A BIBLIOMETRIC SURVEY OF THE MEDICAL TECHNOLOGY LITERATURE

1994-2018

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Abstract

In this study, the literature of the field of *Medical technology* was analysed using bibliometric and common statistical methods. The overall objective was to supply with structured information facilitating more detailed analyses as well as additional research questions. To this end, several appendices with complementary information were generated. Conceptually, the study comprised a descriptive part where the growth of the literature and the contributions of actors on both an organisational and a national level were studied, and a mapping part where the cognitive structure of the field was analysed on basis of citation links between papers. For the mapping part, a cluster analytical approach was applied and a network analytical tools for the displaying of clusters' structures. The findings were divided up in two main parts:

- the *Global view*, and
- the *Local view*,

where the former denotes analyses and findings on a global level and the latter analyses and findings restricted to papers published by *Chalmers University of Technology* or *University of Gothenburg*. The period of observation comprised 25 years for the global part and all years for the local. All analyses were based on bibliographic data from *Web of Science*, *Core Collection*. Findings showed a North American dominance of the field for the whole period, but also an increasing Chinese influence during the middle and later periods. With regard to the cognitive structure on the global level, a large variation of topics were found, and a clear change of emphasis on topics over time. On the local level the diversity and variation of topics was considerably more restricted and emphasised dental research.

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Introduction

The purpose of this study was to accomplish an over-view of the cognitive structure and statistical features of the knowledge field Medical technology. Medical technology is a very broad sector covering any technology that is used in a care setting and it accounts for all devices with which a patient is diagnosed or treated[1]. This field is multidisciplinary, involving knowledge areas like biotechnology, engineering, information technology, medicine, pharmacology, physics and surgery.

Statement of purpose

The objective of this study was to analyse the field of Medical Technology regarding the following aspects:

(1) research contributions of organisations and countries,
(2) collaboration patterns,
(3) growth of the literature,
(4) mapping of cognitive structures, specialties and research themes, and
(5) citation impact of papers.

As there exists an expressed interest in the involvement of *University of Gothenburg* and *Chalmers Technical University* in the field of Medical Technology, special attention was given to the published contributions of these institutions. This implied a so-called *Local view* of the problem where papers published by these institutions, in collaboration or separately, were analysed with the objective of mapping research themes, collaboration and citation impact. The part of the study that aimed at the mapping of the field on a global level was accordingly named the *Global view*. These two approaches separates the reporting of findings in two halves.

Data sampling

Medical Technology is not a specific area of knowledge, nor is it a discipline or a specialty, more so an aspect of research. This implies that it is difficult to construct and maintain a comprehensive vocabulary for retrieving information from databases. Therefore, we applied the kind of standard bibliometric approach of defining a science field through its journals and corresponding journal classifications. Our point of departure was hence in the web of science categories *Engineering, Biomedical* and *Medical Informatics* which were assumed to cover the major Medtech aspects:

> Engineering, Biomedical covers resources that apply engineering technology to solving medical problems. Resources in this category span a wide range of applications including applied biomechanics, biorheology, medical imaging, medical monitoring equipment, artificial organs, and implanted materials and devices.
>
> Medical Informatics covers resources on health care information in clinical studies and medical research. This category includes resources on the evaluation, assessment, and use of health care technology, its consequences for patients, and its impact on society.[2]

It was found that a total 559,674 papers were assigned to either or both of the selected categories (all document types and all years) when searching the Web of Science database in October 2019. In order to focus our attention on genuine research articles, this set was diminished by filtering out

[1] Bidiville, Lea. What is Medtech? LSX the network for Life Sciences executive leaders. 29/11/2016. https://www.lsxleaders.com/blog/what-is-medtech. Accessed 10/02/2019.

[2] Category profile, InCites Journal Citation Reports.

papers not of the document type *article* or *review article*. This implied a reduction to 289,959 papers. Finally, we set the period of observation to 1994-2018. This implied a further reduction to 227,961 papers. We only included full years in order to be able to make comparisons between years. This final set of papers was analysed using on-line bibliometric methods, covering aspects of growth and contributions of organisations and countries. For the analysis of research themes (topics), the more cited papers were selected. We applied a principle of analysing the top 5 percent highly cited papers over three consecutive periods:

Period	total # papers	highly cited 5 %
1994-2003	47843	2392
2004-2013	98762	4938
2014-2018	81356	4068.

For the local view, a separate download from the Web of Science of records with an address to *Chalmers University of Technology* (CUT) or *University of Gothenburg* (UG) was done. Applying the organisation-enhanced index,[3] a total number of 126,058 papers were found of which 1,249 papers were assigned to at least one of the selected categories. The same requirement of category assignment as previously was applied, but we allowed all document types to be included, as we wanted to mirror the research within medical technology for these institutions as exhaustively as possible. We also included papers published during 2019 although this is not a complete year. In total 1,249 papers were downloaded.

Application

The aim of this report was to supply with data and information that may be further analysed, hopefully generating additional, perhaps more to the point, research questions. In order to reach this goal, several appurtenant appendices in Excel format have been generated where more comprehensive and detailed information is supplied. The field of Bibliometrics deals with quantitative analysis of bibliographic data, usually stored in large, international multidisciplinary databases. As a rule, bibliometric analyses should preferably not involve the analysis of small data sets as the risk for statistical instability is impendent, that is, a little deviating method of sampling may generate data that leads to quite different conclusions when results are analysed. This is particularly the case when citation data is analysed. In the section *A Local view*, smaller sets of data are analysed, why the reader should keep this circumstance in mind.

For the greater part of this study, cluster analytical methods have been applied. The order and scope of these analyses should be noted:

1. Global level: cluster analysis based on *n* papers from each period of observation.
2. Local level: cluster analysis based on the set of 1,249 papers.
3. Local level: cluster analysis based on a highly cited sub-set of the set of 1,249 papers.

The objective of cluster analyses in the current context is to identify coherent groups of papers that would reflect the specialty structure of a field of research. When this is the case, the task of deciding the subject content of a cluster (labelling) can be challenging, as the analyst is mostly not a field expert. When the task is to cover large multidisciplinary fields, it may not be practical to rely on several experts' evaluations of hundreds of clusters. Hence, a trade of is often necessary, meaning that the labelling has a point of departure in the frequencies of title words or other meaning bearing

[3] This index unites all possible name variations of an institution.

terms, though, if possible, the main theme of a cluster should be recognized. A more exhaustive and detailed interpretation of clusters' contents can later be added by the field expert, drawing on the main structure of the field under investigation that has been made accessible through the cluster solutions. In several instances, the same or similar labels have been applied to different clusters. Hence, on the non-expert level of labelling, some clusters appear to deal with similar themes, while a closer analysis on the expert's level may add a more finely divided classification. It is also indeed possible that there is some topic drift in clusters, in particular if thresholds of association strength are somewhat low or if the merging of papers into clusters is based on citations. In the latter case the fact that a citation can be directed to any section of a paper makes it impracticable to decide its factual meaning, still every citation is assigned an equal value. Citations directed to the method section of papers tend to increase the topic drift in cluster as methods frequently have a broad area of application.

Due to the special interest in the research performed by CUT and UG in this field, a quite voluminous presentation of the cluster analysis of 1,249 papers is presented in the section *A Local View*. Adhering to tables with clusters' titles, the underlying network of each cluster is displayed as a graph, detailing the citation network for each cluster. Hence, for any two papers in a cluster related by a citation (the direction ignored), the relationship can be scrutinized. Also, these maps facilitate a more comprehensive understanding of clusters as citation networks.

A final point concerning cluster analysis should be made. There exist many cluster methods with quite different basic assumptions and preferences of methods are to some extent related to which field is studied. There is therefore a great possibility that results change with the choice of cluster method. However, if there is a reasonably strong structure in data, these differences may not be decisive.

