Health Policy and Technology (2016) 5, 156–165

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/hlpt

Ranking medical innovations according to perceived health benefit

Jilles M. Fermont[a,b,*], Karla H.P. Douw[a], Hindrik Vondeling[a], Maarten J. IJzerman[a]

[a]*Department of Health Technology and Services Research, MIRA institute for Biomedical Technology & Technical Medicine, University of Twente, The Netherlands*
[b]*Health Economics Research Centre, Nuffield Department of Population Health, University of Oxford, Old Road Campus, Headington, Oxford OX3 7LF, UK*

Available online 16 February 2016

KEYWORDS
Medical innovation;
Health care technology;
Ranking;
Health benefit;
Best-worst scaling;
Netherlands

Abstract
Objectives: In 2001, Fuchs and Sox published a landmark study on the relative importance for patients of thirty preselected medical innovations in the United States. About a decade later, we replicated the study in the Netherlands in response to the continuing debate on rising healthcare costs. The aims were to provide an updated list of medical innovations, categorise these according to their impact and novelty, provide a ranking according to the perceived health benefit by Dutch clinical and health technology experts, and draw conclusions for health technology policy making at a macro-level.
Methods: A search to identify medical innovations introduced in healthcare systems between 1990 and 2010 was performed in Medline. The authors categorised the innovations and disagreement was resolved by majority vote. Dutch health technology- and clinical experts from national agencies and medical societies ranked the innovations by means of best-worst scaling experiments in an online survey.
Results: Forty-one technologies (16 pharmaceuticals and 25 non-pharmaceuticals) were included. Of these, nine were categorised as big ticket technology, 24 as add-on and ten as new. Sixty-six clinical and health technology experts ranked these technologies. Self-monitoring of blood glucose and biological therapies for autoimmune diseases ranked highest.
Conclusions: Study limitations prevent making robust conclusions, however, results indicate that many of the identified innovations are add-on technologies, increasing health care cost at only marginal health benefit. If add-on technologies are the trend and healthcare systems aim to provide value for money, policies might need to be adjusted and research and development strategies should be informed at an earlier stage of technological development.
© 2016 Fellowship of Postgraduate Medicine. Published by Elsevier Ltd. All rights reserved.

*Corresponding author at: Health Economics Research Centre, Nuffield Department of Population Health, University of Oxford, Old Road Campus, Headington, Oxford OX3 7LF, UK. Tel.: +44 1865 289275.
E-mail addresses: jilles.fermont@dph.ox.ac.uk (J.M. Fermont), kdouw@health.sdu.dk (K.H.P. Douw), hvondeling@health.sdu.dk (H. Vondeling), m.j.ijzerman@utwente.nl (M.J. IJzerman).

http://dx.doi.org/10.1016/j.hlpt.2016.02.009
2211-8837/© 2016 Fellowship of Postgraduate Medicine. Published by Elsevier Ltd. All rights reserved.

Introduction

The added value of medical innovations in terms of health benefit and their impact on spending has been an issue since the late 1970s among health care providers, patients, hospitals, insurers and policy-makers. Technological change in health care has not only led to vast improvements in health services and the health status of populations, it is also a major driver and perhaps even the most important contributor to increasing health care expenditure [1,2]. In the Netherlands, the contribution of health technology to rising health care costs is a recurrent topic of debate. The National Institute for Public Health and the Environment (RIVM) states that, infused by the global financial crisis, cost reductions will be a primary motive for innovation in the fields of public health and the environment. This financial aspect represents an indispensable part of a strategic research programme within the institute; aiming to produce a balanced assessment of the significance of technological innovations [3]. This is the first study in the research programme, primarily aiming to provide input to support the discussion about the value for money of medical innovations.

In 2001, Fuchs and Sox [4] addressed the issue of the added value of medical innovations and reported on their relative importance for patients. Their study included thirty innovations that had been introduced in the United States during the previous twenty-five years. In 2010, a similar study was conducted by Athanasakis and colleagues in Greece [5]. They identified forty-two relevant innovations over the past thirty years and differentiated between technological and pharmaceutical innovations. In both studies the respondents were physicians. The highest ranked medical innovations in terms of relative importance were imaging techniques and technologies related to cardiovascular disease such as balloon angioplasty. About a decade later, we replicated the study in the Netherlands in response to the continuing debate on rising health care costs. Building onto the two previous studies [4,5], this study aimed to provide (i) an updated list of medical innovations introduced in the past two decades, (ii) categorise these according to their impact on resource use and novelty, (iii) rank the innovations according to the perceived health benefit by Dutch clinical and health technology experts with a broad overview of pharmaceutical and/or non-pharmaceutical innovations (i.e. devices and procedures) and draw policy conclusions. Pharmaceuticals are defined as "any chemical or biological substance that may be applied to, ingested by or injected into humans", a device as "any physical item, excluding drugs, used in health care", and a procedure as "a combination of provider skills or abilities with drugs, devices or both" [6].

Methods

Identifying medical innovations

Informed by experts from the Health Technology Assessment International (HTAi) Special Interest Group on Information Resources, a systematic search was carried out in Medline to identify medical innovations in the period between 1990 and 2010. Between 10 and 17 October 2011, a search for full-abstract articles was carried out in the four most cited general medical journals: the Journal of the American Medical Association (JAMA), British Medical Journal (BMJ), the Lancet, and the New England Journal of Medicine (NEJM).

