Research Impact of the Dutch University Medical Centers 2024

Bibliometric analyses of the scientific and societal impact by CWTS and NFU

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Authors

R. Iping, MSc – Senior advisor Research Intelligence & Strategy, Erasmus MC University Medical Center
M.E. Kroon, PhD – Senior advisor Research Policy, Leiden University Medical Center
B.W.A. van der Strate, PhD – Head Research Office, University Medical Center Groningen
T.N. van Leeuwen, PhD – Senior Researcher, Centre for Science and Technology Studies (CWTS), Leiden University

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NFU Preface

The mission of the University Medical Centers (umcs) in the Netherlands is to continuously strive for improved health outcomes for all. This endeavor is made possible by our unique integration of research with education and patient care and, increasingly, valorization.

Our research is performed with regional, national, and international partners, in both science and practice, which enables a translation of knowledge into impact. Along with the scientific impact, the report highlights the far-reaching societal and economic impact of the research conducted by the umcs across a multitude of domains. This includes impact by our involvement in clinical guidelines, health policy, patents, media, collaboration with non-academic partners, and our contributions during the COVID-19 pandemic.

The findings presented in this report, 'Research Impact of the Dutch University Medical Centers', underscore the significant scientific influence of the umcs, positioning them alongside leading international institutions. Each umc assumes a distinct and prominent role in advancing research, collectively covering a broad spectrum of topics within the biomedical and health sciences, including public health.

Efficient and widespread dissemination of knowledge is regarded as a priority by the umcs, with a particular emphasis on Open Science principles, advocating for unrestricted access to research findings and optimal utilization of research data.

Notably, by 2022, 87% of the umcs' scientific publications was openly accessible. This openness contributed to the swift dissemination of knowledge during the COVID-19 pandemic and to engaging a broader audience in general.

On behalf of the NFU, I invite you to explore the different dimensions of umc research and impact covered in this report, which underscore the prominent role of the Dutch umcs in shaping the future of health.

Prof. dr. Wiro Niessen, Dean of University Medical Center Groningen

Management summary

This report provides a bibliometric analysis to provide insight into the scientific, clinical, and societal impact of research conducted by Dutch University Medical Centers (umcs) until 2023. The results of the analyses show the notably high scientific impact of umc publications compared to similar institutions worldwide. Each umc consistently ranks among the top institutions in the biomedical field in Europe and the United States, in terms of quantity and quality of the research output, demonstrating their strong international scientific position.

Within the umcs, a rich variety of research domains can be distinguished, which encompass fundamental, clinical, and health sciences, as can be observed from the research landscape maps provided in this report. Such a broad range of activities is a prerequisite for the translation of research from bench to bedside and its subsequent impact on the public, a strength of the Dutch University Medical Centers.

This report covers a period dominated by research performed during the COVID-19 pandemic, which had profound effects on the research community. Also, contributions by the umcs have had a large impact on the COVID-19 research, playing a crucial role in addressing the challenges posed by the pandemic. The COVID-19 period highlighted the importance of effective communication and dissemination of research, exemplified by collaborative efforts within the scientific community, including fast-track peer reviews, preprints, and open data sharing.

The commitment to Open Access (OA) publishing within the umcs has grown steadily, increasing from 70% in 2018 to 87% in 2022. Open Access aims to provide direct access to research findings for the purpose of sharing results and facilitating further research.

The report also uses bibliometric analyses to visualize the collaboration of the umcs, at both the national and the international level. These analyses show that researchers and clinicians collaborate not only within their own institutes but also with stakeholders in the national healthcare system and prominent international institutions. Such collaborations ensure the impact of umc research contributes not only to scientific progress, but also to meaningful advancements in clinical practice, healthcare policies, and societal well-being. Each umc has a special relation with partners in their own region, sharing distinct expertise and skills.

Funding acknowledgments in umc publications reveal a higher frequency of external funding sources compared to the global average, indicating the success of umc researchers in securing external support. Collaboration with industry is evident in the citation and use of umc publications in patent applications, demonstrating economic impact, particularly in the fields of pharmaceuticals and biotechnology.

The umcs actively invest in research infrastructure, including large-scale cohorts and major international clinical trials. The growing magnitude and significance of research based on data from these initiatives can also be observed from the bibliometric analyses.

In summary, bibliometric analyses show the strong position of the umcs internationally. This contributes to the enhancement of our fundamental understanding of diseases, diagnostics, healthcare systems, and overall population health, and thus is a strong driver for socioeconomic impact.

Introduction

Purpose of this report

The purpose of this report is to showcase the impact of the Dutch University Medical Centers, by performing sophisticated bibliometric analyses. In these type of analyses, metadata of scientific publications are studied to assess scientific impact (on peers), societal impact, and economic impact. Bibliometry can also be used to characterize research and shed light on specific themes of importance.
This comprehensive report describes all the analyses that were performed, and the interpretation of the information. Its target readership includes the umc boards, policy makers, researchers, and other interested parties. Parts of this report will be published on the NFU website to address a broader audience.

This report constitutes the second edition in its current format, following the initial Research Impact study of Dutch University Medical Centers (umcs) conducted three years ago. This follow-up emerged in response to earlier analyses primarily centered on traditional bibliometrics.

The methods and approach employed in this report remain pioneering, offering a multidimensional perspective on mapping of research impact. Aligned with contemporary developments in science evaluation, particularly Recognition & Rewards, responsible evaluation, and Open Science, these methodologies acknowledge the value of such developments.

First, it is important to mention some of the key developments and peripheral factors that have been, and still are, of great influence on our research in the period this report covers.

Research in the era of COVID-19

The period studied in this report reflects a tumultuous time for both society and the Dutch umcs, primarily shaped by the unprecedented COVID-19 pandemic. This global crisis not only significantly impacted society, but also brought about profound changes in research dynamics. Numerous researchers swiftly redirected their focus to investigate various aspects of the pandemic, spanning molecular mechanisms of the virus,

treatment modalities, and the societal implications, including mental well-being and rehabilitation. In a short span, an extensive body of knowledge was generated and disseminated through collaborative efforts within the scientific community, emphasizing rapid publishing and the adoption of new channels such as preprints. This report dedicates special attention to the COVID-19 pandemic, showcasing the substantial scientific impact of Dutch research in this domain. Additionally, the analyses on societal impact underscore the influence of umc research on policy documents, clinical guidelines, and news media.

A unique position

Umcs operate at the intersection of patient care, research, and education, forming a unique ecosystem where these core tasks mutually influence and benefit each other. The direct translation of patient and clinician experiences into research questions is facilitated, and research outcomes directly inform clinical practice, education programs, and societal developments. The umcs encompass fundamental and health sciences along with clinical sciences. This report underlines the pivotal role of biomedical research as the foundation for understanding diseases, including their molecular and genetic structures. The integration of health sciences within the umcs ensures that research extends to healthcare system dynamics, healthcare delivery, general practice, prevention, lifestyle, and screening programs, becoming an integral part of the broader healthcare system. Collaboration remains a cornerstone, with regional, national, and international partnerships across diverse sectors, including hospitals, government bodies, research institutions, funders, and companies.

Research as a key to the future Amidst increasing healthcare costs and limited personnel availability, research emerges as a key driver for continuous improvement in the healthcare system. The umcs invest in research areas such as efficiency, cost-effectiveness, telemonitoring, prevention, and technological innovations, aligning with the goals outlined in the Dutch Integral Care Agreement (IZA). The increasing momentum in these research areas is evident in the research topic maps presented in this report.

Structure of this report

This report is structured as follows: Chapter 1 explores the scientific impact of umc research using more traditional bibliometric analyses. In chapter 2 onwards, novel analyses are used to focus on other forms of impact, starting with a umc research landscape visualization. Chapter 3 covers the societal impact of umc publications. Chapter 4 delves into trends in open access to umc publications, followed by an examination of scientific collaborations in Chapter 5. Chapter 6 presents an analysis of funding acknowledgements, while Chapters 7 and 8 focus on the use of clinical trial and cohort data in umc publications and the citation of publications in patent applications, respectively.

1 Scientific Impact

There are numerous ways in which research can make a significant impact. Scientific impact, based on how scientific articles are being cited by peers, is one way to represent this. Citations are a form of acknowledgement of the relevance, importance, or influence and visibility of previous research.

The figures and tables presented in this section show frequently used bibliometric indicators to measure and compare the scientific impact of publications. For more detailed information on the bibliometric methodology, and other methodological choices, see the document entitled 'Explanation of the bibliometric methodology of CWTS'.

The scientific impact of Dutch umcs

The graph below *(Figure 1)* shows the development of the Mean Normalized Citation Score (MNCS) for all umcs over time. The MNCS is the accumulated impact score of all publications of a umc from a certain period. For each individual publication, the number of times the paper is cited is compared against the average number of citations of all publications on the same research topic from the same year. A score of one represents the world average. A score of two implies that a publication is cited twice as often as the world average. The MNCS of the Dutch umcs range between 1.6 and 1.9, reflecting an impact far above the world average.

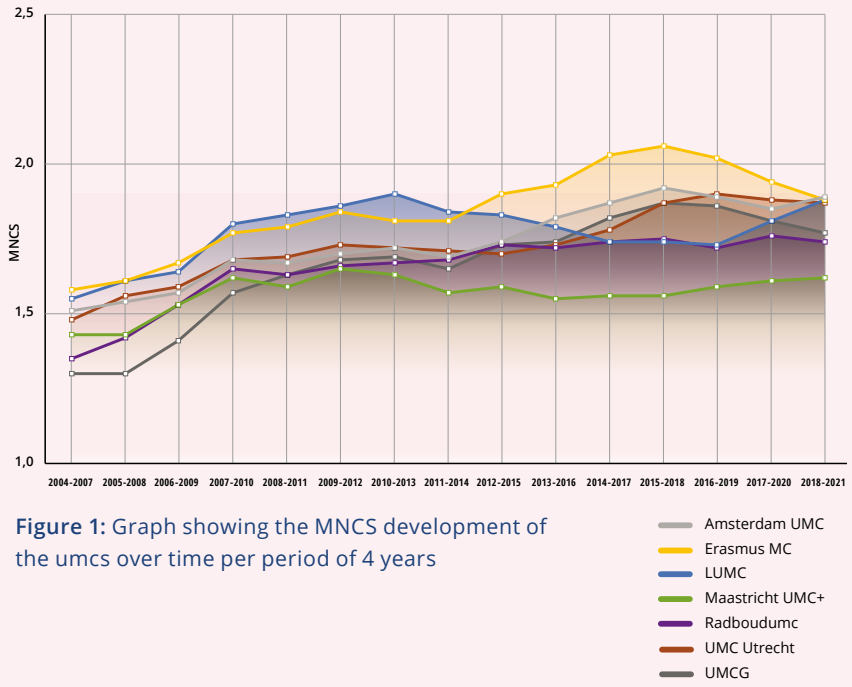

Figure 1: Graph showing the MNCS development of the umcs over time per period of 4 years

Besides MNCS, PP (top10%) is another important bibliometric indicator. This indicator shows the percentage of publications of a umc belonging to the top 10% of most cited papers in their research cluster in the same year of publication. The development of this indicator per umc is shown in figure 2. The PP (top10%) impact scores of all umcs vary between 18% and 21%, demonstrating an overall very high impact, almost twice as much as expected (namely 10%) of the total body of publications originating from the umcs.

Taking the presented indicators MNCS and PP (top10%) into account, the conclusion can be drawn that the scientific impact of umc publications is high compared to the world average. Later in this chapter, this scientific impact is compared with similar scientific institutes in Europe and the United States.