Methods

For the analysis of online data retrieved for the purpose of the descriptive analysis of organisations' and countries' contributions to the field, and the growth pattern of the literature, common statistical tools were applied. For the study of the cognitive structures of the field, several analytical tracks would be applicable. One track is to follow patterns based on meaning building terms like keywords or standardized title words. Another track makes use of associations based on citations between papers and a third compares the number of common attributes between papers, mostly the cited references in their bibliographies. In our case, as we apply longer periods of observation, it is feasible to track citation relations between papers through time. Our basic assumption is that the citation of one paper by another is an expression of subject similarity between them. Such relations may suitably be analysed using network analytical methods, as we in fact generate an implicit network by computing citation relations. To this end the network analytical software *Pajek* was applied for both the generation of clusters and the depiction of their underlying networks. This is an excellent tool offering a multitude of analytical possibilities. In particular, very large sets of data can be partitioned and analysed. In order to favour the comprehension of reported results, the application of various methods are, when needed, elaborated on the context in which they are reported.

Findings

A Global view

The first part of the results section applies a global view, that is, we tried to identify cognitive patterns on a large-scale level in order to reach an understanding of which organisations and countries are the most influential and which research themes are present during the period of observation. As we wished to apply a temporal perspective, three periods were investigated separately. In the commentary on findings from the first period, the application of methods is presented in context and elaborated on to the extent this is deemed necessary for the comprehension. However, this is not repeated for the two following periods of observation and the reader is referred back to the first period when warranted.

Period 1: 1994-2003

For this period a total of 47,843 papers were indexed in the Web of Science database and the *annual percentage growth rate* was 5 (Figure 1).

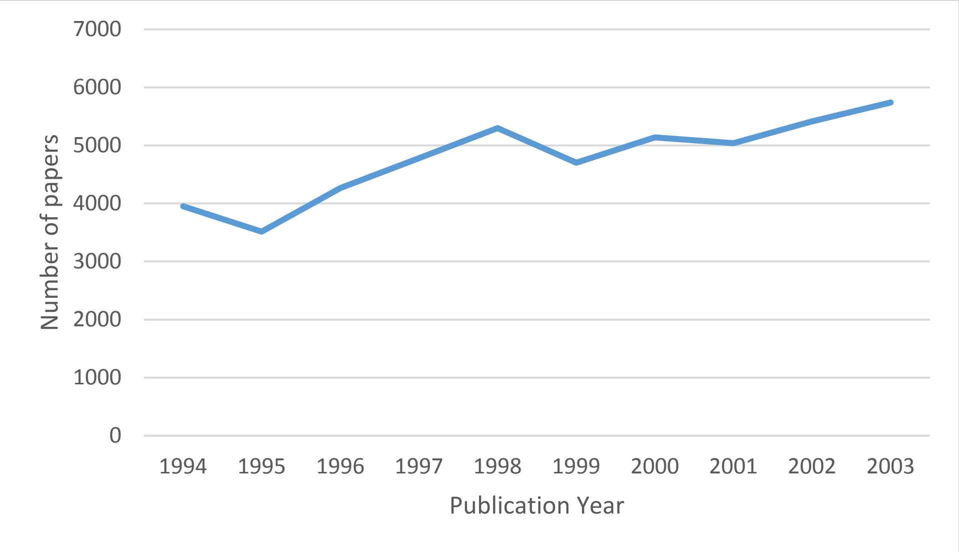

Figure 1. Annual number of published papers, 1994-2003.

The 25 most productive institutions published between 377 and 1,241 papers during this period. At the top positions we see *Harvard University* followed by *University of California System* and *University of London* (Table 1). Though the USA dominate this distribution, other institutions with a European or Asian residence are seen. An aspect intertwined with research is the funding. In Table 2, the distribution of papers over funding organisations is shown. With just one exception, *Wellcome Trust*, which is of British origin, all top funders are associated with the USA, and the greater part belong to the *National Institutes of Health*.

Table 1. The distribution of papers over 25 top-institutions, 1994-2003.

Organisations	# records
HARVARD UNIVERSITY	1241
UNIVERSITY OF CALIFORNIA SYSTEM	1236
UNIVERSITY OF LONDON	1122
VA BOSTON HEALTHCARE SYSTEM	814
PENNSYLVANIA COMMONWEALTH SYSTEM OF HIGHER EDUCATION PCSHE	713
UNIVERSITY OF TEXAS SYSTEM	616

UNIVERSITY COLLEGE LONDON	530
UNIVERSITY OF TORONTO	506
INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE INSERM	491
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	473
UNIVERSITY OF MICHIGAN	462
UNIVERSITY OF MICHIGAN SYSTEM	462
STANFORD UNIVERSITY	458
UNIVERSITY OF PENNSYLVANIA	444
KYOTO UNIVERSITY	441
NATIONAL INSTITUTES OF HEALTH NIH USA	434
UNIVERSITY OF PITTSBURGH	430
UNIVERSITY OF WASHINGTON	420
UNIVERSITY OF WASHINGTON SEATTLE	418
JOHNS HOPKINS UNIVERSITY	415
UTAH SYSTEM OF HIGHER EDUCATION	414
UNIVERSITY OF UTAH	410
COLUMBIA UNIVERSITY	398
CASE WESTERN RESERVE UNIVERSITY	377
MASSACHUSETTS INSTITUTE OF TECHNOLOGY MIT	377

Table 2. The distribution of papers over funding agencies, 1994-2003.

Funding Agencies	# records	Rank
UNITED STATES DEPARTMENT OF HEALTH HUMAN SERVICES	5400	1
NATIONAL INSTITUTES OF HEALTH NIH USA	5269	2
NIH NATIONAL HEART LUNG BLOOD INSTITUTE NHLBI	1346	3
NIH NATIONAL CANCER INSTITUTE NCI	850	4
NIH NATIONAL LIBRARY OF MEDICINE NLM	673	5
NIH NATIONAL INSTITUTE OF ARTHRITIS MUSCULOSKELETAL SKIN DISEASES NIAMS	609	6
NIH NATIONAL CENTER FOR RESEARCH RESOURCES NCRR	391	7
NIH NATIONAL INSTITUTE OF NEUROLOGICAL DISORDERS STROKE NINDS	352	8
NIH NATIONAL INSTITUTE OF DENTAL CRANIOFACIAL RESEARCH NIDCR	323	9
NIH NATIONAL INSTITUTE OF GENERAL MEDICAL SCIENCES NIGMS	290	10
UNITED STATES PUBLIC HEALTH SERVICE	251	11
AGENCY FOR HEALTHCARE RESEARCH QUALITY	210	12
NIH EUNICE KENNEDY SHRIVER NATIONAL INSTITUTE OF CHILD HEALTH HUMAN DEVELOPMENT NICHD	180	13
NIH NATIONAL INSTITUTE ON AGING NIA	178	14
NIH NATIONAL INSTITUTE OF MENTAL HEALTH NIMH	176	15
NIH NATIONAL INSTITUTE OF ALLERGY INFECTIOUS DISEASES NIAID	150	16
NIH NATIONAL INSTITUTE OF DIABETES DIGESTIVE KIDNEY DISEASES NIDDK	147	17
NIH NATIONAL INSTITUTE ON DEAFNESS OTHER COMMUNICATION DISORDERS NIDCD	113	18
NIH NATIONAL EYE INSTITUTE NEI	84	19
WELLCOME TRUST	60	20
NIH NATIONAL INSTITUTE OF ENVIRONMENTAL HEALTH SCIENCES NIEHS	58	21
NIH NATIONAL INSTITUTE ON DRUG ABUSE NIDA	54	22
NIH NATIONAL INSTITUTE OF BIOMEDICAL IMAGING BIOENGINEERING NIBIB	45	23

ODCDC CDC HHS	32	24
NIH NATIONAL INSTITUTE ON ALCOHOL ABUSE ALCOHOLISM NIAAA	29	25

On the aggregate level of countries, the distribution of papers can be illustrated on a geographical map (Figure 2). The darkest areas coincide exclusively with the border of the USA as there is a pronounced shift between the USA and other countries. On a detailed level, we can decide the exact numbers as well as the rank positions of each country (Table 3). Other highly productive countries are England, Japan and Germany. Notably, Sweden holds the ninth position, well above other Scandinavian countries, and, surprisingly, China the 14th. This distribution reveals great differences between countries in terms of volume published research, as mirrored by a range of 17,870 and a relative standard deviation (RSD)[4] of 1.74.