The following terms were used with the expectation of capturing the most relevant innovations: highlight*, trends*, impact*, breakthrough*, milestone* and discovery*, with the following medical subject heading qualifiers: surgery, rehabilitation, trends, diagnostic use, genetics, prevention control, radiotherapy, instrumentation, therapeutic use, therapy, drug therapy, diagnosis and diet therapy. Only articles in English related to humans were included. The search included 'journal articles', 'meta-analysis' and 'reviews'. A secondary search was conducted through Google Books and Google Scholar to identify books and grey literature, which used the following search terms: medical breakthrough, pharmaceutical innovation, healthcare innovation, medical innovation, breakthrough technologies, and medical discoveries.

Filtering medical innovations

To reduce the extensive list of identified innovations, an initial selection was made based on the following three criteria: (i) the citation frequency of the innovation had to be >100, as recorded by Medline, (ii) the innovation had to be a medical intervention or diagnostic procedure, and (iii) the innovation had to be successfully applied to humans in the period between 1990 and 2010 and granted market approval in healthcare.

Categorising medical innovations

Different ways to categorise medical innovations are used within the scientific literature and in healthcare systems to support the understanding of the impact of medical innovations on health and health care costs. Ways to categorise innovations used by for example EuroScan, the National Institute for Health and Clinical Excellence, the International Network of Agencies in Health Technology Assessment, HTAi, Food and Drug Administration, and the European Medicines Agency were reviewed. The identified categorisations were described and a final selection was made by the commissioners of the study (RIVM) to select systems that were supportive in explaining the relation between technology and health care cost. The innovations were categorised individually into the selected categories by the authors. Detailed descriptions of the different categorisation systems are included in a report that can be obtained from the authors [7].

Ranking of medical innovations

Best-worst scaling (BWS) object case (case 1) was used to rank medical innovations based on their perceived health benefit. With the absence of attribute levels (profiles), bounded to just single objects, case 1 BWS was the most appropriate type [8]. BWS is an increasingly used method in health services research and health technology assessment (HTA) to elicit preferences [9]. It is a choice-based method grounded in random utility theory in which respondents are presented with series of choice-sets [8]. From these choice-sets, respondents have to choose the best (most preferred)

	Most health benefits	Least health benefits
3D rotational angiography	○	○
APC gene tests for familial adenomatous polyposis coli	○	○
Automatic External Defibrillator (AED)	○	○
Biventricular pacemakers	○	○
Bone densiometry	○	○

Figure 1 Example of a choice-set. Description: example of a choice-set from the questionnaire including technological innovations.

and the worst item (least preferred) from a group of items [8]. This stated preference technique does not suffer from scaling bias, unlike standard ranking techniques that lack a theoretical background in economic or psychological theory [8,10] and is less complex for respondents as multiple choice-sets compare only a few items instead of comparing all items at once [9].

Due to the large number of identified technologies, two questionnaires were developed to decrease the number of choice-sets each respondent would have to complete. One questionnaire included sixteen pharmaceutical innovations and showed in total sixteen choice-sets that each included six innovations to compare. The other questionnaire included twenty-five non-pharmaceutical innovations (devices and procedures) showing each respondent thirty choice-sets comparing five innovations each. See Figure 1 for an example of a choice-set. Both versions used a balanced incomplete block design to construct choice-sets of innovations. This is a design within BWS that gives fixed set sizes and has various desirable statistical properties such as equal occurrence and co-occurrence of items across all comparison sets [11].

Respondents were asked the following: "Please select from the list of innovations the innovation that has resulted in the most health benefits for patients and the innovation which has resulted in the least health benefits. Also take population size into consideration". Health benefit was defined as the improvement of the patient's health status and/or longevity. For diagnostics, it was assumed that the diagnostic information would affect the course of treatment positively, hence influence health status.

The questionnaire was pilot-tested ($N=6$) among three clinical experts (an epidemiologist, physician and surgeon), two HTA policy advisors and one HTA researcher. Based upon their recommendations minor textual changes were made.

Data collection

The survey was conducted online. In total 268 invitations were sent: 205 for the questionnaire including technological innovations and sixty-three for the questionnaire including pharmaceutical innovations. Survey invitations were distributed by both standard (surface) and electronic mail. Data were collected over a period of two months, from February to April 2012. Depending on the availability of contact details, either an electronic or a postal reminder was sent after one month. According to the Dutch Central Committee on Research Involving Human Subjects (WMO) no ethical approval was required.

Study population

A broad sample was projected with experts known to have a long experience in Dutch health care or health research and an overview over innovations in medicine. Experts and organisations were selected through purposive and/or snowball sampling. Eligible respondents included health technology and clinical experts covering different clinical areas. They work as senior advisors or committee members at national agencies, organisations and councils with a relation to health care, health care policy, health research, science & technology and/or medical innovation. These organisations are: The Dutch Health Council, Ministry of Public Health, Welfare and Sports, Health Care Insurance Board, Dutch Medical Research Council, Rathenau: Science and Technology Institute, TNO: Netherlands Organisation for Applied Scientific Research, Royal Dutch Academy of Sciences, and the Dutch Research Council. In addition, the chairmen of a great number of scientific medical associations, the Dutch Society of General Practitioners, and Centres of Health Research Excellence were asked to select clinical experts. Of the 268 invitations sent, fifty-two invitations were accompanied with 'snowball' letters. Experts and organisations receiving these invitations and letters were known for their expertise in the medical field and were asked to recommend others they considered suitable for study participation.