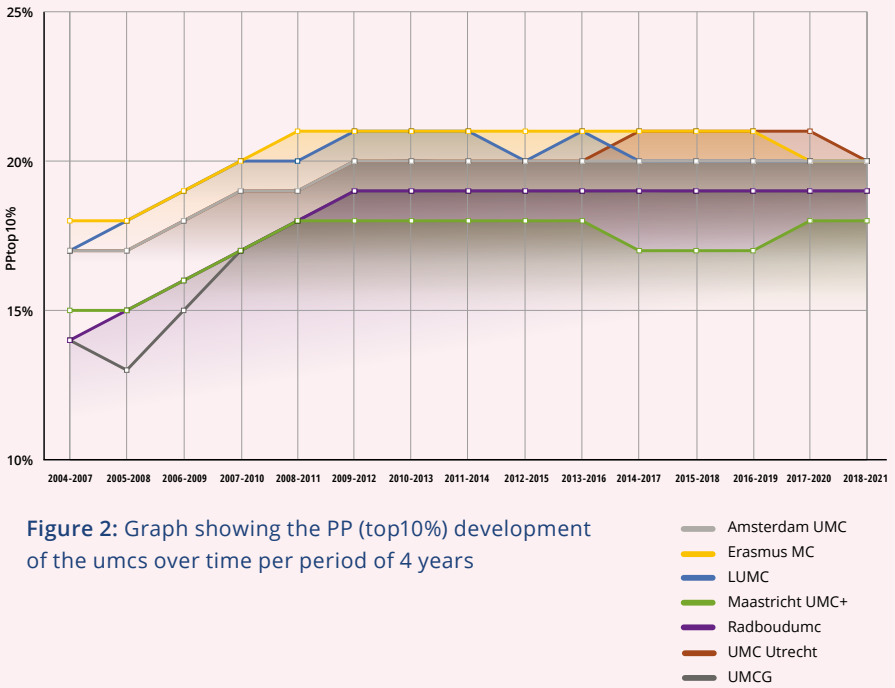

Figure 2: Graph showing the PP (top10%) development of the umcs over time per period of 4 years

Overview of main bibliometric indicators

Tables 1 and 2 show an overview of bibliometric indicators for the individual umcs for the period 2018 – 2021 (citation period up and including 2022), and the development of the same bibliometric indicators for the publications of all umcs combined over time. It is evident that over time the volume of research output is rising, while the impact measured by both bibliometric indicators remains stable.

Period 2018-2021/2022	# Publications	MNCS	PP (top10%)
Amsterdam UMC	25762	1.89	19.9%
Erasmus MC	14615	1.88	20.2%
LUMC	10645	1.88	20.4%
Maastricht UMC+	11878	1.62	17.9%
Radboudumc	12679	1.74	18.9%
UMC Utrecht	10439	1.87	20.4%
UMCG	12866	1.77	18.9%

Table 1: Overview of main bibliometric indicators of individual umcs for 2018-2021/2022

All umcs combined	# Publications	MNCS	PP (top10%)
2013 – 2016	61574	1.68	19.1%
2014 – 2017	63910	1.72	19.1%
2015 – 2018	67012	1.75	19.1%
2016 – 2019	68332	1.74	18.9%
2017 – 2020	71020	1.73	19.0%
2018 – 2021	75326	1.73	18.9%

Table 2: Overview of the main bibliometric indicators for umcs combined over time

International outlook

To establish a benchmark from an international perspective, bibliometric indicators were compared with several renowned scientific institutions in the biomedical and health sciences in Europe and the United States (US), which were selected according to the volume of their scientific output. For this comparison, publications from 2016-2021 were used that can be assigned to the biomedical field, based on the cluster they were published in. Affiliations were subsequently used to link those publications to the correct institutions. Most institutions in Europe and the US do not share the same organizational structure, in which the university medical center is a distinct and separate entity from the university. Therefore, the output of European and American universities active in the biomedical field was used as a proxy for their associated medical centers to be able to compare publication and citation-impact scores.

Figures 3 and 4 show the mean normalized citation score and PP (top 10%) of the Dutch umcs and the top European universities in the biomedical field on the vertical axis, and the number of publications per institute on the horizontal axis.

Irrespective of the volume of their output, all Dutch umcs are amongst the highest in Europe based on their scientific impact (both MNCS and PP (top10%)).

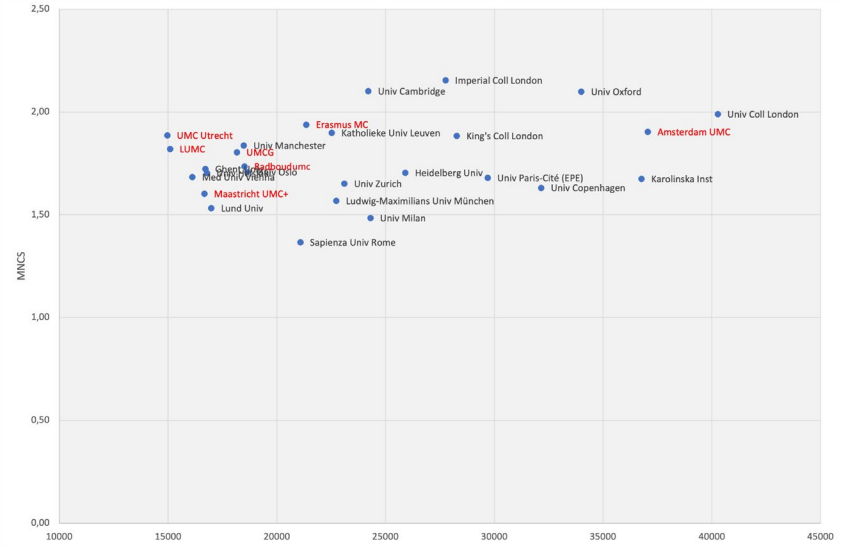

Figure 3: Output compared to impact (MNCS), Dutch umcs and the top 20 European universities active in the biomedical field, 2016 - 2021

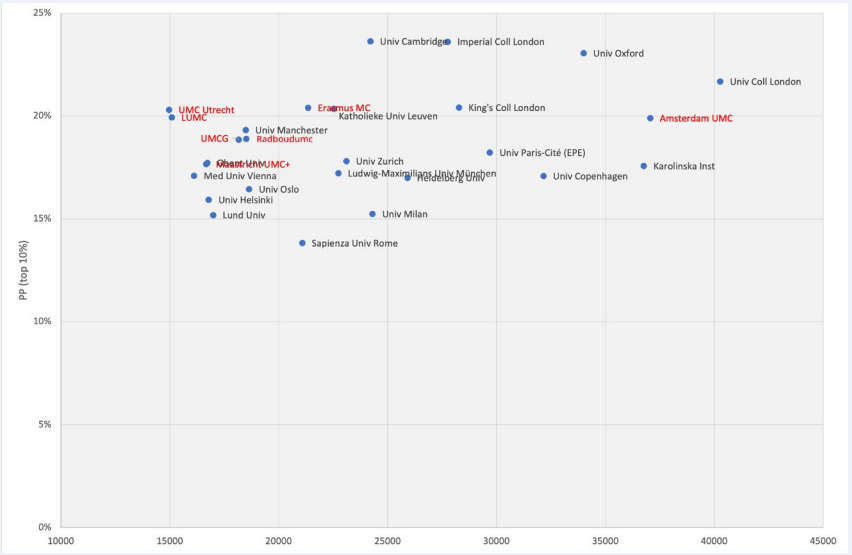

Figure 4: Output compared to impact (PP (top 10%)), Dutch umcs and the top 20 European universities active in the biomedical field, 2016 - 2021

Figures 5 and 6 show the mean normalized citation score and PP (top10%) of the Dutch umcs and the top US universities in the biomedical field on the vertical axis, and the number of publications per institute on the horizontal axis. US institutes active in the biomedical field have a significant publication output, also reflecting the enormous investments in biomedical research.

Based on publication volume, Europe and the United States can hardly be compared. Nonetheless, it can be concluded from figures 5 and 6 that Dutch umcs can compete with some of the largest US institutions in the field in terms of scientific impact.

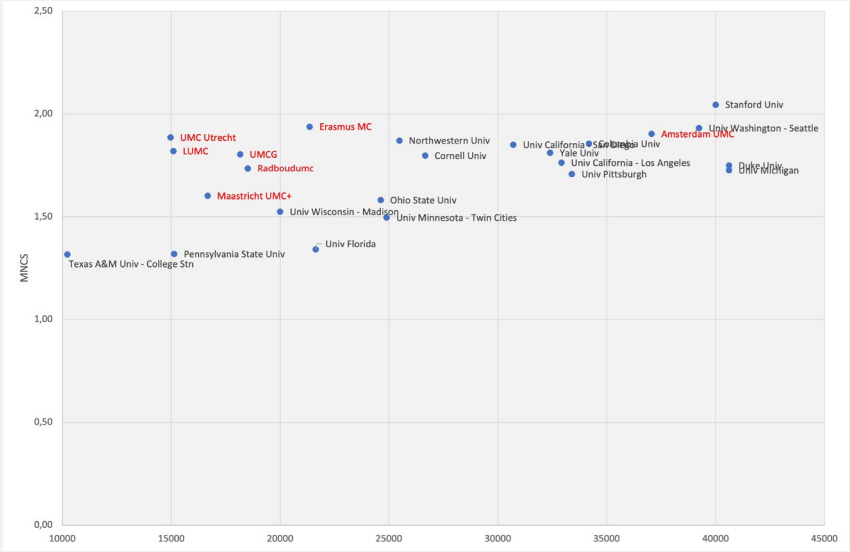

Figure 5: Output compared to impact (MNCS), Dutch umcs and the top 20 US universities in biomedicine, 2016 - 2021

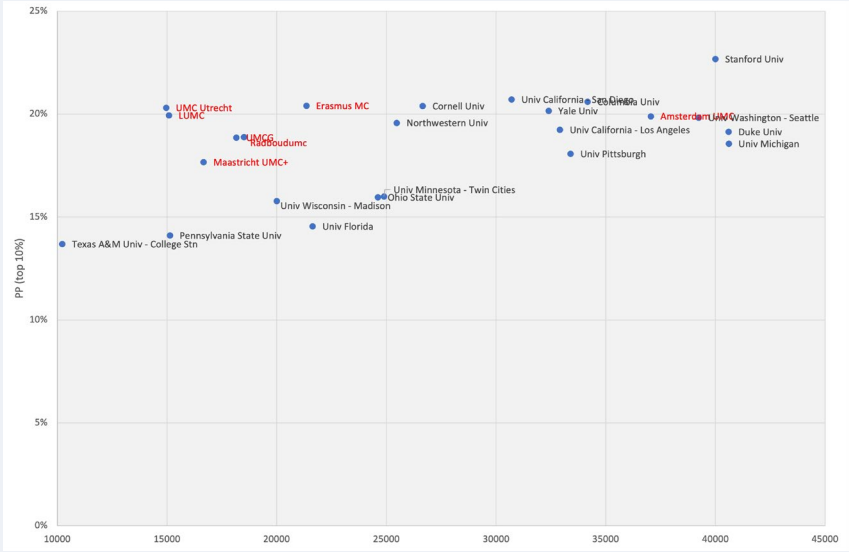

Figure 6: Output compared to impact (PP (top10%)), Dutch umcs and the top 20 US universities in biomedicine, 2016 - 2021

Based on the presented analyses of scientific impact, it can be concluded that research performed within the Dutch umcs measures up to the impact of leading biomedical institutes in both Europe and the US, and this stresses their leading international role in the field of (bio)medical research.

2 Research landscape

The umcs conduct clinical and pre-clinical research within a multitude of research fields. To get an overview of the research landscape in which the umcs operate, an analysis can be performed based on frequently occurring key terms that appear in the titles and abstracts of high-impact publications. This method provides a good visualization of the major themes that the umcs focus on, as well as the connections between different fields, including both fundamental and clinical research.

The visualization below displays a research landscape featuring frequently occurring key terms (extracted from titles and abstracts) found in high-impact scientific papers (affiliation to Dutch umcs) from 2021. Only publications within clusters (see the separate document titled 'Explanation of the bibliometric methodology of CWTS') with over 15 papers in one year were included, and clusters with a joint mean normalized citation impact score higher than 1.5 (i.e. 50% higher than the global average). Given these methodological choices, certain subjects may not be represented due to the broad spectrum of research domains encompassed by the umcs. For example, studies on rare diseases typically exhibit a lower publication count due to their highly specialized nature and, consequently, may not be prominently featured in this form of visualization.

The size of the spheres in Figure 7 indicates the number of occurrences of a term. The position of the terms shows their relatedness and co-occurrence on the same papers. The seven colors roughly indicate major research clusters in the Dutch umc landscape.

These seven main research themes can be discerned within the research performed by the umcs: Fundamental research, its translation towards clinical and societal applications, clinical disease-related research, diagnostics, methodology, public health, and prevention. Within these themes, the colored clusters in the map are described below.

On top in **yellow**, the terms indicate oncological research, varying from more clinically oriented research on the left (treatment and diagnostics) to fundamental tumor research on the right (cellular and immunological), hence the close location to the red cluster.