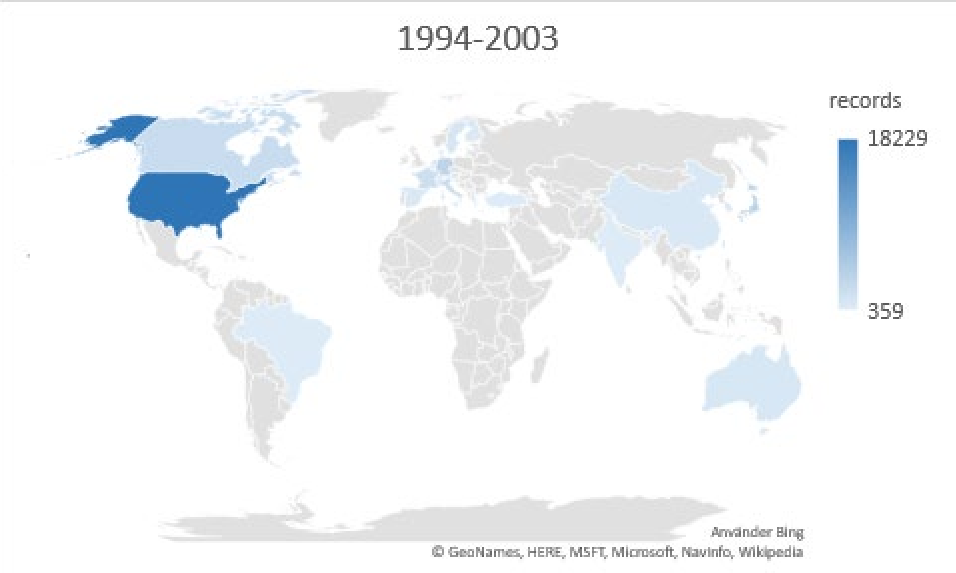

Figure 2. The distribution of papers over countries, 1994-2003.

Table 3. The distribution of papers over countries, 1994-2003.

Countries	# records	Rank
USA	18229	1
ENGLAND	4310	2
JAPAN	4032	3
GERMANY	3852	4
CANADA	2620	5
ITALY	2492	6
FRANCE	2208	7
NETHERLANDS	2175	8
SWEDEN	1219	9
AUSTRALIA	1026	10
SWITZERLAND	1019	11

[4] The relative standard deviation (RSD) is computed as the standard deviation over the arithmetic mean. It is also called the Coefficient of variation (CV). It is useful when comparing distributions on different scales, but can also be applied as a measure of the evenness (concentration) of a distribution.

TAIWAN	824	12
SPAIN	820	13
PEOPLES R CHINA	818	14
BELGIUM	753	15
AUSTRIA	676	16
FINLAND	670	17
ISRAEL	559	18
SOUTH KOREA	531	19
SCOTLAND	518	20
GREECE	504	21
BRAZIL	426	22
TURKEY	420	23
DENMARK	415	24
INDIA	359	25

Next, we will investigate various patterns derived from a select part of the 1994-2003 production of papers. Selecting the five percent most cited papers we can focus on the research that has been used as the cognitive base for much of the later research. In total, 2,392 papers were selected from the total set. The range of citation was 13,087 and the arithmetic mean 304, and indeed, some of the papers qualify as hyper cited. Commonly, such papers are related to method and have a quite broad reach regarding research areas. As the frequency of citation to some extent is a function, not only of quality, but also of time, we need to compute the *Annual Citation Rate* (ACR) in order to be able to make comparisons. This is computed as the total number of citations divided by the number of years since publication (the citation window). Focusing on the absolute top cited papers, those papers with an annual citation rate of at least 100 are displayed in Table 4, where the citation window, the ACR and the title are shown for each paper. A good part of the papers reports empirical research and about half of the papers seem to be method papers. Hyper cited or highly cited papers may render some extra interest as they have an ageing scheme[5] that is comparatively slow. A more comprehensive compilation of all selected papers is given in *Appendix 1*.

Table 4. 19 papers with an annual citation rate of at least 100 citations, 1994–2003.

Citation window – years	ACR	Title
17	778	Quantifying heterogeneity in a meta-analysis
23	250	AFNI: Software for analysis and visualization of functional magnetic resonance neuroimages
20	234	Measuring agreement in method comparison studies
23	217	Multivariable prognostic models: Issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors
18	197	A global optimisation method for robust affine registration of brain images
18	177	Segmentation of brain MR images through a hidden Markov random field model and the expectation-maximization algorithm
16	175	Hydrogels for tissue engineering: scaffold design variables and applications
19	168	Scaffolds in tissue engineering bone and cartilage

[5] The decrease in use of a paper as it grows older. The term "use" in this context implies the citation of the paper in later papers.

21	166	Propensity score methods for bias reduction in the comparison of a treatment to a non-randomized control group
20	157	Nonrigid registration using free-form deformations: Application to breast MR images
21	139	A nonparametric method for automatic correction of intensity nonuniformity in MRI data
22	136	Multimodality image registration by maximization of mutual information
16	127	Silk-based biomaterials
21	127	Extracting summary statistics to perform meta-analyses of the published literature for survival endpoints
19	122	A mechanistic study of the antibacterial effect of silver ions on Escherichia coli and Staphylococcus aureus
16	105	RGD modified polymers: biomaterials for stimulated cell adhesion and beyond
16	104	Mutual-information-based registration of medical images: A survey
17	101	Electrospun nanofibrous structure: A novel scaffold for tissue engineering
18	100	Soft lithography in biology and biochemistry

Now to the more complex analysis of subject content. Computing citations between papers rendered a total of 3,959 pairs of linked papers and the total number of papers was 1,841, which is about 77 percent of all highly cited papers for this period. As a measure of the interconnectedness, and an important feature of the implicit network made up by these citation links, we compute the *average degree* as the number of adjacent lines of a node in the graph representing the network. Lines in this case denote citation links and nodes papers. Thus, we measure the number of times a paper (node) has received a citation from another paper in the set of papers being analysed, as well as the number of times it has cited another paper in the set of papers being analysed. Hence, a citation link has no direction in this type of analysis. For this period we find that the average degree for the network was 4.30. This figure has no real significance right now, but we can use it when making comparisons with the networks from the other periods. The next issue is to decompose this network by identifying coherent groups within it, using a cluster analytical approach. This means that we want to arrive at mutually exclusive clusters or groups where members of a group is more connected with each other than with members in other groups. Applying the VOS-cluster algorithm implemented in Pajek 5.08, different values on the resolution parameter (r) were tested. All test values showed up with satisfactory values for the VOS clustering quality function (Q) (Table 5).

Table 5. The quality function and the resolution parameter, 1994–2003.

r	Q	# Clusters
1.5	0.938	142
1.0	0.945	132
0.5	0.958	122
0.2	0.971	115

However, applying the lowest value r-value, several macro-clusters with a size between 113 and 404 were seen. Such an uneven distribution of cluster sizes does not meet expectations why instead r = 1.0 was tested. This rendered a total of 132 clusters with a size from 2 to 101. In Table 6, all clusters with a size above 10 papers are presented with a label based on the titles of the papers. This corresponds to an approximate 85 percent of the total number of clustered papers. See *Appendix 2* for more information about these clusters.

Table 6. Clusters, 1994–2003.

Cluster	Size	Label
26	101	Medical Imaging I
13	100	Biomaterials I
9	86	Biomaterials II
10	76	Biomaterials III
5	73	Oral implants
2	63	Applications chitosan
4	59	Neural systems
14	54	Calcium phosphate cements
7	52	Vascular systems
25	52	Microstructures
37	52	Bone growth
27	50	Medical imaging II
3	48	Biomaterials IV
43	48	Mechanical properties of human bone
17	44	Human walking
8	43	Biocompatibility and degradability
47	39	Meta-analysis
50	39	Health-information systems
12	35	Mechanical properties
21	35	Biomechanical and elastic properties
11	34	Articular cartilage
19	32	Biomechanical miscellaneous
18	31	Osteoblasts and surface
15	30	Biomaterials V
39	28	Kinematic analysis
48	28	Tomography algorithms
34	27	Blood-material interactions
40	27	Medical Imaging III
28	25	Chitosan - alginates
41	24	Brain analysis
32	22	Statistical models
20	17	ECG
46	15	Wear
6	14	Oral implants
23	14	Radiation therapy
49	14	Optical imaging
16	11	Antibacterial materials
31	10	Medical language
53	10	Electromagnetic analysis (FDTD)

Period 2: 2004-2013

For this period 98,762 papers were indexed in the Web of Science database and the annual percentage growth rate was 13 (Figure 3). Hence, a period of increased growth with a much higher publication output is seen.