Optimum sample sizes for BWS exercises are unknown and there is no minimum sample size addressed by the underlying theory. The BWS literature suggests a minimum of twenty responses per questionnaire [12] or the use of simulation studies [9].

Data analysis

BWS choices were summarised through simple counting, a method described by Marley and Louviere [13]. For each innovation, a standardised score was calculated as follows:

$$\sqrt{\frac{\text{Count}_{\text{best}}}{\text{Count}_{\text{worst}}}}$$

where $\text{Count}_{\text{best}}$ is the total number of times an innovation was selected as having the most health benefits and where

$Count_{worst}$ is the total number of times an innovation was selected as having the least health benefits.

Results

Identifying medical innovations

The search in Medline retrieved 1824 articles ($N=1380$ journal articles and $N=444$ review articles and meta-analyses). The search in Google Books and Google Scholar provided books with a focus on medical advances and health care innovations [14-16]. Finally, the Cleveland Clinic's Top 10 Medical Innovations of the years 2007–2010 was included [17].

Using all identified sources resulted in a list of 540 medical innovations: 182 were derived from the reviews and meta-analysis, 331 from journal articles, and twenty-seven from the Google search. After removal of duplicates ($N=367$), 173 medical innovations remained. After applying the filtering criteria ii and iii (described above), and grouping similar innovations such as antiplatelet drugs and anticoagulants, forty-one medical innovations remained. Of these, sixteen are pharmaceuticals and twenty-five are non-pharmaceuticals. The latter can be subdivided into sixteen devices and nine procedures.

Categorising medical innovations

Several categorisation systems with different perspectives were identified in the literature. The following systems were used in this study: the type of innovation (pharmaceuticals and non-pharmaceutical: devices and procedures) [6], the impact on resource use (big, medium or small ticket) [1,18] and the innovation's relation to existing technologies (new, add-on and substitute) [19,20].

Big ticket innovations are those that require major capital investments and mobilisation of large human, physical and administrative resources [1,18]. Good examples are computerised tomography (CT) scanning and coronary artery bypass grafting. Medium ticket technologies are more difficult to describe; they are products of intensive technological development but they can be used without an elaborate and complex support system and are therefore less costly [18]. An example is upper gastrointestinal endoscopy. Small ticket innovations are those whose adoption does not require mobilisation of many financial and human resources [18]. While Johansen and Racoveanu [21] suggest that small ticket innovations that are utilised extensively should be considered big ticket because of their budget impact, in this study the term small ticket is used according to its original definition.

New (i.e. breakthrough) innovations are those that have a preventive, diagnostic or therapeutic benefit based on a completely new mechanism and may result in a decreased utilisation, for example by allowing better-targeted treatments. Add-on technologies are utilised in combination with existing devices, procedures or pharmaceuticals leading to treatment expansion. Patients can benefit from this but add-on technologies are generally more expensive than the original treatment strategy. Whether the procedure still represents value for money depends on the costs and the marginal health benefit [19]. Substituting innovations can replace more expensive procedures, devices or pharmaceuticals with improved health outcomes [19].

Unanimous agreement among the authors was obtained in categorising the innovations in pharmaceuticals, devices and procedures. For the categorisation in big, medium

Table 1 Self-reported characteristics of survey participants.

Characteristics	Total		Technological		Pharmaceutical	
	N	(%)	*N*	(%)	*N*	(%)
Invited	259	(100)	199	(100)	60	(100)
Responded	150	(58)	119	(60)	31	(52)
Participated	66	(25)	46	(23)	20	(33)
Gender						
Male	58	(88)	42	(91)	16	(80)
Female	8	(12)	4	(9)	4	(20)
Age (years)						
Median	56.5		57.0		54.0	
SD (minimum-maximum)	9.0 (38-81)		9.3 (38-81)		7.7 (39-64)	
Years of work experience						
Median	30.0		30.0		25.0	
SD (minimum-maximum)	10.1 (7-55)		10.3 (10-55)		9.0 (7-40)	
Work environment						
Healthcare policy (government)	17	(26)	12	(26)	5	(25)
Healthcare management	7	(11)	6	(13)	1	(5)
Healthcare provider	38	(58)	24	(52)	14	(70)
Academia	41	(62)	30	(65)	10	(50)
Other (e.g. healthcare inspection and biotechnology)	13	(20)	10	(22)	3	(15)