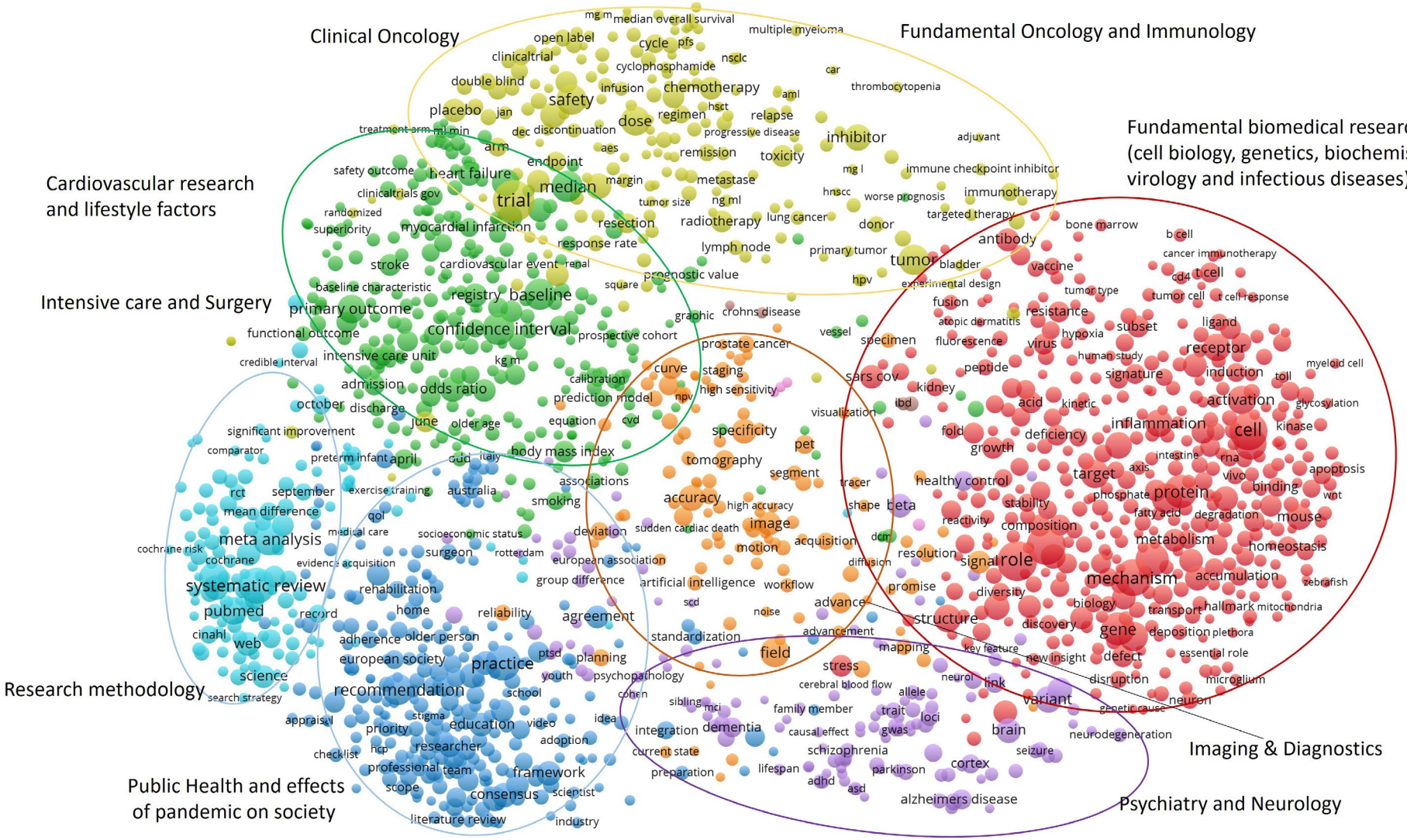

Figure 7: Map showing key terms in the high-impact scientific publications of the Dutch umcs from 2021

The **red** cluster describes much of the fundamental biomedical research performed by the umcs, such as genetics, cell biology, virology, and biochemistry. The high level of activity of the umcs in this cluster shows the great importance of fundamental biomedical research as the foundation for more translationally oriented research. On the left side of this cluster, towards the center of the graph, the term 'sars-cov' is seen, representing all research in this period focused on the coronavirus pandemic. This is a newly emerging term and reflects the rapid response by research during the COVID-19 pandemic and the swift rise of citations for this subject. The term is pulled towards the center of the graph because COVID-19 research has been important/performed in most of the other clusters as well: the implications of COVID-19 for clinical practice and treatment, pandemic management, and implications for society (in the blue cluster on the bottom left).

The term is part of the red cluster, implying that most of the umc COVID-19 research was more fundamentally virologic in nature, although links to the other research areas are readily visible. In the next section, a more detailed analysis of umc research activity in COVID-19 will be presented.

In **purple** on the bottom right of the visualization, more fundamentally oriented neuroscientific research is shown, gradually shifting to psychiatric disorders towards the left. In the middle, some terms relating to lifestyle factors are observed. These factors are often studied in relation to mental health, cardiovascular diseases, infectious diseases, oncology, and public health. They are pulled towards different sides of the entire research spectrum and therefore are displayed in the middle of the figure.

In the middle of the figure in **orange**, a new cluster is observed compared to the previous analyses. This cluster focuses predominantly on imaging techniques in different diseases. Interestingly, artificial intelligence is visible as a new term.

On the bottom left, in **dark blue**, a cluster is formed that focuses on societal health issues and ageing and pandemic society interactions. In **light blue**, a focus on research methodology can be observed. This was also visible in the previous report, and research on methodology remains an important aspect of biomedical research.

Finally, the **green** cluster focuses on cardiology research, ranging from specialized treatments (in patient trials) to broad cardiovascular risk studies (cohorts).

COVID-19 research

Since the outbreak of the COVID-19 pandemic, the umcs have invested a significant amount of time and resources in research on various aspects of the virus outbreak, as demonstrated by a significant body of research articles published on this topic, making it a distinct development that deserves further analysis. COVID-19 research encompassed molecular virological investigations into the origin, transmission, and operation of the virus, as well as clinical treatments and the study of societal effects.

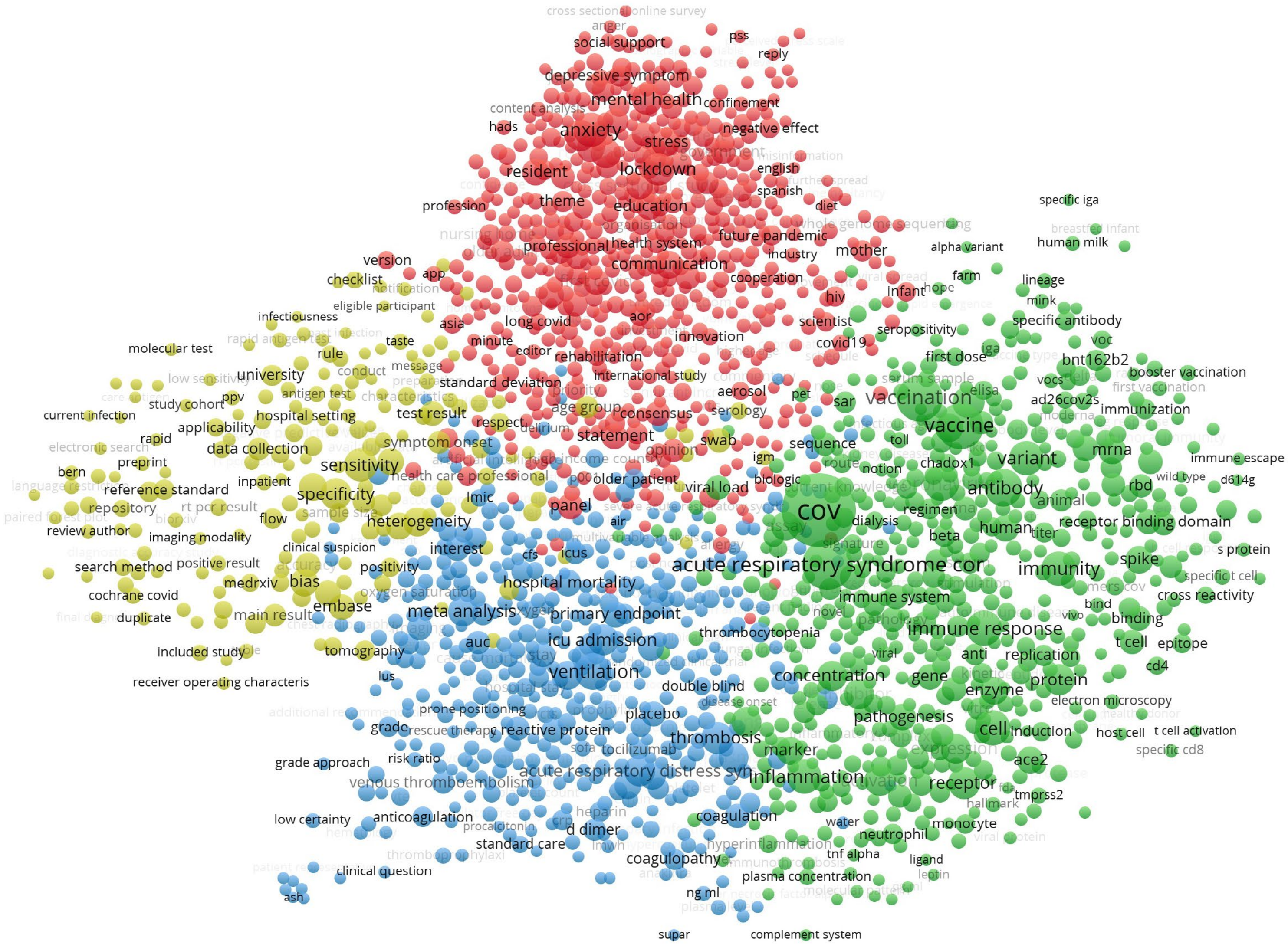

Figure 8: Term map showing the most important themes in umc COVID-19 publications (2020 - 2022)

At an exceptionally rapid pace, an extensive amount of research was initiated and conducted, with researchers communicating their findings to their peers and society through scientific publications. This research played a crucial role in rapidly adapting clinical practices, the way COVID-19 patients were treated, and the development of vaccines and medications. Additionally, umc researchers have made substantial contributions to informing the public based on the most recent research results, influencing national COVID-19 policies accordingly *(see also figure 27)*. Between 2020 and 2022, over 4,244 scientific articles on COVID-19 were published by the Dutch umcs (of a total of 67,797 publications; 6%). These COVID-19-oriented publications had a substantial scientific impact, as the citation impact, expressed in an MNCS of 2.4, is 140% above the worldwide average impact level, and their presence in the top of the fields to which the publications belong, expressed in a PP (top10%) of 26%, is 16% above the expected 10% value. Figure 8 presents a visualization of the most common terms in the COVID-19 research publications from the umcs.

In **green**, mostly fundamental molecular virology and immunological research can be observed, which has been essential in understanding the mechanisms and structure of the virus. The **blue** cluster focusses on clinical research on disease characteristics, progression, and treatment of COVID-19 patients in the ICU and complications during treatment. The **Red** cluster describes population and public health research into the effects of the pandemic on society. Finally, the yellow cluster describes epidemiologic research and research methodology.

3 Societal Impact

In this section, examples of the societal impact of umc publications are highlighted. This form of impact is hard to quantify comprehensively. Therefore, the relative uptake of publications in channels relevant to patients and society was used as an indicator.

We highlight three dimensions: clinical guidelines, policy documents, and news media. For each of these dimensions, the previously shown topic map (research landscape, see figure 7) is used to show which research areas exhibited a high relative uptake of umc publications. The color scale in these images indicates high (yellow) to low (blue) relative uptake.

The three highlighted dimensions are defined as follows:

1. **(clinical) guidelines:** the translation of research into standard treatment procedures for medical practitioners *(figure 9)*;

2. **policy documents:** government documents concerning health and medicine, both national and international, and their evidence of the influence of umc research on government strategy *(figure 10)*;

3. **news media:** an indication of topics covered in newspapers, television, radio, and digital media and their evidence of the direct influence of umc research on societal knowledge and awareness *(figure 11)*.

In general, publications from the clinical domains (oncology, cardiovascular, surgery, etc.) find their way into clinical guidelines *(figure 9)*. A higher uptake is observed of publications containing certain methodological terms, like trials, meta-analyses, and systematic reviews. Understandably, fundamental research is less often incorporated into guidelines, but it does form the basis of understanding processes on a cellular and molecular level. Ultimately, this knowledge is of key importance for the translation to clinical practice.

Publications that have a higher uptake in policy documents are concentrated in the public health domain *(figure 10)*. But across the entire map, hotspots of uptake in policy documents are visible. Uptake in the clinical domains is observed, albeit lower than into guidelines. Furthermore, coronavirus research, virology, and vaccine research stand out in the fundamental research domain. This is to be expected as the analyzed time frame was during the height of the pandemic. Umc publications contributed greatly to policy making during this time.

The uptake of umc publications in news media *(figure 11)* also highlight COVID-19 research, as well as terms such as Alzheimer, dementia, AI, ADHD, and weight gain. These are all subjects with a high societal burden, and for which better treatments could improve the quality of life, and therefore they receive a lot of media attention.