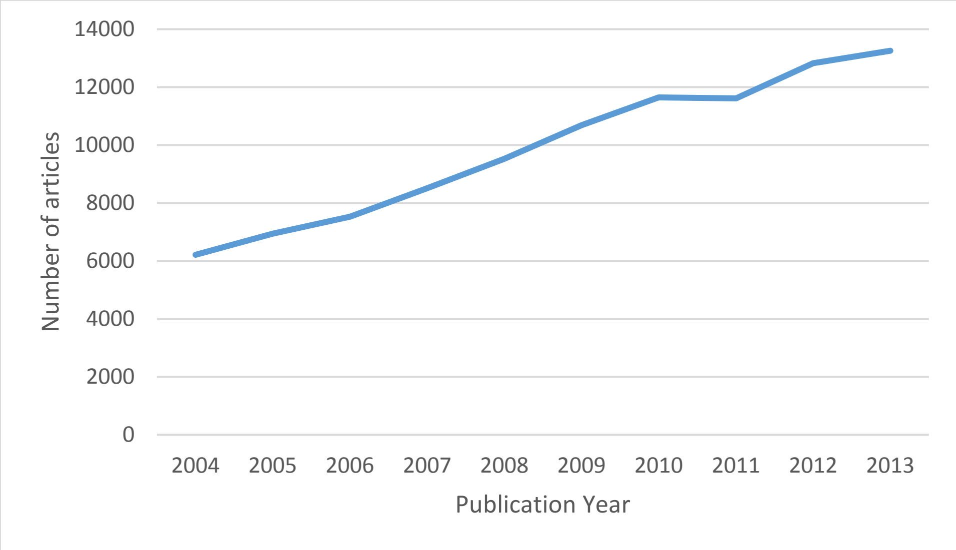

Figure 3. Annual number of published articles, 2004-2013.

The 25 most productive institutions published between 787 and 2,721 papers during this period. The dominance of American institutions is evident also in this period and we see the same universities as in the previous period on the top positions (Table 7). A minor difference is that *University of California System* moves to the first rank position. There are, however, some more interesting changes: on the 11th rank position *Chinese Academy of Sciences* is seen. In the previous period, no Chinese organisation was seen above the 26th rank position, implying a radical change during the second period. On the funding side, this is mirrored by the emergence of *National Natural Science Foundation of China* on the third rank position of funding agencies (Table 8). Another change is that *Centre national de la recherché scientifique* (CNRS) has risen from a 10th position in the first period to a fourth position in this period, marking important contributions in the field of basic research.

Table 7. The distribution of papers over 25 top-institutions, 2004-2013.

Organisations	# papers
UNIVERSITY OF CALIFORNIA SYSTEM	2721
HARVARD UNIVERSITY	2459
UNIVERSITY OF LONDON	1713
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	1594
PENNSYLVANIA COMMONWEALTH SYSTEM OF HIGHER EDUCATION PCSHE	1575
UNIVERSITY OF TEXAS SYSTEM	1421
VA BOSTON HEALTHCARE SYSTEM	1337
INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE INSERM	1272
UNIVERSITY OF TORONTO	1235
UNIVERSITY OF PITTSBURGH	1035
CHINESE ACADEMY OF SCIENCES	1022
UNIVERSITY OF MICHIGAN	1017
UNIVERSITY OF MICHIGAN SYSTEM	1017
UNIVERSITY SYSTEM OF GEORGIA	942

UNIVERSITY COLLEGE LONDON	909
SEOUL NATIONAL UNIVERSITY SNU	902
STANFORD UNIVERSITY	890
MASSACHUSETTS INSTITUTE OF TECHNOLOGY MIT	889
NATIONAL UNIVERSITY OF SINGAPORE	880
UNIVERSITY OF WASHINGTON	837
UNIVERSITY OF WASHINGTON SEATTLE	830
STATE UNIVERSITY SYSTEM OF FLORIDA	828
HELMHOLTZ ASSOCIATION	817
COLUMBIA UNIVERSITY	807
NATIONAL TAIWAN UNIVERSITY	787

Table 8. The distribution of papers over funding agencies, 2004-2013.

Funding Agencies	# papers
UNITED STATES DEPARTMENT OF HEALTH HUMAN SERVICES	14604
NATIONAL INSTITUTES OF HEALTH NIH USA	14309
NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA	3311
NATIONAL SCIENCE FOUNDATION NSF	2786
NIH NATIONAL INSTITUTE OF BIOMEDICAL IMAGING BIOENGINEERING NIBIB	1632
NIH NATIONAL CANCER INSTITUTE NCI	1547
NIH NATIONAL HEART LUNG BLOOD INSTITUTE NHLBI	1547
NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA	1400
MINISTRY OF EDUCATION CULTURE SPORTS SCIENCE AND TECHNOLOGY JAPAN MEXT	1316
NATIONAL SCIENCE COUNCIL OF TAIWAN	1201
ENGINEERING PHYSICAL SCIENCES RESEARCH COUNCIL EPSRC	1158
EUROPEAN UNION EU	1056
NATIONAL BASIC RESEARCH PROGRAM OF CHINA	1054
CANADIAN INSTITUTES OF HEALTH RESEARCH CIHR	984
NIH NATIONAL INSTITUTE OF ARTHRITIS MUSCULOSKELETAL SKIN DISEASES NIAMS	932
GERMAN RESEARCH FOUNDATION DFG	862
MINISTRY OF EDUCATION SCIENCE AND TECHNOLOGY REPUBLIC OF KOREA	828
NIH NATIONAL CENTER FOR RESEARCH RESOURCES NCRR	781
NIH NATIONAL LIBRARY OF MEDICINE NLM	744
MEDICAL RESEARCH COUNCIL UK MRC	710
NIH NATIONAL INSTITUTE OF NEUROLOGICAL DISORDERS STROKE NINDS	685
NIH NATIONAL INSTITUTE OF DENTAL CRANIOFACIAL RESEARCH NIDCR	677
JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE	597
UNITED STATES DEPARTMENT OF DEFENSE	570
AUSTRALIAN RESEARCH COUNCIL	553

The increase of the Chinese impact on the field of Medical technology is clearly mirrored also in the distribution of papers over countries (Figure 4, Table 9), where China now holds the second rank position. The difference in volume between the USA and China is, however, significant. The RSD is now 1.47 indicating a more even distribution. Other notable changes are India rising from the 25th rank position to the 17th and Sweden descending to the 18th rank position from the 9th.

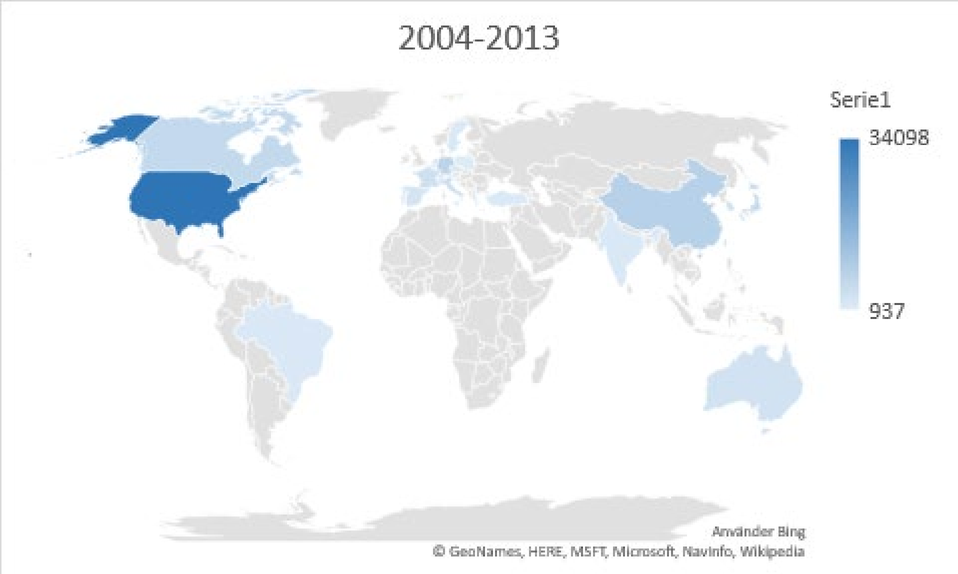

Figure 4. The distribution of papers over countries, 2004-2013.