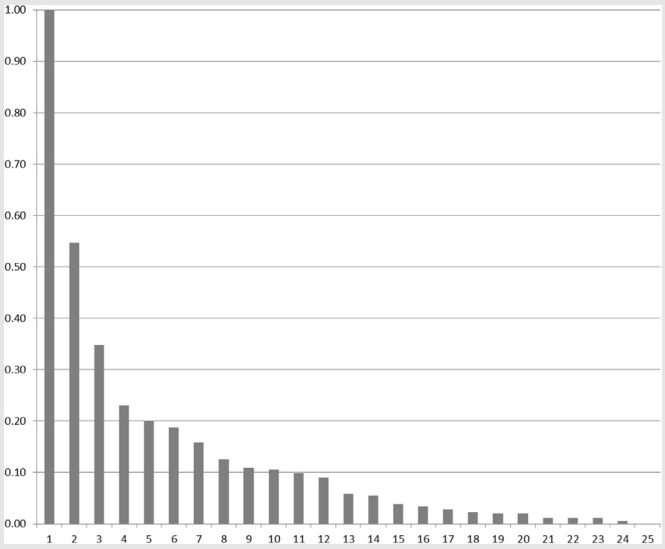
Description: Summary of self-reported characteristics. SD is standard deviation.

and small ticket, agreement was achieved for thirty out of forty-one innovations (73%) and for the categorisation in new, add-on and substitute for thirty-two out of forty-one innovations (78%). Where there was disagreement, a majority rule was applied.

Self-reported characteristics of survey respondents

The respondents were HTA- and clinical experts employed at national agencies and medical societies such as the Dutch Health Council, the Committee Pharmaceutical Aid, the

Table 2 Relative importance of non-pharmaceutical innovations.



Rank	Attributes	Category	Sqrt (b/w)
1	Self-monitoring of blood glucose	Small ticket, substitute	10.46
2	Biventricular pacemakers	Big ticket, add-on	5.83
3	Hybrid imaging systems (PET/CT or SPECT/CT or MRI/CT)	Big ticket, add-on	3.80
4	Automatic External Defibrillator (AED)	Small ticket, add-on	2.60
5	Portable monitor for home testing of sleep-related breathing disorders	Medium ticket, substitute	2.29
6	3D rotational angiography	Medium ticket, add-on	2.17
7	Real-time 3D ultrasound Imaging	Medium ticket, add-on	1.87
8	Percutaneous aortic heart valves	Medium ticket, substitute	1.54
9	Tandem mass spectrometry for biochemical genetic disorders and newborn screening	Medium ticket, new	1.36
10	Minimally invasive imaging (e.g. capsule endoscopy)	Medium ticket, new	1.33
11	Bone densitometry (DEXA-scan)	Medium ticket, add-on	1.26
12	Low-volume, low-pressure tracheal tube cuff to reduce ventilator-associated pneumonia	Medium ticket, substitute	1.16
13	High intensity focused ultrasound (HIFU)	Medium ticket, add-on	0.85
14	APC gene tests for familial adenomatous polyposis coli	Small ticket, new	0.81
15	Bronchial thermoplasty for asthma patients	Medium ticket, add-on	0.63
16	Pre-implantation genetic diagnosis (PGD)	Medium ticket, new	0.59
17	Ventricular assist device (VAD)	Big ticket, substitute	0.54
18	Intracytoplasmic sperm injection (ICSI)	Big ticket, new	0.48
19	Warm organ perfusion device for the heart	Medium ticket, new	0.46
20	Deep brain stimulation (DBS)	Big ticket, add-on	0.45
21	Optical position measurement systems (OPMS)	Medium ticket, new	0.37
22	Whole-blood interferon gamma (IFN-gamma) assay for tuberculosis	Medium ticket, add-on	0.36
23	Diaphragm pacing system	Big ticket, new	0.36
24	Optical coherence tomography (OCT)	Medium ticket, add-on	0.31
25	Cerebrospinal fluid (CSF) biomarkers for Alzheimer's disease diagnosis	Medium ticket, add-on	0.25

Description: $N=46$, 1380 number of sets. Sqrt is square root. B is the total number of times an innovation was selected as having the most health benefits. W is the total number of times an innovation was selected as having the least health benefits. PET is positron emission tomography. CT is computed tomography. SPECT is single-photon emission computed tomography. MRI is magnetic resonance imaging. DEXA is dual-energy X-ray absorptiometry.

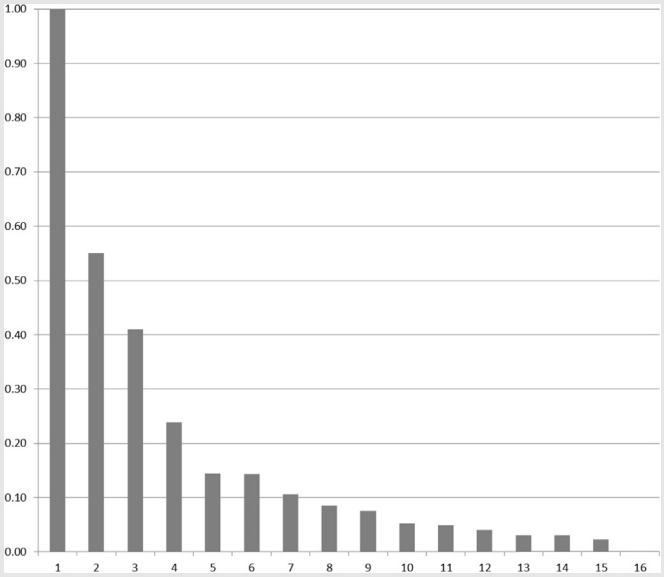
Council for Public Health and Health Care, Rathenau Institute, members of the Dutch scientific medical associations and members of the Royal Dutch Academy of Sciences. Self-reported characteristics are summarised in Table 1. In total sixty-six questionnaires were completed: forty-six questionnaires with non-pharmaceutical innovations and twenty questionnaires with pharmaceutical innovations. The majority of the respondents were male (88%), had a median age of 56.5 (sd=9.0) years, and a median of 30 (sd=10.1) years of work experience. Most respondents worked in academia (62%) and/or as a health care provider (58%). Respondents could select multiple organisations.