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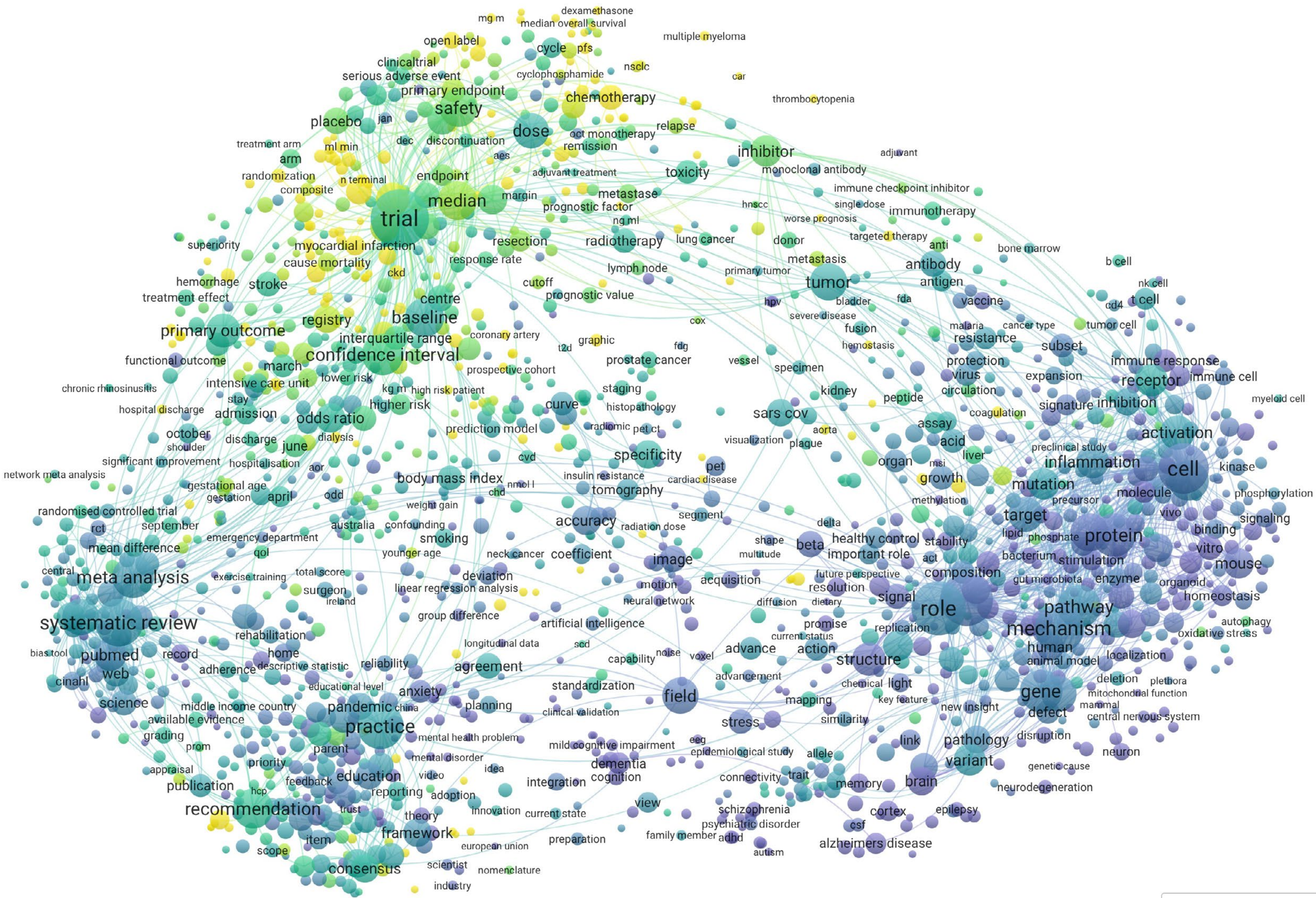

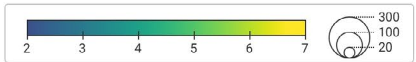

Figure 9: Relative uptake of umc publications in clinical guidelines in 2021

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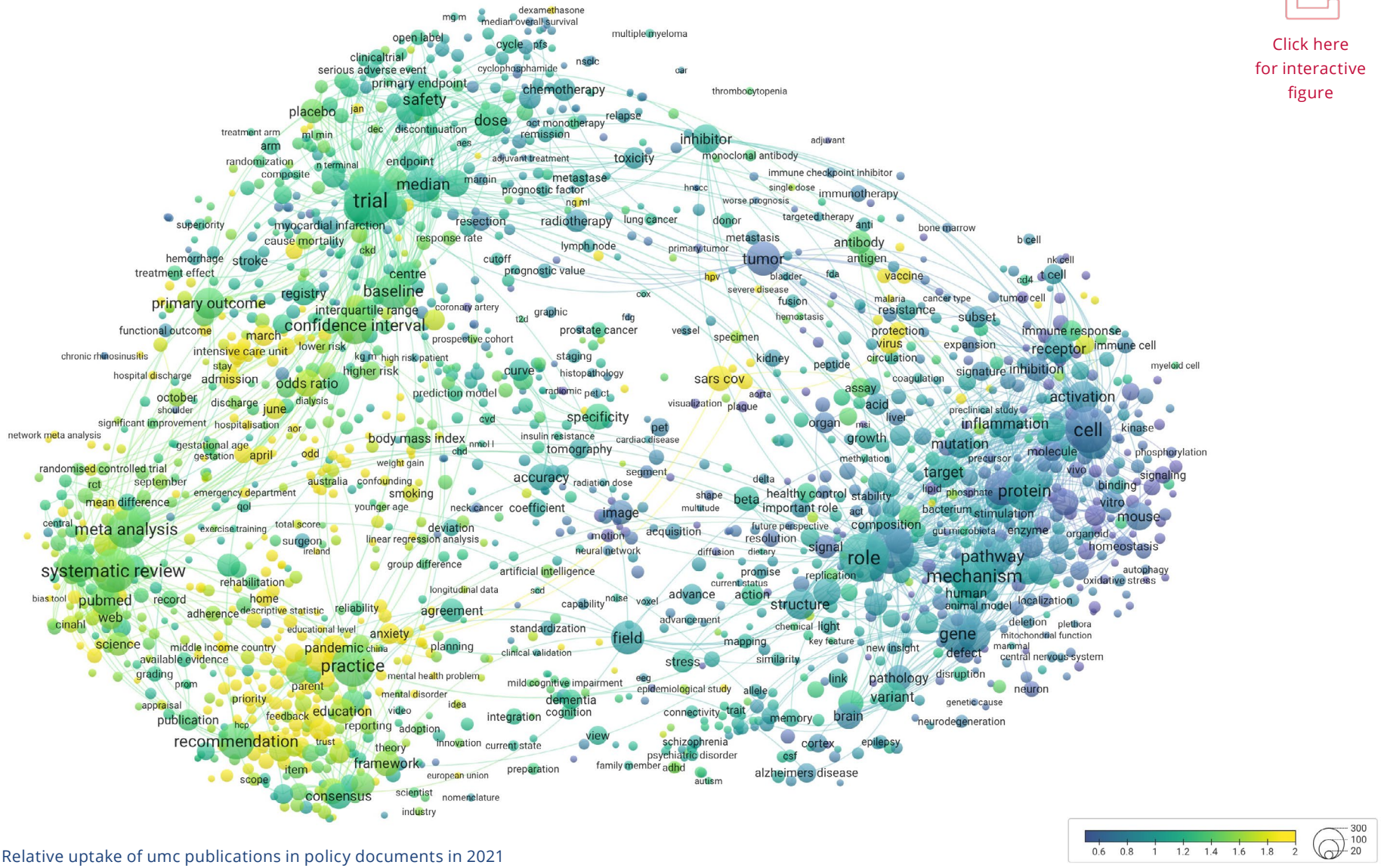

Figure 10: Relative uptake of umc publications in policy documents in 2021

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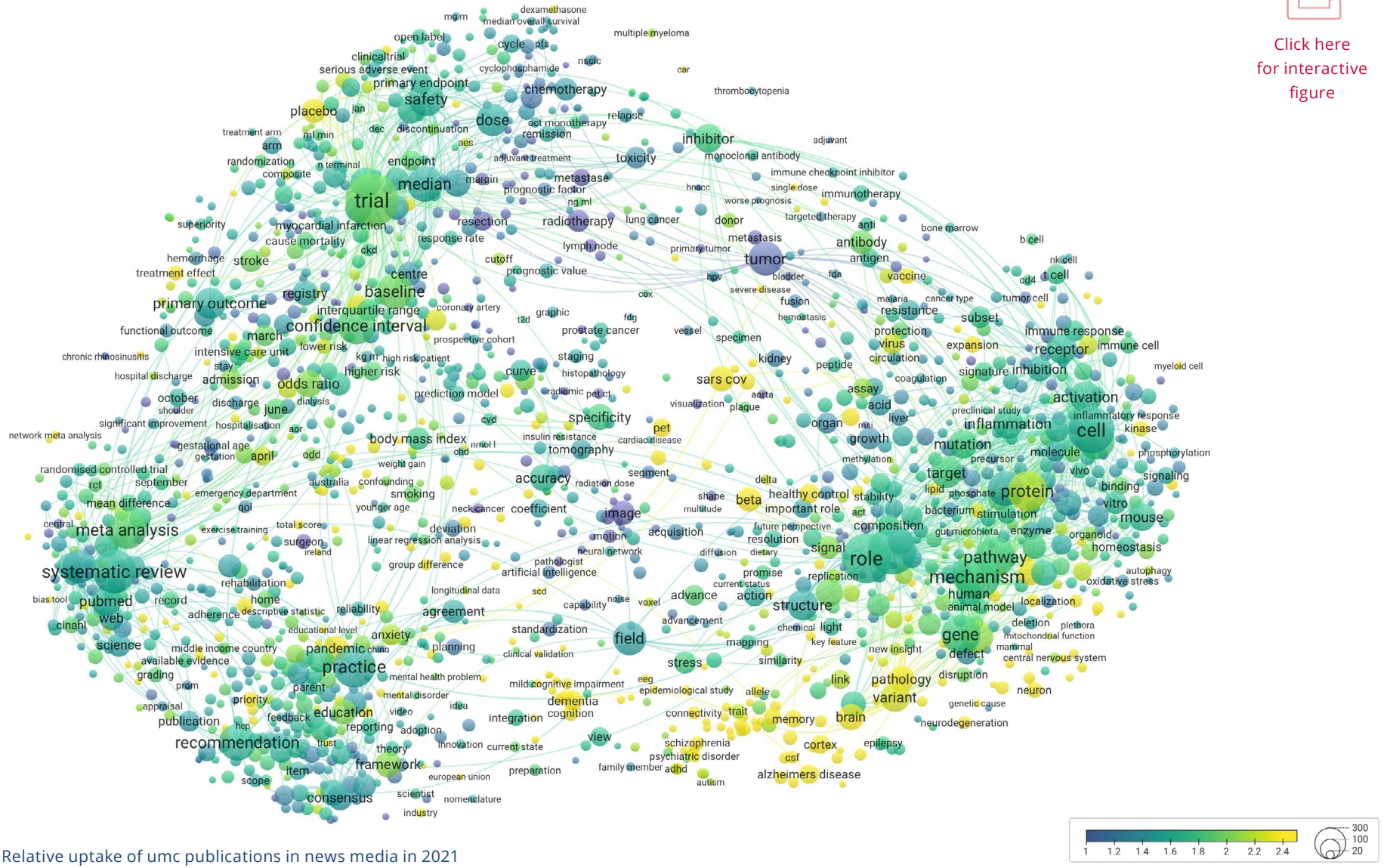

Figure 11: Relative uptake of umc publications in news media in 2021

4 Open access developments

The NFU participates in the National Program Open Science, and open access (OA) is an important facet of Open Science. Scientific knowledge should not be restricted only to those who are fortunate enough to have subscriptions but should be available to anyone looking to increase their knowledge and to apply and implement their findings in practice. In this way, increasing open access to umc publications broadens their impact and is therefore an interesting aspect to analyze over time.

In 2018, 70% of all umc publications were published as open access. In 2021, this has grown to 87%, which is above the national average (85%). This indicates that the national program resonates within the umcs. Figures 12 and 13 show the development of open access publications of the Dutch umcs over time, and for the different **types of open access**.

The totals of the different categories do not add up because Green open access regularly overlaps with the other types of open access publishing. Green open access has become increasingly important. It means that a form of the scientific article is accessible in a trusted repository. This is often a final approved version before the final journal layout.