Table 9. The distribution of papers over countries, 2004-2013.

Country	# records
USA	34098
PEOPLES R CHINA	8243
GERMANY	7460
ENGLAND	7347
CANADA	5947
JAPAN	5703
ITALY	4738
FRANCE	4061
SOUTH KOREA	3741
NETHERLANDS	3728
AUSTRALIA	3381
TAIWAN	2966
SPAIN	2807
SWITZERLAND	2601
SINGAPORE	1702
BRAZIL	1652
INDIA	1647
SWEDEN	1644
TURKEY	1433
BELGIUM	1426
AUSTRIA	1195
POLAND	1051
GREECE	1012
ISRAEL	986
PORTUGAL	937

Selecting the five percent most cited papers for this period, we focus on the part of the field's intellectual base which has a strong impact on later research. In total, 4,938 papers were selected from the total set of papers. The range of citation was 8131 and the arithmetic mean 210 which is below the corresponding figures for the previous period. On the other hand, the number of papers with an ACR of at least 100 is 30, reflecting a considerably larger citation volume than in the previous period. This is of course in line with a larger volume of papers, in turn mirroring a much higher growth rate during this period. In Table 10, the 30 high impact papers are shown with ACRs and titles. For this period, the top papers seem to deal mostly with empirical research. On top of the list though, we see method and review papers. A more comprehensive compilation of all selected papers is given in *Appendix 3*.

Table 10. 30 papers with an annual citation rate of at least 100 citations, 2004-2013.

Window	ACR	Title
10	824	Research electronic data capture (REDCap)-A metadata-driven methodology and workflow process for providing translational research informatics support
13	340	How useful is SBF in predicting in vivo bone bioactivity?
11	331	Evaluating the added predictive ability of a new marker: From area under the ROC curve to reclassification and beyond
14	320	Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications
8	292	Multiple imputation using chained equations: Issues and guidance for practice
14	221	Porosity of 3D biomaterial scaffolds and osteogenesis
7	220	The Effect of Nanoparticle Size, Shape, and Surface Chemistry on Biological Systems
6	198	Optical properties of biological tissues: a review
13	174	Magnesium and its alloys as orthopedic biomaterials: A review
13	172	Biodegradable and bioactive porous polymer/inorganic composite scaffolds for bone tissue engineering
11	166	Electro spinning: Applications in drug delivery and tissue engineering
9	158	elastix: A Toolbox for Intensity-Based Medical Image Registration
8	157	Extensions of net reclassification improvement calculations to measure usefulness of new biomarkers
6	152	Review of bioactive glass: From Hench to hybrids
8	142	An overview of tissue and whole organ decellularization processes
8	137	A review of the biological response to ionic dissolution products from bioactive glasses and glass-ceramics
9	126	Effects of particle size and surface charge on cellular uptake and biodistribution of polymeric nanoparticles
8	126	miRWalk - Database: Prediction of possible miRNA binding sites by "walking" the genes of three genomes
11	121	Symmetric diffeomorphic image registration with cross-correlation: Evaluating automated labeling of elderly and neurodegenerative brain
10	118	Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples
14	115	ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion - Part II: shoulder, elbow, wrist and hand
6	114	Dual and multi-stimuli responsive polymeric nanoparticles for programmed site-specific drug delivery
9	113	Using the Internet to Promote Health Behavior Change: A Systematic Review and Meta-analysis of the Impact of Theoretical Basis, Use of Behavior Change Techniques, and Mode of Delivery on Efficacy
12	111	OpenSim: open-source software to create and analyze dynamic Simulations of movement
11	107	Plasmonic photothermal therapy (PPTT) using gold nanoparticles

10	107	The BUGS project: Evolution, critique and future directions
9	104	N4ITK: Improved N3 Bias Correction
7	103	A review of wearable sensors and systems with application in rehabilitation
11	101	On the mechanisms of biocompatibility
14	101	In vivo corrosion of four magnesium alloys and the associated bone response

Exploring the cognitive structure of this period, a total of 12,604 paper pairs based on 4,231 distinct papers were generated when computing citation links. The average degree for the total network was 5.95. In all, we now deal with a citation network that is approximately three times the size of the network from the first period. It is also a more interconnected network with 86 percent of all of the 4,938 highly cited papers associated by citations and the average degree is also notably higher than in the first period. Applying the same cluster algorithm as for first period, a total of 164 clusters were generated, with a size varying from 2 to 302. Despite keeping the resolution parameter at $r = 1$ and a somewhat lower value on the quality function ($Q = 0.92$), we still arrived at some very large clusters; in total 13 cluster with 100 members or more. Clearly, we need to break up the largest clusters and rising the resolution parameter to 1.5 we steer clear from macro clusters at the small cost of lowering Q to 0.91. Now the largest cluster is split up and the number of clusters with a size > 100 is ten. A total of 55 clusters with a minimum size of 20 were identified. These clusters are presented in Table 11, and the labels are, as before, derived from the titles of the papers constituting the clusters. In some instances no clear research theme could be identified and therefore the most frequent title words replaced the label. This possibly reflect some topic drift in the clusters. See *Appendix 4* for more information about these clusters.

Table 11. Clusters, 2004–2013.

Cluster	Size	Label
41	191	Drug delivery, targeting (cancer) cells
29	143	Health-information technology
25	140	Surface features, nanoscale
34	125	Tissue engineering: regeneration, wound healing
17	111	Coatings, antimicrobial, antibacterial
3	105	Oral implants
18	103	Nanoparticles, graphene, gold, therapy, delivery
10	102	Bioactive glasses, ceramics, scaffolds
16	102	Medical Image, MRI, 3-D
2	101	Brain-Computer Interface
1	93	Tissue engineering, bio-printing, films
11	89	Bone replacement and repair, calcium phosphate
44	88	Tissue engineering: cartilage, silk-based scaffolds
7	87	Stem cells (neural), brain, mesenchymal, hydrogels
39	86	Computer tomography, MRI, Radiotherapy
31	82	Nanoparticles for drug delivery, magnetic nanoparticles
52	79	Medical monitoring, Gait-analysis, sensors
46	75	Muscle control, Human Motion (walking)
30	74	Hydrogels, stem cells, regeneration
43	71	Neural-tissue, stimulation, conductive
49	71	Tissue engineering: scaffolds, bone
23	69	Tissue engineering: hydrogels, scaffolds
6	67	Blood vessel tissue engineering
9	67	Biomedical alloys, corrosion

19	67	Bone implants
33	66	Nerve regeneration
35	66	Biomedical signal analysis: ECG, EEG, EMG
32	63	Matrix, tissue, extracellular, scaffolds
22	62	Neurorehabilitation, neural control
12	61	Hydroxyapatite, bone, human, tissue
26	61	Biomechanics: blood flow
45	59	Nano particles: drug delivery systems, imaging, treatment
21	58	Imaging, Micro-CT, bone, tissue engineering
4	57	Stem cells, tissue engineering
13	55	Chitosan in tissue engineering
28	53	Tissue engineering: hydrogels, injectable
53	53	Tissue engineering: collagen scaffolds
66	53	Medical Imaging: Retinal images, segmentation
5	52	Stem cells, mesenchymal, differentiation, cartilage
54	51	Surfaces, nanoparticles, proteins, adhesion
51	45	Tissue, biodegradable, endothelial, scaffolds.
58	45	Hydrogels, stem cells
42	43	Nano particles (fibres): peptides, drug delivery, therapy
59	43	Nano particles: drug delivery, anti-tumour therapy
14	42	Bone, tissue engineering
37	38	Tissue engineering, cartilage
27	36	Nanotubes, monolayers, surfaces, self-assembled
38	33	Meta-analysis
36	29	Propensity scores, statistical models
20	28	Biomimetic, biomedical applications
47	28	Biomechanics: strain, bone, cartilage, articular
56	23	Imaging systems: EIT, PET, etc.
15	20	Implants, bone, orthodontic
57	20	PET-scanning
67	20	Tissue engineering: stem cells, collagen

Period 3: 2014-2018

For this period 81,356 papers were indexed in the Web of Science database and the annual percentage growth rate was 5 (Figure 5). This means that the growth rate has levelled out. In terms of number of publications, during these five years, approximately 82 percent of the number of papers published during the second period were published, and in comparison with the first period, about 70 percent more papers were produced.