Ranking of medical innovations

In Tables 2 and 3, the relative differences in the scores for each innovation are shown. Innovations are placed in order of their relative importance and scores are ratio-scaled data. For example, self-monitoring of blood glucose (10.46) is perceived almost twice as important as biventricular pacemakers (5.83) and nineteen times more important than deep brain stimulation (0.45).

According to the experts, the non-pharmaceutical innovations (Table 2) that provided most health benefit are self-monitoring of blood glucose (SMBG) followed by biventricular pacemakers, hybrid imaging systems, automatic external defibrillators and portable monitors for home testing of sleep-related breathing disorders. The non-pharmaceutical innovations that have resulted in the least health benefits, according to the experts, are cerebrospinal fluid biomarkers for the diagnosis of Alzheimer's disease, optical coherence tomography, diaphragm pacing system, whole-blood interferon gamma (IFN-gamma) assay for the diagnosis of tuberculosis, and optical position measurement systems.

Table 3 Relative importance of pharmaceutical innovations.



Rank	Attributes	Category	Sqrt (b/w)
1	Biological therapies for autoimmune diseases	Medium ticket, add-on	9.22
2	Bisphosphonates for osteoporosis	Small ticket, add-on	5.15
3	Newer antiviral drugs for hepatitis A/C, influenza A/B, and herpes viruses	Small ticket, add-on	3.87
4	Ranibizumab for age-related macular degeneration	Big ticket, substitute	2.32
5	Genetically engineered vaccines (e.g. HPV vaccine)	Big ticket, new	1.46
6	Newer antifungals (e.g. Voriconazole)	Small ticket, add-on	1.46
7	Newer antithrombotic drugs (e.g. Dabigatran)	Small ticket, add-on	1.12
8	Non-sedating antihistamines	Small ticket, add-on	0.93
9	Drugs for the treatment of erectile dysfunction (e.g. Sildenafil)	Small ticket, add-on	0.85
10	Drugs for non-small cell lung cancer (e.g. Erlotinib)	Big ticket, add-on	0.63
11	Newer antidiabetic agents (e.g. Glitazones)	Small ticket, add-on	0.61
12	Drugs for the treatment of urinary incontinence (e.g. Oxybutynin)	Small ticket, add-on	0.53
13	Newer atypical antipsychotics (e.g. Amisulpride)	Small ticket, add-on	0.44
14	Newer proton pump inhibitors (PPIs) (e.g. Esomeprazole)	Small ticket, add-on	0.44
15	Acetylcholinesterase inhibitors for the treatment of Alzheimer's disease	Small ticket, substitute	0.36
16	Inotropic drug (e.g. Vesnarinone)	Small ticket, add-on	0.16

Description: *N*=20, 320 number of sets. Sqrt is square root. B is the total number of times an innovation was selected as having the most health benefits. W is the total number of times an innovation was selected as having the least health benefits. HPV is human papillomavirus.

Table 3 shows the ranking of the pharmaceutical innovations, ranking biological therapies for autoimmune diseases the highest followed by bisphosphonates for osteoporosis, newer antiviral drugs, Ranibizumab for age-related macular degeneration, and genetically engineered vaccines. Pharmaceutical innovations that have resulted in the least health benefits according to the experts are inotropic drugs followed by acetylcholinesterase inhibitors for the treatment of Alzheimer's disease, newer proton pump inhibitors, newer atypical antipsychotics and drugs for the treatment of urinary incontinence.

SMBG, being the highest ranked non-pharmaceutical innovation, is a small ticket- and potentially a substitute technology in relation to current methods. The second and third highest ranked innovations are big ticket add-on technologies (biventricular pacemakers and hybrid imaging systems). Biological therapies, the highest ranked pharmaceutical innovation, are considered a medium-ticket add-on technology. The second and third highest ranked pharmaceutical innovations are small ticket add-on technologies (bisphosphonates for osteoporosis and newer antiviral drugs).

Discussion

Ranking results in perspective

In the two previous discussed ranking studies [4,5], the highest ranked non-pharmaceutical innovations are magnetic resonance imaging and CT scanning, and balloon angioplasty. This reflects a period in medicine when new imaging devices diffused widely in healthcare systems and it was hoped that these imaging techniques would play a role in reducing uncertainty in diagnostic procedures. Simultaneously there was enormous technological development, for example in the area of interventional cardiology [22]. The highest ranked innovations in the current study, SMBG and biological therapies, may reflect the current focus of healthcare systems in industrialised countries on the management of common diseases in an ageing population. These high ranking innovations aim to prevent, reduce or treat individuals suffering from diseases that are often chronic and degenerative in nature [23]. Although imaging is still highly ranked, ageing and its related developments are gradually moving closer to the patient's home, leading to home therapies with a focus on chronic diseases and comorbidity [24]. Some say that the golden age of imaging has come to an end. Improvements are becoming incremental and in essence are often a modification of existing technology [25].

