https://doi.org/10.1056/NEJMoa1109653 PMID: 22149876

44. Schlumberger M, Tahara M, Wirth LJ, Robinson B, Brose MS, Elisei R, et al. Lenvatinib versus placebo in radioiodine-refractory thyroid cancer. N Engl J Med. 2015; 372: 621–630. https://doi.org/10.1056/NEJMoa1406470 PMID: 25671254

45. Brahmer J, Reckamp KL, Baas P, Crinó L, Eberhardt WE, Poddubskaya E, et al. Nivolumab versus Docetaxel in Advanced Squamous-Cell Non-Small-Cell Lung Cancer. N Engl J Med. 2015; 373: 123–135. https://doi.org/10.1056/NEJMoa1504627 PMID: 26028407

46. Borghaei H, Paz-Ares L, Horn L, Spigel DR, Steins M, Ready NE, et al. Nivolumab versus Docetaxel in Advanced Non-squamous Non-Small-Cell Lung Cancer. N Engl J Med. 2015; 373: 1627–1639. https://doi.org/10.1056/NEJMoa1507643 PMID: 26412456

47. Robert C, Long GV, Brady B, Dutriaux C, Maio M, Mortier L, et al. Nivolumab in previously untreated melanoma without BRAF mutation. N Engl J Med. 2015; 372: 320–330. https://doi.org/10.1056/NEJMoa1420882 PMID: 25998552
48. Motzer RJ, Escudier B, McDermott DF, George S, Hammers HJ, Srinivas S, et al. Nivolumab versus Everolimus in Advanced Renal-Cell Carcinoma. N Engl J Med. 2015; 373: 1803–1813. https://doi.org/10.1056/NEJMoai150665 PMID: 26406148

49. Finn RS, Crown JP, Lang I, Boer K, Bondarenko IM, Kulyk SO, et al. The cyclin-dependent kinase 4/6 inhibitor palbociclib in combination with letrozole versus letrozole alone as first-line treatment of oestrogen receptor-positive, HER2-negative, advanced breast cancer (PALOMA-1/TRIO-18): a randomised phase 2 study. Lancet Oncol. 2015; 16: 25–35. https://doi.org/10.1016/S1470-2045(14)71559-3 PMID: 25524798

50. Turner NC, Ro J, André F, Loi S, Verma S, Iwata H, et al. Palbociclib in Hormone-Receptor-Positive Advanced Breast Cancer. N Engl J Med. 2015; 373: 209–219. https://doi.org/10.1056/NEJMoai1505270 PMID: 26030518

51. Robert C, Schachter J, Long GV, Arance A, Grob JJ, Mortier L, et al. Pembrolizumab versus Iplimumab in Advanced Melanoma. N Engl J Med. 2015; 372: 2521–2532. https://doi.org/10.1056/NEJMoai1503093 PMID: 25891173

52. Fuchs CS, Tomasek J, Yong CJ, Dumitru F, Passalacqua R, Goswami C, et al. Ramucirumab monotherapy for previously treated advanced gastric or gastro-oesophageal junction adenocarcinoma (REGARD): an international, randomised, multicentre, placebo-controlled, phase 3 trial. Lancet. 2014; 383: 31–39. https://doi.org/10.1016/S0140-6736(13)61719-5 PMID: 24004768

53. Garon EB, Ciuleanu TE, Arrieta O, Prabhash K, Syrigos KN, Goksel T, et al. Ramucirumab plus docetaxel versus placebo plus docetaxel for second-line treatment of stage IV non-small-cell lung cancer after disease progression on platinum-based therapy (REVEL): a multicentre, double-blind, randomised phase 3 trial. Lancet. 2014; 384: 665–673. https://doi.org/10.1016/S0140-6736(14)60845-X PMID: 24933332

54. Tabernero J, Yoshino T, Cohn AL, Obermannova R, Bodoky G, Garcia-Carbonero R, et al. Ramucirumab versus placebo in combination with second-line FOLFIRI in patients with metastatic colorectal carcinoma that progressed during or after first-line therapy with bevacizumab, oxaliplatin, and a fluoropyrimidine (RAISE): a randomised, double-blind, multicentre, phase 3 study. Lancet Oncol. 2015; 16: 499–508. https://doi.org/10.1016/S1470-2045(15)70127-0 PMID: 25877855