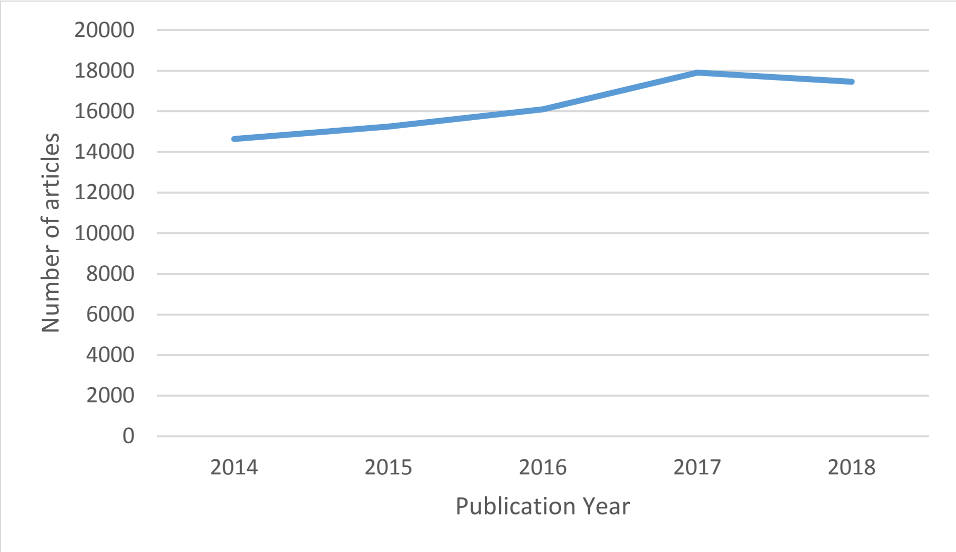

Figure 5. Annual number of papers, 2014-2018.

The distribution of papers over organisations for this period is similar to the previous one in terms of top positions, though the *Chinese Academy of Science* falls back from the second to the fourth rank position (Table 12). However, another Chinese university emerges at the 12th rank position – *Shanghai Jiao Tong University*. With regard to the funding agencies, we note that the *European Union* has reached a fifth rank position during this period (Table 13), as compared with a 12th position during the second period and below the 25th rank during the first.

Table 12. The distribution of papers over 25 top-institutions, 2014-2018.

Organisations	# papers
UNIVERSITY OF CALIFORNIA SYSTEM	1976
HARVARD UNIVERSITY	1906
UNIVERSITY OF LONDON	1458
CHINESE ACADEMY OF SCIENCES	1325
UNIVERSITY OF TEXAS SYSTEM	1317
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	1251
PENNSYLVANIA COMMONWEALTH SYSTEM OF HIGHER EDUCATION PCSHE	1083
VA BOSTON HEALTHCARE SYSTEM	1007
INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE INSERM	1004
UNIVERSITY OF MICHIGAN	880
UNIVERSITY OF MICHIGAN SYSTEM	880
SHANGHAI JIAO TONG UNIVERSITY	832
UNIVERSITY OF TORONTO	811
UNIVERSITY COLLEGE LONDON	806

STANFORD UNIVERSITY	803
JOHNS HOPKINS UNIVERSITY	787
UNIVERSITY OF NORTH CAROLINA	753
UNIVERSITY SYSTEM OF GEORGIA	735
UNIVERSITY OF PITTSBURGH	696
UNIVERSITY OF PENNSYLVANIA	695
IMPERIAL COLLEGE LONDON	650
HARVARD MEDICAL SCHOOL	639
NATIONAL UNIVERSITY OF SINGAPORE	637
COLUMBIA UNIVERSITY	630
SEOUL NATIONAL UNIVERSITY SNU	626

Table 13. The distribution of papers over funding agencies, 2014-2018.

Funding Agencies	# papers
UNITED STATES DEPARTMENT OF HEALTH HUMAN SERVICES	9816
NATIONAL INSTITUTES OF HEALTH NIH USA	9489
NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA	7670
NATIONAL SCIENCE FOUNDATION NSF	3088
EUROPEAN UNION EU	1669
MINISTRY OF EDUCATION CULTURE SPORTS SCIENCE AND TECHNOLOGY JAPAN MEXT	1438
NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA	1432
ENGINEERING PHYSICAL SCIENCES RESEARCH COUNCIL EPSRC	1156
NATIONAL BASIC RESEARCH PROGRAM OF CHINA	1114
FUNDAMENTAL RESEARCH FUNDS FOR THE CENTRAL UNIVERSITIES	1020
GERMAN RESEARCH FOUNDATION DFG	978
JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE	937
CANADIAN INSTITUTES OF HEALTH RESEARCH CIHR	892
NIH NATIONAL CANCER INSTITUTE NCI	824
MEDICAL RESEARCH COUNCIL UK MRC	654
NATIONAL COUNCIL FOR SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT CNPQ	618
EUROPEAN RESEARCH COUNCIL ERC	611
NIH NATIONAL HEART LUNG BLOOD INSTITUTE NHLBI	597
UNITED STATES DEPARTMENT OF DEFENSE	597
AUSTRALIAN RESEARCH COUNCIL	595
NIH NATIONAL INSTITUTE OF BIOMEDICAL IMAGING BIOENGINEERING NIBIB	565
NATIONAL INSTITUTE FOR HEALTH RESEARCH NIHR	523
AMERICAN HEART ASSOCIATION	469
FRENCH NATIONAL RESEARCH AGENCY ANR	466
CHINA POSTDOCTORAL SCIENCE FOUNDATION	461

The geographical map for this period reflects the dominance of the USA and the established influence from China (Figure 6). On the country level, we see a similar rank order with regard to the top positions as in the previous period (Table 14). Some changes take place though: South-Korea moves up from a ninth position in the previous period to a sixth position and Sweden falls back two positions to the 20th position. India continues to climb and rises from a 17th position in the previous period to a 12th position. The difference between the USA and China is now less pronounced. In the previous period, the *relative percentage difference* between the USA and China was 122 percent, and in this period it has dropped to 60 percent[6]. This distribution is more even as the previous as reflected by a lower RSD of 1.33.

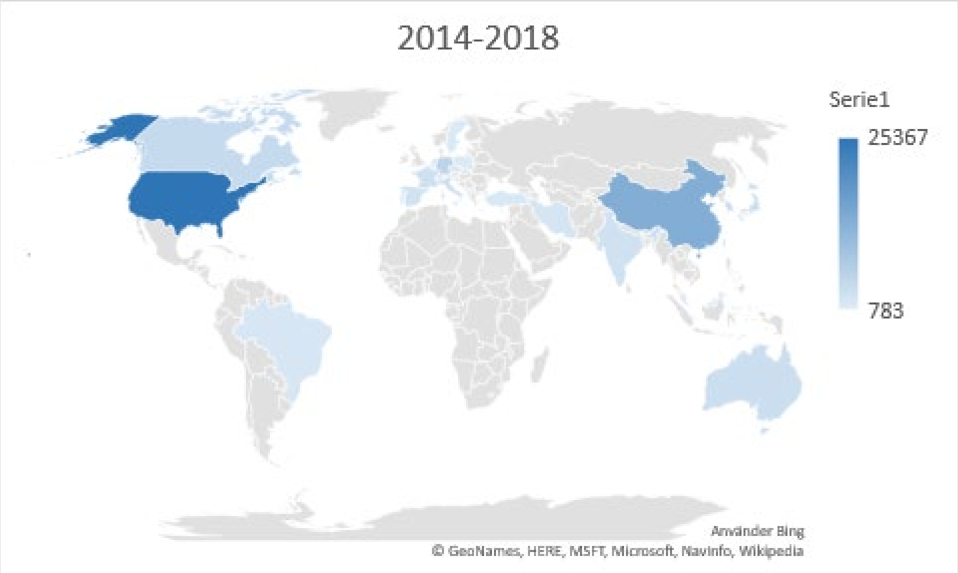

Figure 6. The distribution of papers over countries, 2014-2018.