Medical innovations in an aging population

SMBG and biological therapies relate to chronic diseases such as diabetes and autoimmune disorders for which treatment is costly for the healthcare system. These patients consume more medication and visit a hospital more frequently than those without a chronic disease [26]. In 2010, most health care costs were generated in hospitals [27]. Advanced medical innovations such as SMBG or biological therapies can lead to a reduction in hospital visits [28,29]. SMBG leads to a better metabolic control, hence postpones the onset of chronic complications. This allows for additional savings in treatment costs [30]. However, even though SMBG is a small ticket technology with the potential to decrease health care costs by replacing more expensive technologies, the technique is applied to patients suffering from a high incidence disease. Therefore even with small initial and operational costs, the budget impact will markedly increase if innovations like these are utilised extensively [21].

Biological therapies - genetically engineered drugs derived from substances occurring naturally in the body and produced by the immune system - are add-on and medium ticket technologies with a potential of widening the treatment indication. In 2010, there were as many as 250 different biologics on the market [31]. Adalimumab and Etanercept ranked number 1 and 2 on a list of the top 100 pharmaceuticals in 2010 with €185 million being spent on Adalimumab and €158 million on Etanercept [32]. It has been proposed that biologics should be assessed at an early stage involving different stakeholders in order to jointly estimate the costs and benefits. Consequently prices can be set according to performance once there is market acceptance and this way availability of biologics would be guaranteed [31]. In the meantime however, the Dutch Ministry of Health has decided to alter reimbursement of biologics due to their high budget impact; hospitals currently need to pay for these themselves. It is expected that this leads to more appropriate prescription [33].

Study limitations

It was attempted to elicit the relative importance of medical innovations of the past decades in relation to Dutch public health with the objective to provide input to the debate about the added value of medical innovations. In a ranking study such as this one, that of Fuchs and Sox [4], and of Athanasakis et al. [5] dissimilar objects were compared, as medical innovations are highly heterogeneous in their working mechanism and application. This poses challenges to the methods that were used. Methods were carefully selected for this study and described as transparent as possible, albeit some arbitrary, to clarify the choices that have been made. Nevertheless, there are drawbacks in the application and careful interpretation of results is warranted.

Methods of the ranking study in perspective

Compared to the previous two ranking studies [4,5], we aimed to be more transparent in the identification, selection and ranking of innovations. However, it does not exclude the probability of investigator bias being introduced after applying the filter criteria. Categorising the innovations was difficult due to the use of ambiguous definitions in the literature and the lack of operationalisation. The technology's categorisation did not play a role in the ranking exercise but was added to provide extra information to the analysis, about the technology's type, its impact on resource use, and relation to existing technologies. Methods of categorisation were selected on pragmatic grounds. A systematic consensus method to obtain unequivocal categorisation was preferred and would have been more valid but was not feasible within the restricted time frame of 7 months for this study. Therefore the

categorisation of the medical innovations can be arguable and may differ when the study is repeated. In 27% of innovations there was disagreement about whether it was a small or medium ticket technology, and in 22% whether an innovation was new, add-on or substitute. In relation to our conclusions based on the categorisation we believe that the amount of innovations that are add-on and not substituting existing health technologies holds, and therefore also our conclusion that a majority of innovations in the past two decades have only marginal health benefit. We also believe that categorising health innovations in these terms could support policy makers at a macro-level to get a better grip on what type of innovations are preferable to regulate. For this purpose, more clearly operationalised definitions would have to be developed on the basis of consensus.

Choice of respondents and sampling method

In these types of studies, a trade-off must be made between generalists and specialists. Specialists in one clinical area cannot relate to all the different options for different medical problems, whereas generalists might be too generalist to manage. For this study the perspective of generalists was taken. Various organisations were asked to point out experts with either a clinical or policy perspective that could relate to the study question. For the Netherlands, this deemed to be the right sample of respondents. This was supported by the commissioning agency (RIVM), which has a long-standing tradition in advising on the value of health technology to the Dutch government. Using a snowball sampling method poses challenges. Firstly, it is based on the assumption that the organisations and experts affiliated with these organisations would know suitable candidates. This might not always have been the case. Secondly, it was not feasible to record the snowball effect - that is who was invited by the experts themselves to participate in the study - and therefore a response rate could not be calculated. Those who completed the questionnaire had a median of 30 years of work experience, matching our desire to select experts with a long work experience in health care. However, the rationale behind this approach fails to meet its end when the number of useable responses is low. Possible reasons are the difficulty or the length of the questionnaires. Due to the small sample size no subgroup analysis could be conducted for example to explore for preference heterogeneity related to e.g. work experience and workplace.