Hybrid open access has also steeply increased since 2014. More and more journals offer the option to publish in open access while remaining a closed journal themselves. Gold open access is gradually increasing. This covers fully open access journals. Bronze open access is a choice of publishers to make certain previously closed articles openly available (often after a certain period of time).

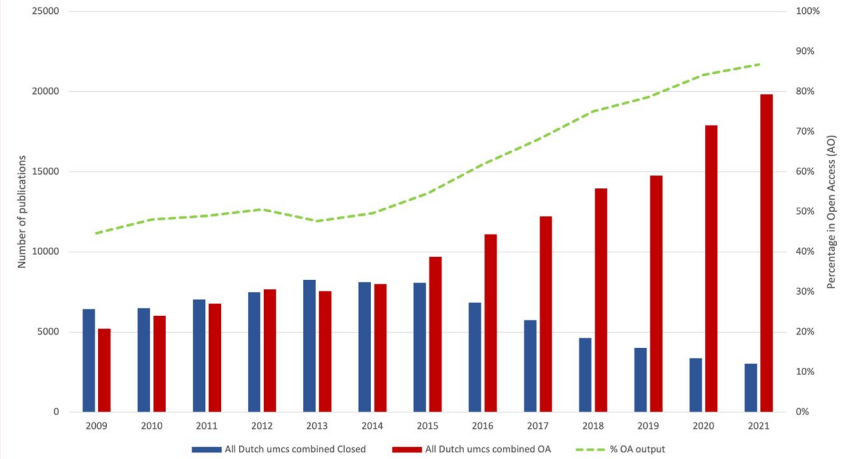

Figure 12: Graph showing the development of Open Access (OA) for umc publications between 2009 and 2021

Because the journals can decide at any moment to close access to these articles again, this is considered a non-sustainable form of open access. Bronze open access was seen during the COVID-19 pandemic, as a form of contribution by publishers to battling the crisis. However, many of the articles that were opened up during this period are now closed again.

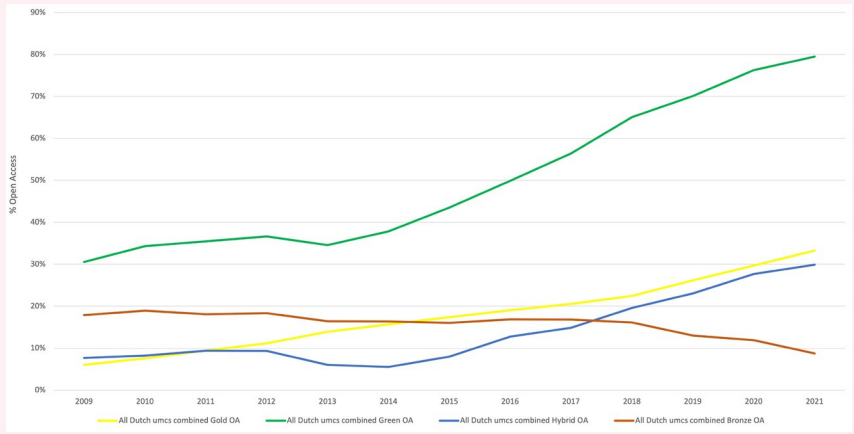

Figure 13: Graph showing the development of Open Access (OA) in the different classes (Gold, Hybrid, Green, Bronze) between 2009 and 2021

5 Collaboration

In academic research, participating in (inter)national networks has become more and more important over time. These collaborations are essential for sharing knowledge and expertise and are therefore pathways of impact. They allow the researchers to compare their results in different countries, across different populations, thereby utilizing the full power of all available techniques in the most efficient way. In addition, it has become increasingly important to collaborate in consortia to be eligible for significant European and other subsidies. In this section, the importance of collaborations with various types of partners and the scientific impact are analysed.

Collaboration between umcs

The umcs collaborate intensively with each other. The table below shows that collaboration between the umcs covers 33%-49% of their publications, which is a very significant part of the output and testifies to the high level of collaboration between them.

All umcs have their own profile and specific expertise, but in collaboration with researchers and clinicians from other umcs, larger studies can be designed to make use jointly of expensive high-end infrastructure, translate findings, and implement them in clinical practice and in societal applications. By collaborating, unnecessary duplication of research is prevented.

Table 3: Overview of collaborations between umcs in 2021 reflected in scientific publications

	#Publications 2021	#Publications in collaboration with another umc	%Publications in collaboration with another umc
Amsterdam UMC	7874	3090	39%
Erasmus MC	4535	1794	40%
LUMC	3290	1411	43%
Maastricht UMC+	3971	1320	33%
Radboudumc	3926	1779	45%
UMC Utrecht	3512	1733	49%
UMCG	4533	1522	34%

Collaboration with non-academic national partners

Scientific collaborations involving clinicians affiliated with regional healthcare facilities support the bidirectional exchange of knowledge and the sharing of expertise and research infrastructures. Occasionally, clinical professionals from regional hospitals are engaged on a part-time basis at the umcs for the explicit purpose of fostering this transfer of knowledge. In some instances, these clinicians may be conferred professorial appointments through specialized arrangements, thereby enhancing and streamlining the dissemination of valuable insights to the broader medical community and ultimately benefiting patients. This collaborative framework exemplifies a strategic and symbiotic relationship between academic institutions and regional healthcare facilities, fostering a dynamic ecosystem conducive to the advancement of medical science and improved patient care.

Table 4 shows the top national non-academic partners for the umcs (based on co-authorships per umc in 2021), demonstrating the importance of national and regional collaboration.

Partner	# of publications
Netherlands Cancer Institute - Antoni van Leeuwenhoek Hospital	220
Princess Máxima Center for Pediatric Oncology	113
Royal Netherlands Academy of Arts and Sciences (KNAW)	111
St. Antonius Hospital	110
Catharina Hospital	80
Onze Lieve Vrouwe Gasthuis	76
Zuyderland Medisch Centrum	72
Isala	64
Reinier Haga Groep	63
National Institute of Public Health & Environment (RIVM)	58
Haaglanden Medisch Centrum	54
HagaHospital	47
Jeroen Bosch Hospital	42
Netherlands Comprehensive Cancer Organisation (IKNL)	42
Noordwest Hospital group	42
Rijnstate	41
Amphia Hospital	40
Elisabeth-TweeSteden Hospital	39
Maasstad Hospital	39
Máxima Medical Center	39
Medisch Centrum Leeuwarden	37
Sint Franciscus Vlietland Groep	36
Medisch Spectrum Twente	34
Sanquin Blood Supply Foundation	34
Spaarne Gasthuis	33

Table 4: Overview of the most important non-academic partners, based on co-authorship of publications in 2021

Collaboration with international academic partners

Besides national collaborations, the umcs boast extensive research networks, forging collaborations with prominent international academic institutions (table 5). Based on the number of co-publications, the most important international academic partners are presented in the table below. Collaboration within the Western world predominates. In research areas such as tropical diseases, or on a smaller scale, there are certainly important collaborations with partners in the rest of the world, but they are not visible in this overview.

Partner	# of publications
University of London	775
Harvard University	476
University College London	407
Assistance Publique - Hopitaux de Paris	384
Katholieke Universiteit Leuven	378
University of California	365
Swiss universities	335
Karolinska Institutet	312
French Institute of Health and Medical Research (INSERM)	289
University of Toronto	287
University of Oxford	283
King's College London	268
Imperial College London	267
University of Copenhagen	243
Heidelberg University	241
Université de Paris	234
Humboldt-Universität zu Berlin	214
Freie Universität Berlin	209
University of Texas System	209
University of Melbourne	207
Charité - Universitätsmedizin Berlin	204
Ghent University	201
University of Cambridge	191
University of Oslo	191
Johns Hopkins University	190

Table 5: Overview of the most important partner international academic institutions, based on co-authorship of publications in 2021

Collaborations with other sectors

Table 6 provides a closer look into some of the other collaboration partners of umcs (national and international), across different sectors, other than medical and/or academic.

Collaborations with partners in different sectors *(for an explanation, see appendix 2)* on research publications is not always self-evident and concerns only a small portion of the output (ranging from 4% – 26%). Involving other partners (societal) in scientific publications can lead to more 'applicable research,' making it easier to translate the results into practice.

Collaboration partner	#Publications in 2022	% of total umc output
Research Organisation	5829	26%
Companies	1826	8%
Funding Organisation	1620	7%
Governmental Institution	878	4%
Teaching Organisation	807	4%

Table 6: Overview of collaborations of umcs with different sectors in 2022

Topics of collaboration

For two major sectors with which the umcs frequently collaborate, key term maps were created that show the most frequent topics featured in the resulting publications. In figure 14, the collaboration with non-academic hospitals is shown, using the previously presented topic map (figure 7) with a colour overlay. Topics with collaboration partners from non-academic hospitals are depicted in yellow. These topics are concentrated in the cluster of clinical sciences: oncology, cardiovascular, surgery, and (intensive) care.

Similarly, Figure 15 shows the topics where publications from umcs with companies are concentrated (yellow colours). These mostly involve medicine trials, oncology, and immunology, but notably also in the more fundamental domains in virology, vaccines, antibodies, cells, and genes.

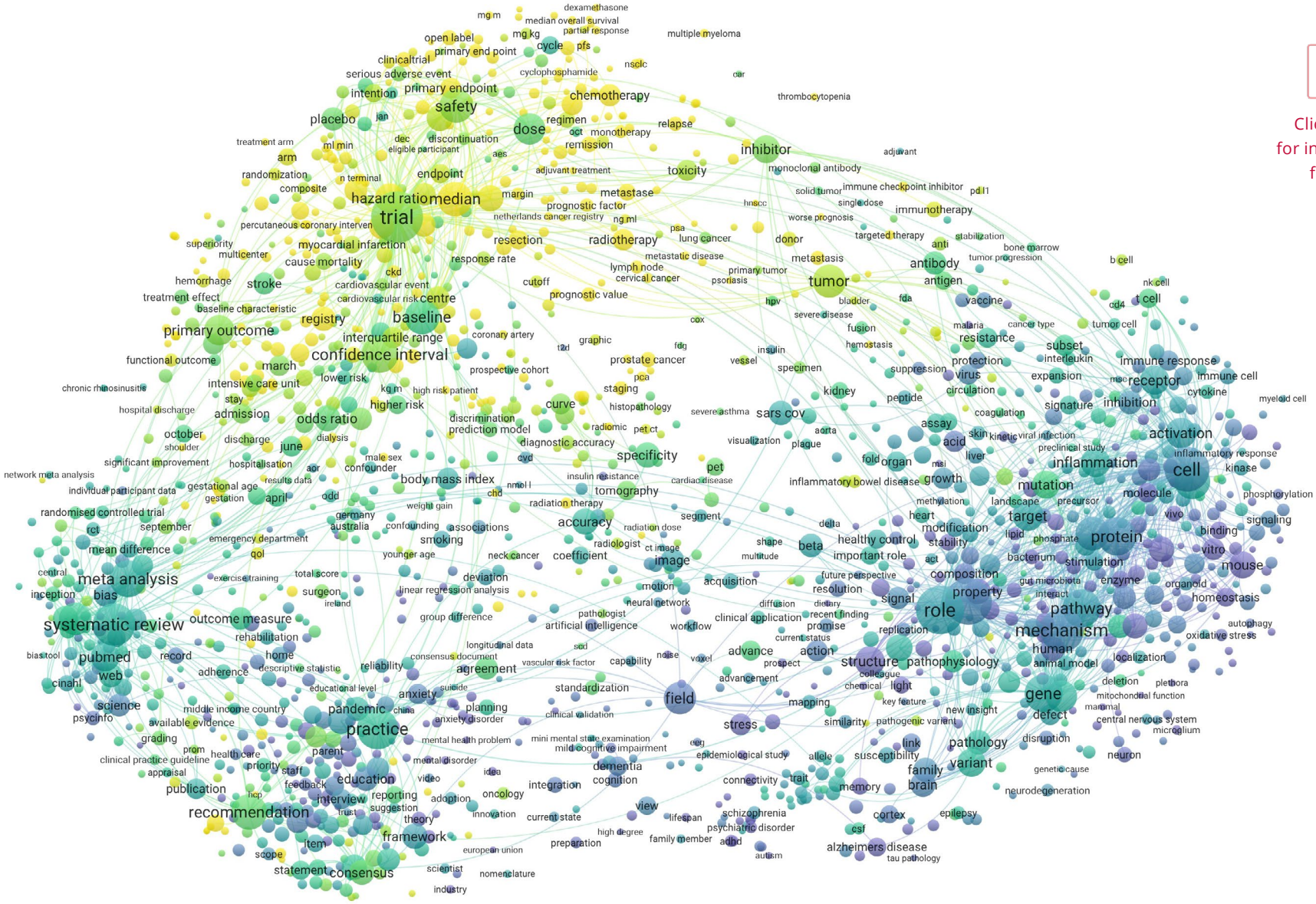

Figure 14: Topics featured in scientific collaborations of umcs with non-academic hospitals in 2021