Table 14. The distribution of papers over countries, 2014-2018.

Country	# records
USA	25367
PEOPLES R CHINA	13602
ENGLAND	5858
GERMANY	5480
CANADA	4262
SOUTH KOREA	3608
JAPAN	3574
ITALY	3454
AUSTRALIA	3405
FRANCE	2978
NETHERLANDS	2887
INDIA	2802
SPAIN	2691
SWITZERLAND	2199
IRAN	2107
TAIWAN	1787
BRAZIL	1740
TURKEY	1500
BELGIUM	1304
SWEDEN	1288
SINGAPORE	1182
POLAND	1104

[6] The relative percentage difference was computed as: $\frac{N_1-N_2}{\frac{N_1+N_2}{2}} \cdot 100$, where N_1 signifies the first number and N_2 the second.

PORTUGAL	1002
AUSTRIA	845
MALAYSIA	783

For the last period, the five percent most cited papers constituted a set of 4,068 papers. The range of citation was 768 and the arithmetic mean was 60, which is in line with expectations for this shorter period of observation. In a similar sense, we chose to display top cited papers with an ACR of at least 70, a total of 32 papers (Table 15). We can appreciate that the top listed papers deal with novel methods and techniques and that the major part of papers concern methods and new techniques related to medical imaging. A more comprehensive compilation of all selected papers is given in *Appendix 5*.

Table 15. 32 papers with an ACR of at least 70 citations, 2014-2018.

Window	ACR	Title
2	401	A survey on deep learning in medical image analysis
3	239	Deep Convolutional Neural Networks for Computer-Aided Detection: CNN Architectures, Dataset Characteristics and Transfer Learning
2	206	Efficient multi-scale 3D CNN with fully connected CRF for accurate brain lesion segmentation
2	204	Brain tumor segmentation with Deep Neural Networks
2	177	Near-infrared fluorophores for biomedical imaging
2	149	Deep Learning in Medical Image Analysis
4	145	The Multimodal Brain Tumor Image Segmentation Benchmark (BRATS)
3	135	Convolutional Neural Networks for Medical Image Analysis: Full Training or Fine Tuning?
5	117	Kubios HRV - Heart rate variability analysis software
2	116	Antibacterial anti-oxidant electroactive injectable hydrogel as self-healing wound dressing with hemostasis and adhesiveness for cutaneous wound healing
3	115	Brain Tumor Segmentation Using Convolutional Neural Networks in MRI Images
4	110	Moving towards best practice when using inverse probability of treatment weighting (IPTW) using the propensity score to estimate causal treatment effects in observational studies
3	109	Topological design and additive manufacturing of porous metals for bone scaffolds and orthopaedic implants: A review
5	107	Conductive polymers: Towards a smart biomaterial for tissue engineering
1	106	Recent progress on semiconducting polymer nanoparticles for molecular imaging and cancer phototherapy
3	100	Nanoparticles in the clinic
3	91	Mechanisms and biomaterials in pH-responsive tumour targeted drug delivery: A review
4	91	Synthesis, properties, and biomedical applications of gelatin methacryloyl (GelMA) hydrogels
1	89	Deep convolutional neural network for the automated detection and diagnosis of seizure using EEG signals
3	88	Current advances and future perspectives in extrusion-based bioprinting
5	84	A doxorubicin delivery platform using engineered natural membrane vesicle exosomes for targeted tumor therapy
2	84	Large scale deep learning for computer aided detection of mammographic lesions
1	82	Prediction of cardiovascular risk factors from retinal fundus photographs via deep learning
2	77	Deep Learning for Health Informatics
2	76	Extracorporeal Life Support Organisation Registry International Report 2016
1	75	Mesoporous Silica and Organosilica Nanoparticles: Physical Chemistry, Biosafety, Delivery Strategies, and Biomedical Applications

1	75	Surface functionalized exosomes as targeted drug delivery vehicles for cerebral ischemia therapy
3	75	Lung Pattern Classification for Interstitial Lung Diseases Using a Deep Convolutional Neural Network
3	73	Pulmonary Nodule Detection in CT Images: False Positive Reduction Using Multi-View Convolutional Networks
5	73	Curcumin nanoformulations: A review of pharmaceutical properties and preclinical studies and clinical data related to cancer treatment
4	72	Mobile App Rating Scale: A New Tool for Assessing the Quality of Health Mobile Apps
2	70	Current status on clinical applications of magnesium-based orthopaedic implants: A review from clinical translational perspective

For the last period, the cluster analysis generated 3,530 pairs based on citation links between 2,494 papers, which is about 60 percent of the total number of papers for the period. This time a resolution parameter set to $r = 1$ did not result in macro clusters, there were no clusters with a size > 100 and the total number of clusters was 275. Thus, this partition is much more finely divided than the previous ones. The cluster quality was also higher with $Q = 0.96$ and the average degree was only 1.0, reflecting a less interconnected network. Conclusively, this network differs substantially from the previous ones. In Table 16, 47 clusters with a minimal size of 20 are presented. More information about these clusters is given in *Appendix 6*.

Table 16. Clusters, 2014-2018.

Cluster	Size	Label
31	85	Bioprinting
5	70	Imaging-guided therapy, photo-thermal therapy
43	65	Osteointegration, antimicrobial
25	61	Bone biomaterials, Cytocompatibility, regeneration
3	59	Scaffolds, stem cells, matrix, regeneration, hydrogel
10	59	Theranostics, nanoparticles, cancer
23	58	Computer aided detection and diagnosis
2	51	3-d printing, tissue engineering, stem cells
9	49	Drug delivery systems
14	49	Hydrogel, cardiac, self-healing
27	48	Tissue engineering, scaffolds
6	45	Photothermal therapy, imaging, drug delivery
59	45	Computer methods, deep learning
22	43	Drug delivery, tumour therapy
67	43	Health monitoring, clinical information
7	39	Drug delivery, nanoparticles, tumour therapy
15	39	Biomaterials, metals, magnesium
30	36	Tissue engineering, biomaterials, hydrogels
49	36	Cardiovascular tissue engineering
8	34	Chitosan, mussel derived
45	34	EEG: epileptic seizures, sleep
24	32	Biomedical materials, mechanical behaviour, porous
50	32	Biomedical materials, bone, tissue
1	31	Tissue engineering, bone, muscle
39	31	Tissue engineering miscellaneous
51	31	Drug delivery, anticancer therapy
71	31	Tissue regeneration
82	31	EMG, myoelectric control

34	30	SSVEPs, BCI
91	30	Tissue engineering, tissue regeneration
26	29	Tissue engineering, wound healing
19	28	Neural tissue engineering
37	27	Antimicrobial coatings
62	27	Tissue regeneration, wound healing
18	26	Drug delivery, nanoparticles, photothermal therapy
38	25	Drug delivery, nanoparticles
74	25	Tissue engineering, tissue regeneration
100	24	Cell differentiation, stem cells, graphene
109	24	Health information
12	23	Cancer (stem cell) therapy, nanoparticles
58	23	Medical imaging: 3-D segmentation
56	22	Health information, portals
57	22	Tissue engineering, stem cells
80	22	Osteochondral tissue engineering
44	21	Tissue engineering, cartilage, bones
72	21	Fluorescent probes, cells
21	20	Classification, ECG

A Local View

Now we change our focus to papers with an address associated with UG or CUT. We are particularly interested in papers with addresses to both institutions, identifying research collaboration between these institutions. But first, an overview of the data pertaining to the local view. In total 1,249 papers were downloaded from the Web of Science where all document types and all publication years were allowed (Table 17). We can appreciate that most papers are articles or proceedings papers but there are also 17 review papers. Note that some proceedings papers can also be assigned to the document type article.