Ranking method

In this study BWS was used, which enables pair-wise ranking instead of standard ranking. Respondents were asked to select the innovations they perceive as having the most and least health benefit for patients and to keep the patient population in mind. Fuchs and Sox [4] stated that comparing and ranking different innovations is complex and challenging for clinicians due to potential differences in health outcomes. For example, grouping technologies by diseases (e.g. autoimmune diseases) versus a single disease (e.g. non-small cell lung cancer) could have affected their position on the ranking. Similarly, the uncertainty of for example diagnostics could also affect the ranking, and despite defining health benefit this might have been conceived as being ambiguous. Yet, the survey was piloted and led to only minor textual changes. Although it was expected that ranking through BWS would be easier compared to standard ranking, as indicated in the literature, 58% of the respondents who finished the questionnaire still thought that the survey was difficult to complete. There was no statistical significant difference between the difficulty and the type of questionnaire (Fisher's exact test, 0.324). The number of responses that was useable was low and we included only those that were completed. Several experts explained that they found it difficult to weigh health benefits related to a specific innovation and make comparisons of different innovations, and simultaneously consider the population size. Similar to Fuchs and Sox, 'We are well aware of the complexity of the question we posed to the survey population'. As we were aware of this problem, we preferred BWS in comparison to standard ranking as we thought this would make the task easier for the respondents and therefore less prone to errors. This indicates that not only the ranking method itself but also the sampling method to identify experts is crucial for the outcomes. A large pool of experts with a helicopter view on medical innovation is hard to realise and is one of the critical factors for a valid ranking exercise. Having experts complete both questionnaires would have been interesting for the analysis but this would have been cognitively too burdensome for the respondents. It seems that measuring the relative importance of medical innovations remains difficult to determine with any of the available methods.

Conclusions

Despite the limitations, the categorisation and ranking of innovations as applied in this study are believed to provide additional valuable information if the results are used to inform decisions regarding more in-depth studies on the role of medical innovations on health and health care costs, or in planning appropriate use of technologies. However, additional research taking the study limitations into account is required to provide more robust policy recommendations.

This study identified a minority of new and substitute technologies. The majority of the highest ranked innovations were add-on technologies. These do not offer new treatment opportunities and often lead to increased health care cost at marginal health benefit [19]. According to Christensen, "new technologies could deliver tremendous value, when embedded in disruptive business models, that capitalise on increased convenience and affordability" [34]. The experts' high ranking of a small ticket substitute technology such as SMBG can therefore be considered as a positive sign. SMBG is an example of a potentially disruptive innovation: cheaper, simpler or more convenient products or services that ultimately result in fewer and less expensive professionals providing sophisticated services in affordable settings [35]. To realise its potential in terms of value for money potential in the appropriate setting, the right policies need to accompany its adoption.

Knowledge on the estimated benefit of the new technology is required before widespread use in healthcare in order to provide guidance to professionals and patients. HTA is a frequent applied policy-tool but often carried out at a time

that many crucial decisions have already been made for example by product developers and manufacturers in the research and development (R&D) process, which will affect whether a technology provides added value [36]. IJzerman and Steuten [36] propose a model for (very) early HTA based on different quantitative methods for consecutive decision moments in the R&D process [36]. If innovations are assessed in the stage before major investments are made, when there is enough time to make significant changes, it may be possible to prevent the adoption of medical innovations with marginal health benefit.

Author statements

Funding

The study was financially supported by the National Institute for Public Health and the Environment (RIVM) in the Netherlands.

Competing interests

The authors declare that they have no competing interests.

Ethical approval

Not required

Author contribution

JMF designed the study, conducted the analysis and drafted the manuscript. KHPD designed and supervised the study and drafted the manuscript. HC and MJIJ co-supervised the study and helped to draft the manuscript.

Acknowledgements

The study was financially supported by the National Institute for Public Health and the Environment (RIVM) in The Netherlands.