55. Grothey A, Van Cutsem E, Sobrero A, Siena S, Falcone A, Ychou M, et al. Regorafenib monotherapy for previously treated metastatic colorectal cancer (CORRECT): an international, multicentre, randomised, placebo-controlled, phase 3 trial. Lancet. 2013; 381: 303–312. https://doi.org/10.1016/S0140-6736(12)61900-X PMID: 23177514

56. Migden MR, Guminski A, Gutzmer R, Dirix L, Lewis KD, Combemale P, et al. Treatment with two different doses of sonidegib in patients with locally advanced or metastatic basal cell carcinoma (BOLT): a multicentre, randomised, double-blind phase 2 trial. Lancet Oncol. 2015; 16: 716–728. https://doi.org/10.1016/S1470-2045(15)70100-2 PMID: 25981810

57. Escudier B, Lassau N, Angevin E, Soria JC, Chami L, Lamuraglia M, et al. Phase I trial of sorafenib in combination with IFN alpha-2a in patients with unresectable and/or metastatic renal cell carcinoma or malignant melanoma. Clin Cancer Res. 2007; 13: 1801–1809. https://doi.org/10.1158/1078-0432.CCR-06-1432 PMID: 17363536

58. Motzer RJ, Hutson TE, Tomczak P, Michaelson MD, Bukowski RM, Oudard S, et al. Overall survival and updated results for sunitinib compared with interferon alfa in patients with metastatic renal cell carcinoma. J Clin Oncol. 2009; 27: 3584–3590. https://doi.org/10.1200/JCO.2008.20.1293 PMID: 19487381

59. Demetri GD, van Oosterom AT, Garrett CR, Blackstein ME, Shah MH, Verweij J, et al. Efficacy and safety of sunitinib in patients with advanced gastrointestinal stromal tumour after failure of imatinib: a randomised controlled trial. Lancet. 2006; 368: 1329–1338. https://doi.org/10.1016/S0140-6736(06)69446-4 PMID: 17046465

60. Verma S, Miles D, Gianni L, Krop IE, Welslau M, Baselga J, et al. Trastuzumab emtansine for HER2-positive advanced breast cancer. N Engl J Med. 2012; 367: 1783–1791. https://doi.org/10.1056/NEJMoai1209124 PMID: 23020162

61. Hudes G, Carducci M, Tomczak P, Dutcher J, Figlin R, Kapoor A, et al. Temsirolimus, interferon alfa, or both for advanced renal-cell carcinoma. N Engl J Med. 2007; 356: 2271–2281. https://doi.org/10.1056/NEJMoai066838 PMID: 17538086

62. Long GV, Stroyakovskiy D, Gogas H, Levchenko E, de Braud F, Larkin J, et al. Combined BRAF and MEK inhibition versus BRAF inhibition alone in melanoma. N Engl J Med. 2014; 371: 1877–1888. https://doi.org/10.1056/NEJMoai1406037 PMID: 25265492

63. Van Cutsem E, Tabernero J, Lakomy R, Prehen H, Prausová J, Macarulla T, et al. Addition of afibltrcept to fluorouracil, leucovorin, and irinotecan improves survival in a phase III randomised trial in patients with metastatic colorectal cancer previously treated with an oxaliplatin-based regimen. J Clin Oncol. 2012;(28): 3499–3506. https://doi.org/10.1200/JCO.2012.42.8201 PMID: 22949147
64. Roncato R, Cecchin E, Montico M, De Mattia E, Giodini L, Buonadonna A, et al. Cost Evaluation of Related Toxicities Associated With the UGT1A1*28 Patient Genotype. Clin Pharmacol Ther. 2017; https://doi.org/10.1002/cpt.615 PMID: 28074472

65. Arondekar B, Curkendall S, Monberg M, Mirakhur B, Oglesby AK, Lenhart GM, et al. Economic burden associated with adverse events in patients with metastatic melanoma. J Manag Care Spec Pharm. 2015;(2): 158–164. https://doi.org/10.18553/jmcp.2015.21.2.158 PMID: 25615005

66. Bilir SP, Ma Q, Zhao Z, Wehler E, Munakata J, Barber B. Economic Burden of Toxicities Associated with Treating Metastatic Melanoma in the United States. Am Health Drug Benefits. 2016;(4): 203–213. PMID: 27688833

67. Russi A, Chiarion-Sileni V, Damuzzo V, Di Sarra F, Pigozzo J, Palozzo AC. Case study on an Ipilimumab cost-containment strategy in an Italian hospital. Int J Technol Assess Health Care. 2017; 13: 1–7.