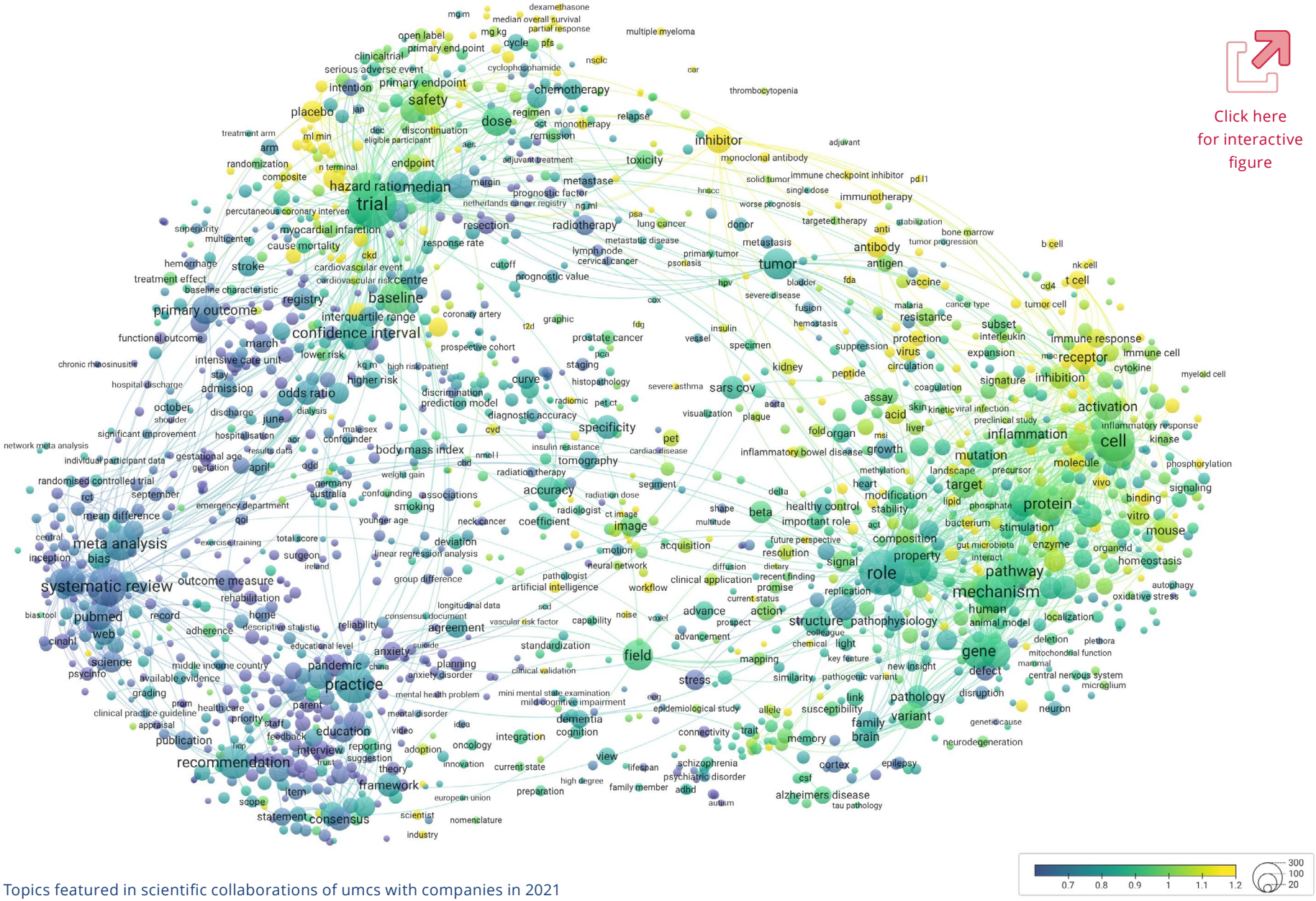

Figure 15: Topics featured in scientific collaborations of umcs with companies in 2021

Impact of collaboration

The charts below illustrate the scientific impact of the papers:

- Papers that were published in collaboration with at least one partner abroad *(figure 16)*.
- Papers that were published in collaboration with only national collaborators *(figure 17)*.
- Papers that were published by a single institution (without external collaboration) *(figure 18)*.

The charts show both MNCS (on the y-axis) and PP (top10%) (on the z-axis) in the same figure (time period 2018 - 2021, citations up to and including 2022). The MNCS is shown with bars, and the PP (top10%) with triangles. To get an impression of the size of the various clusters in the table below, the number of publications in each category is shown.

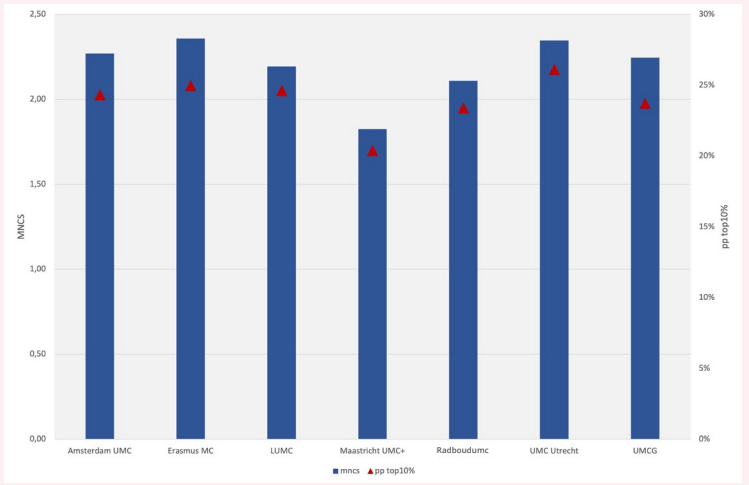

Figure 16: Impact of publications from international collaborations (2019 - 2021/2022)

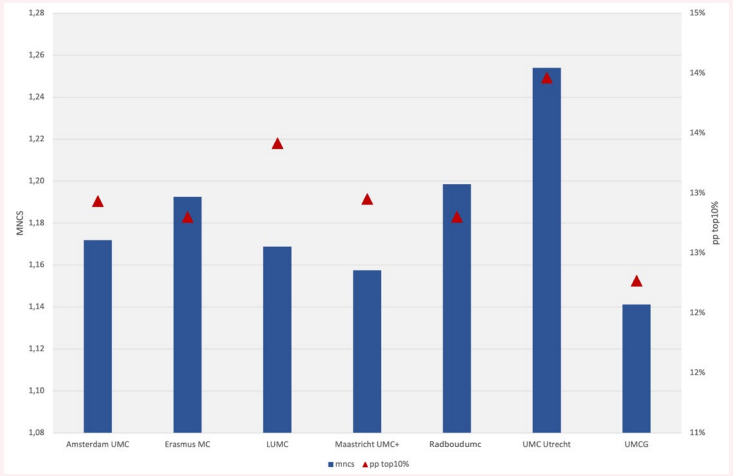

Figure 17: Impact of publications from national collaborations (2019 - 2021/2022)

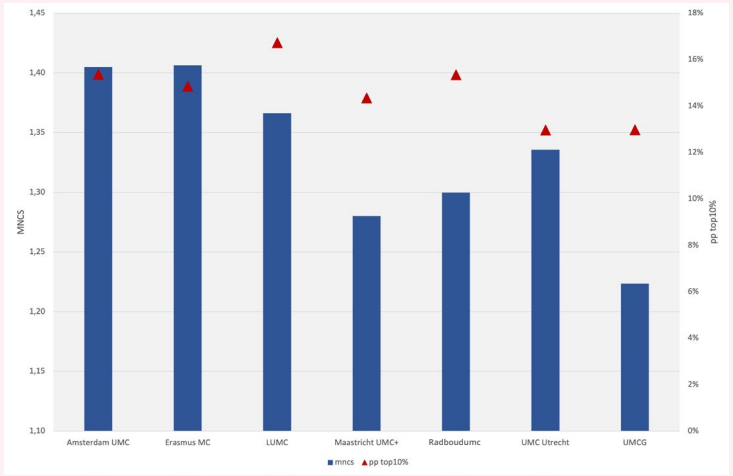

Figure 18: Impact of single institute publications (2019 - 2021/2022)

	Single Institute	% of total output	National Collaboration	% of total output	International Collaboration	% of total output
Amsterdam UMC	2234	9%	7629	31%	14550	60%
Erasmus MC	1472	10%	3935	28%	8694	62%
LUMC	1162	12%	2978	30%	5844	59%
Maastricht UMC+	881	8%	2837	26%	7034	65%
Radboudumc	1199	10%	3857	32%	7159	59%
UMC Utrecht	1042	11%	3251	34%	5302	55%
UMCG	1513	13%	3276	28%	6937	59%

Table 7: Overview of the collaboration types and number of umc publications (2018-2021)

The majority of publications are published with international collaborators, followed by publications with only national collaborators (most often with regional partners), while a small share is the result of single institute work.

For about 80% of all publications resulting from national and/or international collaborations, an author from a umc occupies a primary authorship position (first, second, first to last, last, or corresponding), indicating a leading role in the writing of the publication and in the underlying research performed *(table 8)*.

The graphs below show that especially publications with international collaborators have a very high scientific impact, probably because their results are often relevant to a broad scientific community in multiple countries as a result of large-scale studies or trials, which therefore leads to more citations. Publications with national collaborators often focus on more specific clinical challenges especially relevant to the Dutch setting and health care system, such as improvements in efficiency, cost-effectiveness, prevention, and practical guidelines.

	Number of publications in 2021	% primary authorships
Amsterdam UMC	7874	75%
Erasmus MC	4535	84%
LUMC	3290	82%
Maastricht UMC+	3971	84%
Radboudumc	3926	77%
UMC Utrecht	3512	80%
UMCG	4533	84%

Table 8: Overview of the percentage of primary authorships of publications from 2021 per umc

6 Funding Acknowledgements

Bibliometric analyses of funding acknowledgments are a type of study that focuses on examining the acknowledgment sections of scholarly publications to understand patterns related to funding sources. This approach provides insights into the financial support received by researchers and institutions.

Researchers in umcs are largely reliant on obtaining external funding to be able to perform their research, often by writing grant proposals for highly competitive funding opportunities offered by national governments, the European Union, charities, and other sources. Medical research is also supported by industry funds.

Authors are often required to mention their grants or funding sources as metadata with their publications. It has to be taken into account that funding sources are not available for all publications/journals in the database used. The registration of funding sources has increased over the years but is not fully covered. Therefore, the numbers that are shown are expected to be an underrepresentation.

This analysis focused on publications in which umc authors have a primary authorship position to signify research where a umc was in the lead and often initiated the study. Still, it has to be noted that the funding acknowledgements of all authors are included in the metadata, and no distinction can be made between the funding of the primary authors and that of the other authors.

From the results presented in table 9, it can be concluded that the European Union, NWO, and ZonMw are the main sources of external funding.

The charity funds KWF and Dutch Heart Foundation are important sources of funding for two of the main research themes for the umcs. The funding from several pharmaceutical companies is important for the initiation of clinical trials and enhancing translational research, i.e. the accessibility of research findings for patients.

The analysis of the overall degree of funding for umc publications indicates that 63% of all publications carry at least one reference to a funding agency. The global situation shows that 45% of all publications in the biomedical field carry at least one reference to a funding agency, so the Dutch umc situation stands out when compared to the global context. The fact that so many umc publications acknowledge external funding sources suggests that umc researchers are very successful in acquiring external funding for their research.