References

[1] Costa-Font J, Courbage C, McGuire A. The Economics of New Health Technologies: incentives organization and financing. Oxford University Press; 2009.
[2] Blumenthal D, Stremikis K, Cutler D. Health care spending – a giant slain or sleeping? New Engl J Med 2013;369(26):2551–7. PubMed PMID: 24369080.
[3] J. D. Strategic Research RIVM 2011—2014. Project summaries. National Institute for Public Health and the Environment, 2011 Contract No.: RIVM Report 000201101.
[4] Fuchs VR, Sox HCJ. Physicians' views of the relative importance of thirty medical innovations. Health Aff (Millwood) 2001;20 (5):30–42. PubMed PMID: 11558715. Epub 2001/09/18. eng.
[5] Athanasakis K, Konstantinou E, Thireos E, Kyriopoulos J. The relative value of medical innovations on population health status. Physicians' views in Greece. Arch Hell Med 2010;27 (6):963–9.
[6] Banta HD, Luce BR. Health care technology and its assessment: an international perspective.Oxford University Press; 1993.
[7] Fermont JM, Douw KHP, Vondeling H, IJzerman MJ. Ranking of medical innovations based on their perceived health impact. A background study. Health Sciences Series (HSS) 12-0082012.
[8] Flynn TN. Valuing citizen and patient preferences in health: recent developments in three types of best-worst scaling. Expert Rev Pharmacoecon Outcomes Res 2010;10(3):259–67. PubMed PMID: 20545591. English.
[9] Flynn TN, Louviere JJ, Peters TJ, Coast J. Best–worst scaling: What it can do for health care research and how to do it. J Health Econ 2007;26(1):171–89. PubMed PMID: Medline:16707175. English.
[10] Cohen S, Markowitz P, editors. Renewing market segmentation: some new tools to correct old problems. Amsterdam, the Netherlands: ESOMAR; 2002.
[11] Street D, Street AP. Combinatorics of experimental design. Oxford: Clarendon; 1987.
[12] Lancsar E, Louviere J. Conducting discrete choice experiments to inform healthcare decision making: a user's guide. Pharmacoeconomics. 2008;26(8):661–77. PubMed PMID: 18620460. Epub 2008/07/16. eng.
[13] Marley AA, Louviere JJ. Some probabilistic models of best, worst, and best–worst choices. J Math Psychol 2005;49:464–80.
[14] Spekowius G, Wendler T. Advances in Health care Technology Care Shaping the Future of Medical Care. Dordrecht: Springer; 2006.
[15] Straus EW, Straus A. Medical Marvels. The 100 Greatest Advances in Medicine. 1 edPrometheus Books; 2006.
[16] Queijo J. Breakthrough! How the 10 Greatest Discoveries in Medicine Saved Millions and Changed Our View of the World:. FT Press Science; 2010.
[17] Cleveland Clinic. Top 10 Medical Innovations: 20122011:[1-23 pp.]. Available from: ⟨⟨http://www.clevelandclinic.org/innovations/summit/top-ten-innovations/2012.html⟩⟩.
[18] Battista RN. Innovation and diffusion of health-related technologies. A conceptual framework. Int J Technol Assess Health Care 1989;5(2):227–48. PubMed PMID: Medline:10303488. English.
[19] Cutler DM, McClellan M. Is technological change in medicine worth it? Health Aff. (Millwood) 2001;20(5):11–29. PubMed PMID: 11558696. Epub 2001/09/18. eng.
[20] Simpson S. HJ, Gutierrez-Ibarluzea I, Kearney B, Norderhaug I, Fay AF, Packer C, et al. A toolkit for the identification and assessment of new and emerging health technologies. Birmingham: EuroScan; 2009. Contract No.: ISBN: 0704427257/ 9780704427259.
[21] Johansen KS, Racoveanu NT. Big ticket health technology: is rational utilization possible? Med Prog Technol 1991;17 (2):85–91. PubMed PMID: 1835754. English.
[22] Sonderegger-Iseli K, Burger S, Muntwyler J, Salomon F. Diagnostic errors in three medical eras: a necropsy study. Lancet 2000;355(9220):2027–31.
[23] Organisation for Economic Co-operation and Development (OECD). Improving Value in Health Care. Measuring quality; 2010 Contract No.: ⟨issn:2074-319X⟩ (online).
[24] Arnrich B, Mayora O, Bardram J, Troster G. Pervasive healthcare: paving the way for a pervasive, user-centered and preventive healthcare model. Methods Inf Med 2010;49 (1):67–73. PubMed PMID: 20011810. English.
[25] European Science Foundation. Medical Imaging for Improved Patient Care. Science Policy Briefing [Internet]. 2007; September 2007(28):[1—8 pp.]. Available from: ⟨http://www.esf.org/fileadmin/links/EMRC/ESF_POLICY28_V09_HD.pdf⟩.
[26] Zhang P, Zhang X, Brown J, Vistisen D, Sicree R, Shaw J, et al. Global healthcare expenditure on diabetes for 2010 and 2030. Diabetes Res Clin Pract 2010;87(3):293–301. PubMed PMID: 20171754. English.
[27] Health Accounts, expenditure (in current and constant prices) and funding. (Zorgrekeningen; uitgaven (in lopende en constante

prijzen) en financiering). [Internet]; 2010. Available from: ⟨⟨http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=71914ned&D1=0-23&D2=a&HDR=G1&STB=T&VW=T⟩⟩.

[28] National Institute for Health and Clinical Excellence (NHS). Costing statement: ustekinumab for the treatment of adults with moderate to severe psoriasis. NHS; 2009.

[29] Giaccari A, Grassi G, Ozzello A. Self-monitoring of blood glucose: guideline application rather than utilization restrictions on testing strips has potential to reduce diabetes healthcare costs in Italy. Diabetes Technol Ther 2012;14(10):862–7.

[30] St John A, Davis WA, Price CP, Davis TME. The value of self-monitoring of blood glucose: a review of recent evidence. J Diabetes Complicat 2010;24(2):129–41. PubMed PMID: 19230717. English.

[31] Van Herwaarden CLA. Everything you want to know about biologics (Alles wat u wilt weten over biologicals). ILD Care Today 2010:10–7.

[32] Top 100 drugs based on the total cost in 2010 (Top 100 van geneesmiddelen o.b.v. de totale kosten in 2010) [Internet]; 2010 [cited April 2012]. available from: ⟨http://www.gipdatabank.nl/⟩.

[33] Sint Maartenskliniek. Reimbursement of expensive rheumatic drugs changes in 2012 (Vergoeding dure reumamiddelen verandert in 2012); 2011 [April 2012]. available from: ⟨http://www.maartenskliniek.nl/nieuws/actueel/andere-vergoeding-biologicals/⟩.

[34] Hwang J, Christensen CM. Disruptive innovation in health care delivery: a framework for business-model innovation. Health Aff 2007;27(5):1329–35.

[35] Christensen C. Health care: the simple solution. When it comes to reform, we should drop the public-private debate. The way to cut costs is to put care and insurance in the same bed. Bloomsberg Businessweek; 2010, March 4. Sect. Outside shot.

[36] IJzerman MJ, Steuten LMG. Early assessment of medical technologies to inform product development and market access. A review of methods and applications. Appl Pharmacoecon Policy 2011;9(5):331–47.