Funders	Total	% of total umc output
European Commission	6712	8%
Dutch Organization for Scientific Research (NWO)	5513	6%
Dutch Organization for Health Research and Development (ZonMw)	5146	6%
United States Department of Health & Human Services	4979	6%
National Institutes of Health (NIH) - USA	4913	6%
European Research Council (ERC)	2812	3%
UK Research & Innovation (UKRI)	2466	3%
KWF Dutch Cancer Society	2249	3%
Dutch Government	2176	3%
Medical Research Council UK (MRC)	2075	2%
Dutch Heart Foundation	1777	2%
German Research Foundation (DFG)	1629	2%
European Commission Joint Research Centre	1271	1%
Wellcome Trust	1269	1%
China Scholarship Council	1068	1%
National Health and Medical Research Council (NHMRC) of Australia	910	1%

Funders	Total	% of total umc output
National Institute for Health Research (NIHR)	902	1%
NIH National Cancer Institute (NCI)	775	1%
Canadian Institutes of Health Research (CIHR)	727	1%
National Natural Science Foundation of China (NSFC)	678	1%
Federal Ministry of Education & Research (BMBF)	655	1%
FWO	655	1%
AstraZeneca	650	1%
Pfizer	644	1%
NIH National Heart Lung & Blood Institute (NHLBI)	642	1%
Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT)	577	1%
Novartis	561	1%
Bristol-Myers Squibb	522	1%
NIH National Institute on Aging (NIA)	509	1%
Merck & Company	430	1%

Table 9: Number of funding acknowledgements in articles with primary authorship from a umc (2016-2022)

7 Cohort Studies & Clinical Trials

In this section, the focus is on two specific types of frequently used research methods: cohort studies and clinical trials. Cohort studies are a type of observational research design used in epidemiology and medicine. They are often used to investigate the causes and risk factors of diseases and health outcomes. In a cohort study, a group of individuals who share a common characteristic or experience (such as being born in the same year, living in the same area, having the same exposure to a risk factor, suffering from the same disease, etc.) is followed over a period of time to observe and record specific outcomes. These outcomes can include the development of a disease, changes in health status, or other relevant events.

Cohort studies are often long standing and are very rich data sources. They may be further enriched by the availability of biomaterials (e.g. serum/plasma, biopsies) that can be used for further research (mechanistic). Many umcs have their own cohort studies to study specific, local, or regional aspects in populations or patient groups.

Figure 19 shows the development of the use of the term 'cohort' in umc publications. A rapid increase over the past years is observed, signifying the increasing importance of these studies and the investments of umcs in this type of research. This is further corroborated by calculating the percentage contribution of cohort publications to the total number of publications.

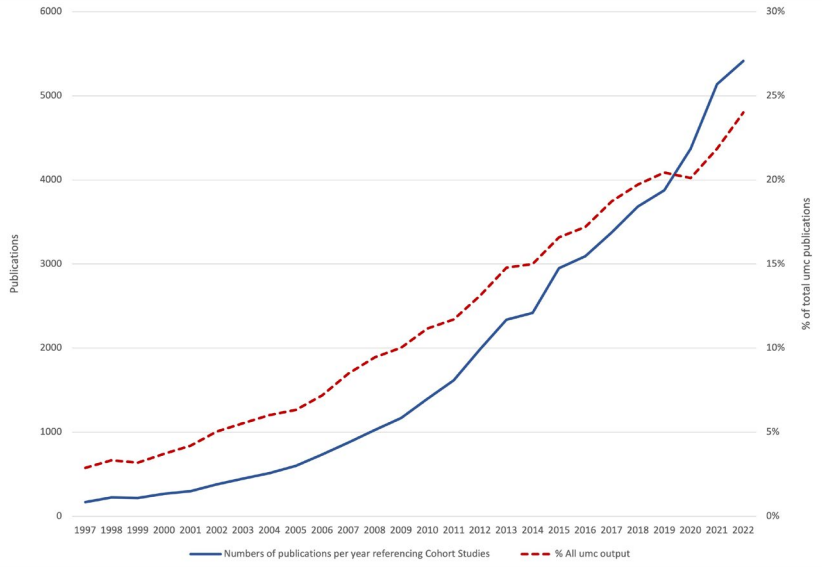

Figure 19: Development of umc publications referring to cohorts in absolute numbers and percentages of total publications from 1997 - 2022

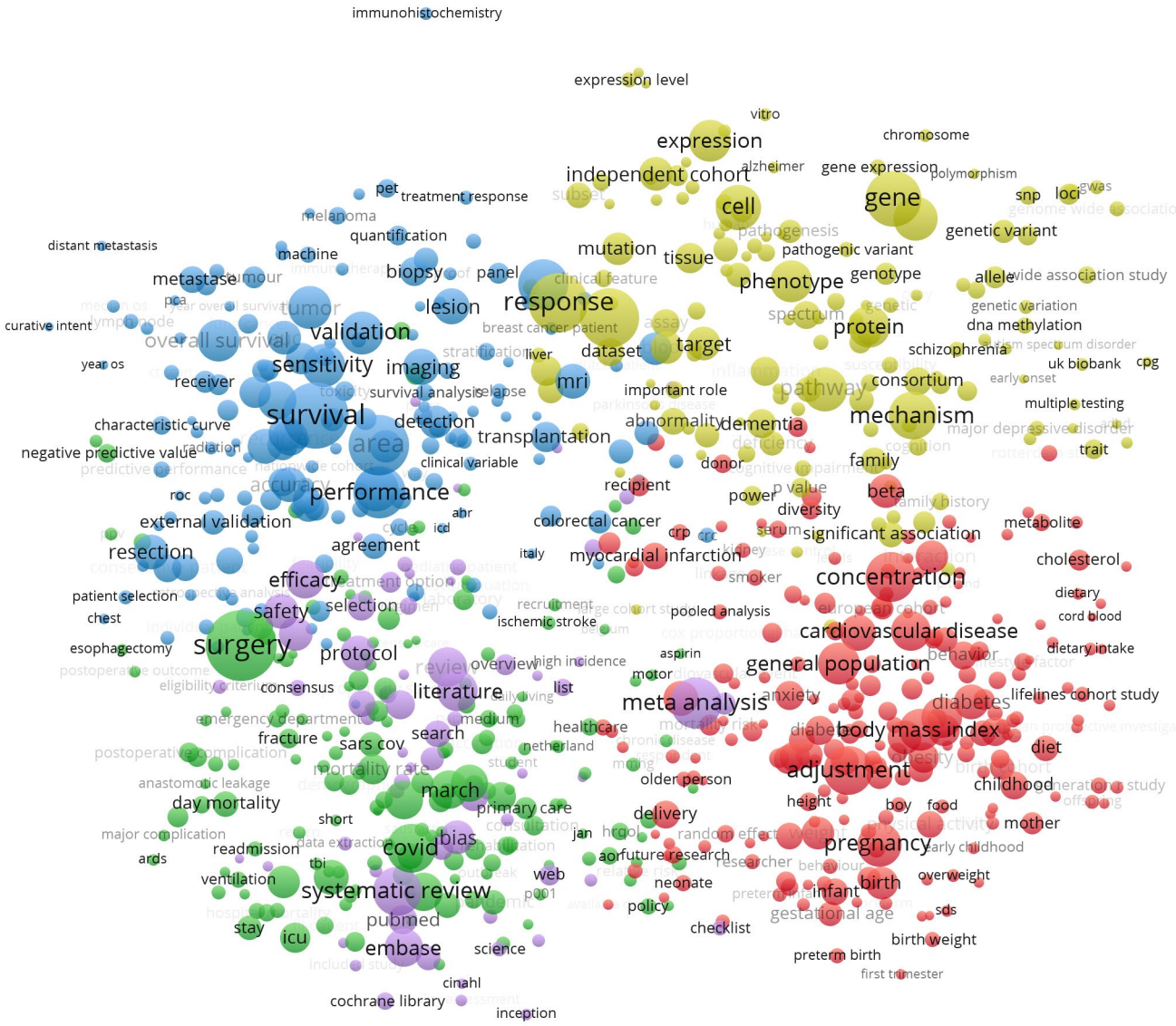

Figure 20: Map of research topics covered in publications from cohort studies in 2021

The most prominent topics of research in which cohorts are used are depicted in the term map in figure 20.

Five clusters are identified in this term map. The **yellow** cluster focusses on research related to genotyping and phenotyping related to specific diseases in cohorts. The **red** cluster contains/describes research on health and lifestyle factors associated with diseases such as cardiovascular diseases and diabetes, and their influence on pregnancy and childhood. The **blue** cluster contains primarily clinical research, most notably on oncological conditions and organ transplantation. In the adjacent **green** cluster, other clinical cohorts focus on surgery and intensive care, but this includes cohorts used during the COVID-19 pandemic to study clinical outcomes. Finally, the **purple** cluster contains terms indicative of the research methodology frequently used in cohort studies.

Clinical trials are another important type of study in medical research. They, for instance, seem to elicit a higher uptake into clinical guidelines. A clinical trial is a research study conducted with human volunteers (healthy or diseased) to evaluate the safety, efficacy, and/or effectiveness of a medical intervention or treatment. These interventions can include drugs, vaccines, medical devices, surgical procedures, behavioral therapies, and other types of medical or healthcare interventions.

These studies are often the first of the final steps towards clinical implementation and can have a direct clinical impact. Although small, local trials are performed at a umc, clinical trials are often comprehensive and large studies, often conducted in multiple centers, not only national but often international ones. Initiating a clinical trial takes a lot of effort and investment, but they are crucial for advancing clinical practice.

Figure 21 shows the development of umc publications using clinical trials in titles, abstracts, or keywords. Publications derived from clinical trials are increasing over time, not only in absolute numbers, but also in proportion to the total number of publications. This signifies both the growing importance of clinical trials in medical research and the increasing role of Dutch umcs in this type of research. Figure 22 shows the most prominent topics on which umc researchers publish using clinical trial data.

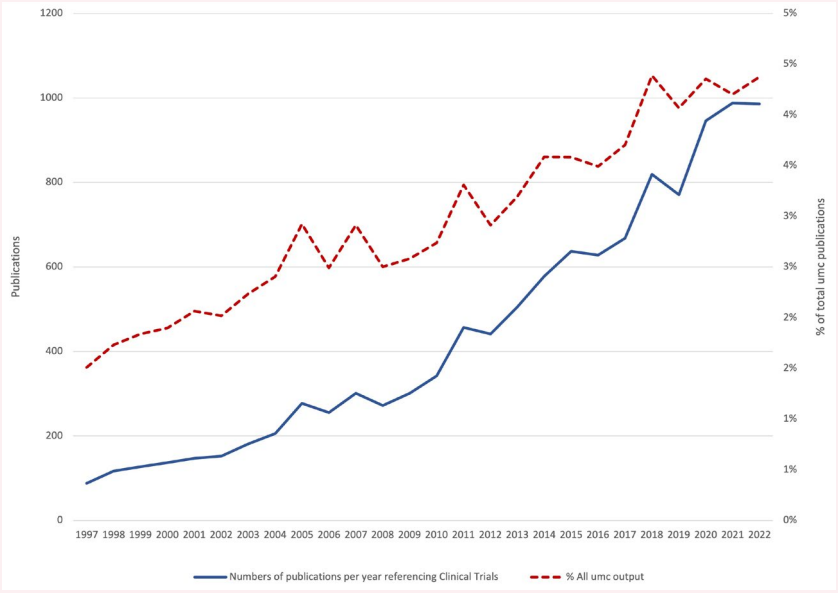

Figure 21: Development of umc publications referencing clinical trials in absolute numbers and percentages of total publications from 1997 - 2022

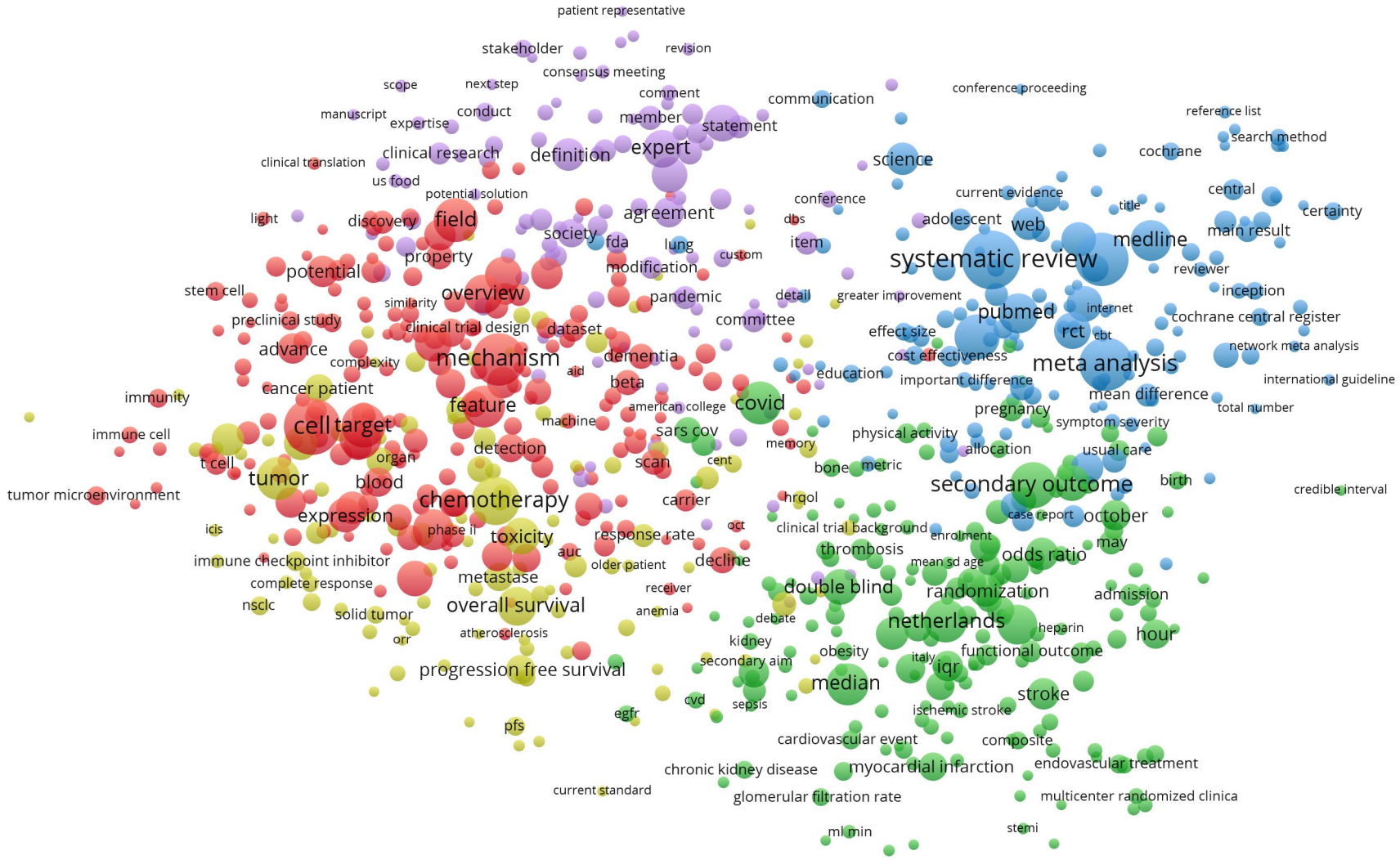

Figure 22: Map of research topics covered in publications referencing clinical trials in 2021

Similar to the previous map on cohort studies, five clusters can be observed in this map about the use of clinical trials in research. The **red** cluster contains pre-clinical cellular and mechanistic research. The **yellow** cluster is very close to the red cluster, indicating the close translation between pre-clinical and clinical research, mostly in oncology and immunology. The **green** cluster contains primarily clinical cardio-vascular research. The **blue** cluster shows methodological aspects of research on clinical trials. And finally, the **purple** cluster contains terms that are associated with the translation of clinical trial research into national and international guidelines and definitions.

8 Patent citations

Research often leads to valuable knowledge that can contribute to the development of inventions or innovations. To legally protect these findings, researchers can apply for a patent. To support a patent application, they cite previous work that forms the basis of the requested patent. A granted patent is often the crucial starting point for the development of a product, tool, or application and is a form of economic impact that is a direct consequence of research results. Therefore, analysis of patent citations was performed as a first approach to investigate the economic impact of biomedical research.

Because patent applications take a lot of time and are not openly published right away, but after approximately 8 years, and often cite older publications, quantification of these results is difficult. Nevertheless, it is important to show that umcs contribute to this kind of knowledge application.

Figure 23 gives an overview of the different technology areas in which umc research is cited in patent applications. The most cited technology areas are in pharmaceuticals and biotechnology, and to a lesser extent organic (fine) chemistry, analysis of biological materials, and medical technology.

This is further corroborated in figure 24, which shows an analysis of the most frequently used words in the cited umc output in patent applications in this time frame (1998 - 2022). Many clusters on the left describe fundamental research, whereas the right-side clusters describe clinical research and outcomes. The term map shows a mix of fundamental research into disease mechanisms and treatments for diseases using trials and methods like pharmaceuticals and biotechnology.

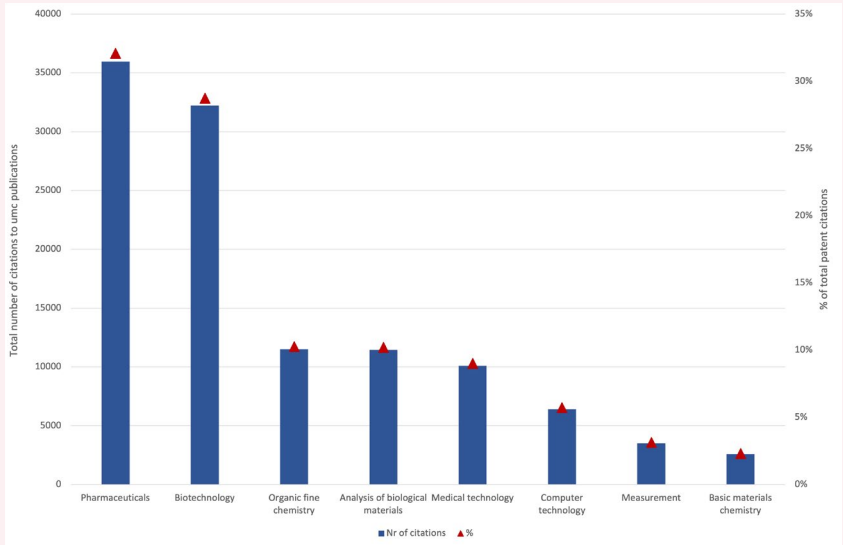

Figure 23: Numbers and percentages of patent citations in different technology areas (1998 - 2021/2022)

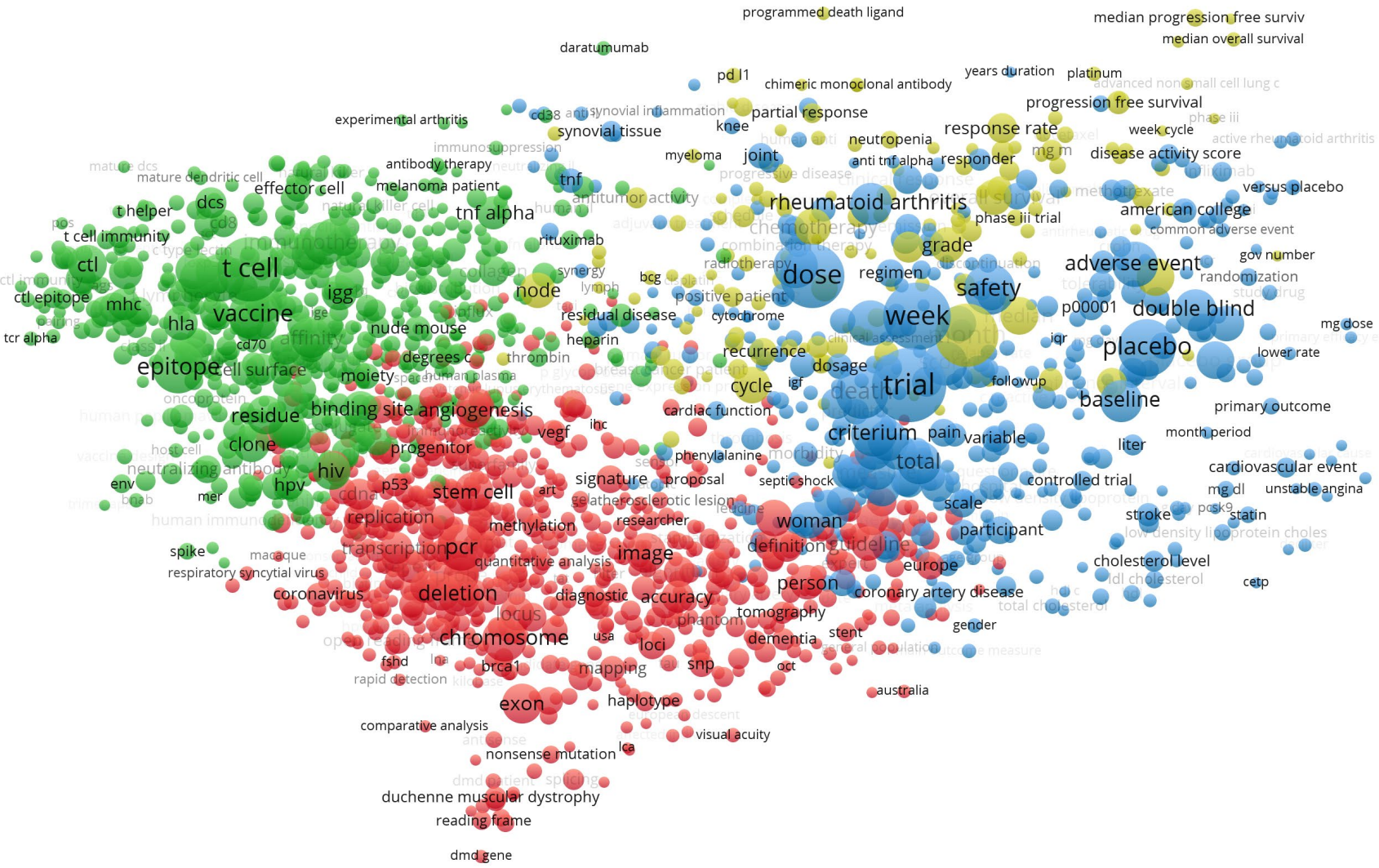

Figure 24: Map showing topics of umc publications referred to most often in patents in 2021

Appendix 1: Background to the bibliometric analyses

While this report refrains from providing detailed descriptions of the methodology, a comprehensive document dedicated to this purpose is available separately. The analyses presented herein were conducted in 2023, utilizing publication data up to and including 2021, and citation data up to and including 2022. This approach allows publications a minimum of one year for citation, aligning with common practice in bibliometric analyses.

Bibliometrics involves the scrutiny of bibliometric metadata extracted from scientific publications. umc researchers are obligated and encouraged to disseminate their clinical and research findings, primarily through scientific publications, but also via inclusion in policy documents, clinical guidelines, and coverage in the general press and media. Collectively, the umcs published 86,754 scientific peer-reviewed articles (full articles and reviews) between 2019 and 2022, with approximately 23,500 articles appearing in 2021 alone. Bibliometric analyses, rooted in these publications and indicating scientific impact, may encompass metrics such as the number of citations relative to other publications on the same topic.

Collaborations are also assessed through co-authorships or term mapping derived from umc publications. Societal impact-oriented analyses include evaluating the accessibility of publications through open access data and assessing the uptake of publications in sources relevant to society, such as news media, guidelines, and policy documents. The outcomes of these analyses are visualized through graphs and tables, utilizing network mapping software.

The network mapping software employed in these analyses is VOSviewer. In these visualizations, the size of a sphere corresponds to the number of publications by an institution or the frequency of a term occurring in titles or abstracts. Lines connecting institutions signify collaboration based on co-authorship of the same publications. The color and position of a term or institution are determined by its relatedness to other terms or institutions on the map. Frequent co-occurrence of terms results in a higher level of attraction and closer placement on the map. Similarly, collaborating institutions are positioned together. Clusters of co-occurring terms, indicated by the same color, serve as proxies for larger research topics. For instance, within oncology research, terms cover treatment methods like chemotherapy and fundamental research on oncogenesis.

Colors can serve as overlays to convey additional dimensions. In a term map, colors may indicate the degree of open access, the societal uptake of publications on these topics, or citation impact.

Appendix 2: Explanation of sectors

Research Organization

This category refers to organizations that carry out research, an activity understood as "systematic investigation to establish facts." A research organization can be an independent organization or belong to a national government, but it must be not-for-profit. Examples of these include the National Institute for Public Health and the Environment (RIVM) and the Netherlands Cancer Research Institute (NKI).

Companies

This category refers to for-profit companies and is used for large multinationals as well as for SMEs. Spin-offs from universities, whether independent or affiliated to the university, fall under this category as long as they are for-profit. Other organizations that fall under this category are pharmaceutical and biomedical companies, for despite acting as funding agents of research institutes, their core activity is still to sell products and services.

Funding Organization

Funding organizations are ones whose primary stated goals are concerned with the stimulation and support of science through the allocation of funds (examples include research institutes directly funded by both NWO and KNAW, such as the Hubrecht Lab or the Netherlands Brain Research Institute, as well as foreign organizations and their institutions, such as the NHS in the UK, the CNRS in France, or the Academy of Science in China).

Government organization

The governmental institution category lumps together all identified institutions that are primarily governmental. This definition is mostly one of exclusion, as they are institutions which are not primarily research or funding organizations. In practice, most of the organizations in this category are ministries, departments, and governments.

Teaching organization

The main criteria for designating an institution as a teaching organisation is that its core activities are educational, yet it cannot grant doctoral degrees, and, in many cases, it is not recognized as a university in its own country (Hogescholen).

NFU
Netherlands Federation of
University Medical Centres

nfu@nfu.nl
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