Table 17. The distribution of papers over document types.

Document type	# papers
Article	938
Proceedings Paper	161
Meeting Abstract	61
Article; Proceedings Paper	43
Review	17
Note	16
Letter	4
Editorial Material	3
Article; Retracted Publication	1
Article; Early Access	1
Review; Early Access	1
Item About an Individual	1
Discussion	1
Correction	1
Total	**1249**

The next issue of interest is the temporal development of these papers (Figure 7). We can see a clear annual increase of papers over time. The first paper is published 1973 and the diagram shows the annual number of papers from 1973 through 2018. For 2019, and so far, 27 papers have been published. The pattern, however, is quite erratic, and the best fit of the curve was achieved using a 6th grade polynomial. Thus, we conclude that the focus on medical technological aspects is clearly increasing over time but there seems to be no steadfast publishing strategy.

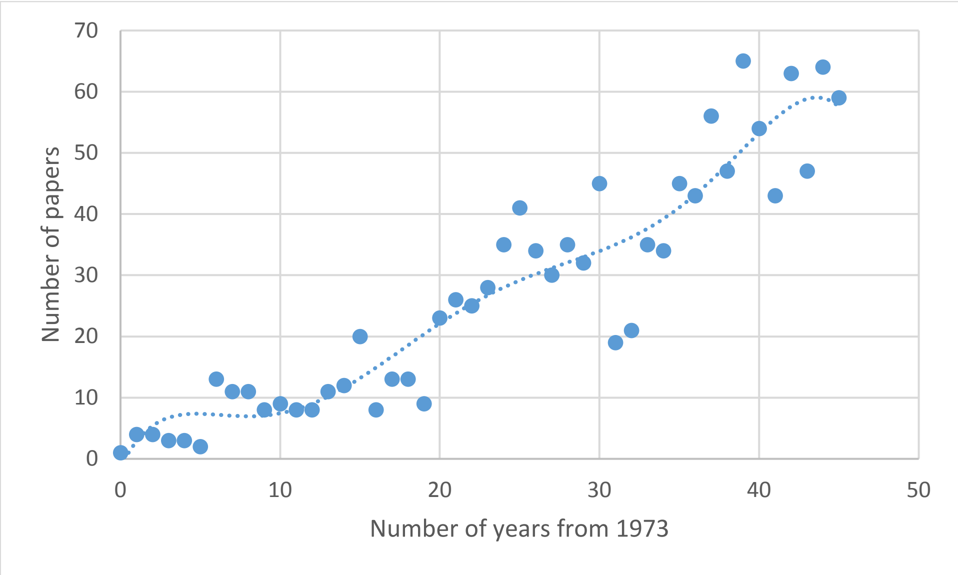

Figure 7. The temporal development of publishing within Medical technology, 1973-2018. All document types.

Collaboration

Maintaining a quantitative perspective, we next count the number of papers for UG and CUT each. For UG we count 866 papers and for CUT 401, including overlapping papers. As university hospitals have great influence on a university's research and publishing, it is often a good idea to include such addresses as they tend to overlap with the medical faculties. For Sahlgrenska University Hospital (SUH) we count 103 papers. Note that this count is only relevant in the sense that it mirrors collaboration with either CUT or UG or both. Now we need to find out the collaborative pattern for these three institutions. With regard to the whole period of observation, we find the following collaborative pattern (Table 18):

Table 18. The distribution of collaborative papers over pairs of institutions.

# collaborative papers	Institution A	Institution B
119	CUT	UG
62	SUH	UG
48	CUT	SUH

We can appreciate that the strongest link of collaboration is between CUT and UG, followed by the link between SUH and UG. The weakest link is between CUT and SUH. In a relative sense, approximately ten percent of the total number of CUT and UG papers were generated in collaboration with each other. Considering the temporal aspect, we count the number of collaborative papers over the whole period of observation in order to intercept trends (Figure 8).

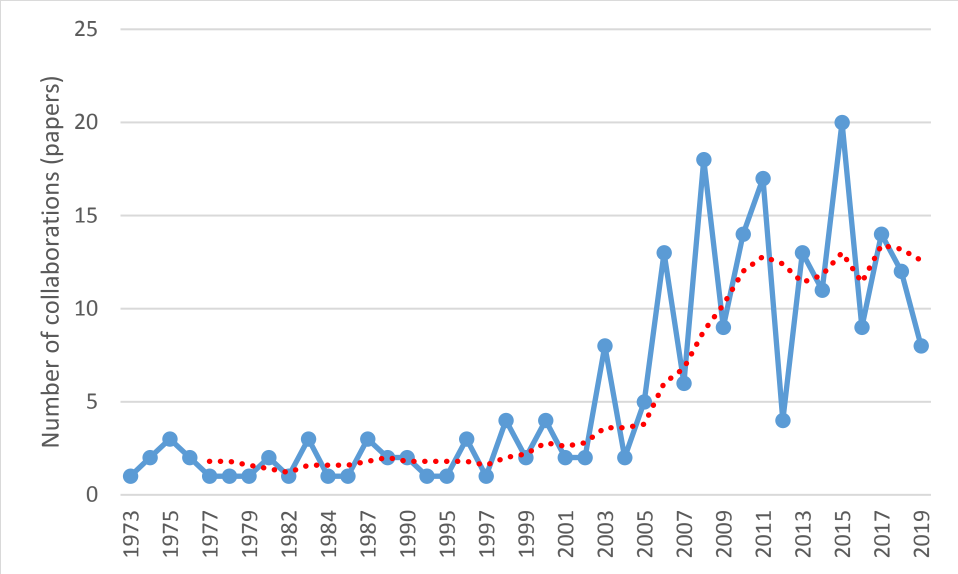

Figure 8. The distribution of collaborations between University of Gothenburg, Chalmers Institute of Technology and Sahlgrenska University Hospital. Number of collaborative papers per year and moving averages with five year periods.

Using a five-period moving averages, an increasing trend of collaboration is seen over the period of observation. A clear shift somewhere around 2004 indicate a change of trend with considerably more collaboration. We see the most frequent collaboration during 2015 and the largest dip during 2012. The number of collaborations for 2019 is of course preliminary. Next, we consider the collaboration over time for all combinations of the three institutions. In order to facilitate the interpretation of data, we compress the distribution of years to five-year periods and focus on the last 25 years (Table 19).

Table 19. The distribution of collaborative papers over collaborating institutions.

Period	CUT-SUH	CUT-UG	SUH-UG
1995-1999	5	9	1
2000-2004	0	15	3
2005-2009	8	23	20
2010-2014	14	28	16
2015-2019	21	32	20
Total	48	107	60

For all periods, the most frequent collaboration is between CUT and UG and the collaboration is continuously increasing over time. With regard to SUH, collaboration increase over time but is less continuous. It is also of interest to map the collaboration with regard to external organisations. We applied two levels: (1) organisational and (2) national. Starting with (1), a total of 774 distinct organisations were identified after a thorough standardisation where spelling variations of organisational names were unified. Organisations occurring in at least ten papers during the period of observation were selected for the further analysis, a total of 27 organisations. Applying Pajek for the drawing of the network, a graph centred on UG and CUT was generated (Figure 9). In this figure, the size of nodes representing organisations are proportional to the number of papers in which they occur. Surrounding a core constituted of UG, CUT, SUH, we recognize Swedish universities along with BIOMATCELL and SP (nowadays RISE). Private corporations, foreign research institutions and foreign universities are more peripheral. We could also look at the composition of this network:

- the number of universities is 17,
- the number of private corporations is 3,
- the number of university hospitals is 1, and
- the number of research institutions or affiliated organisations is 6.

Note that this count is valid only for organisations occurring at least ten times. Still, we may conclude that there are not so many frequently collaborating university hospitals nor is there as many frequently collaborating private corporations, as one may have expected. The exact numbers of collaborations for pairs of institutions, down to a frequency of five, are given in Table 20.

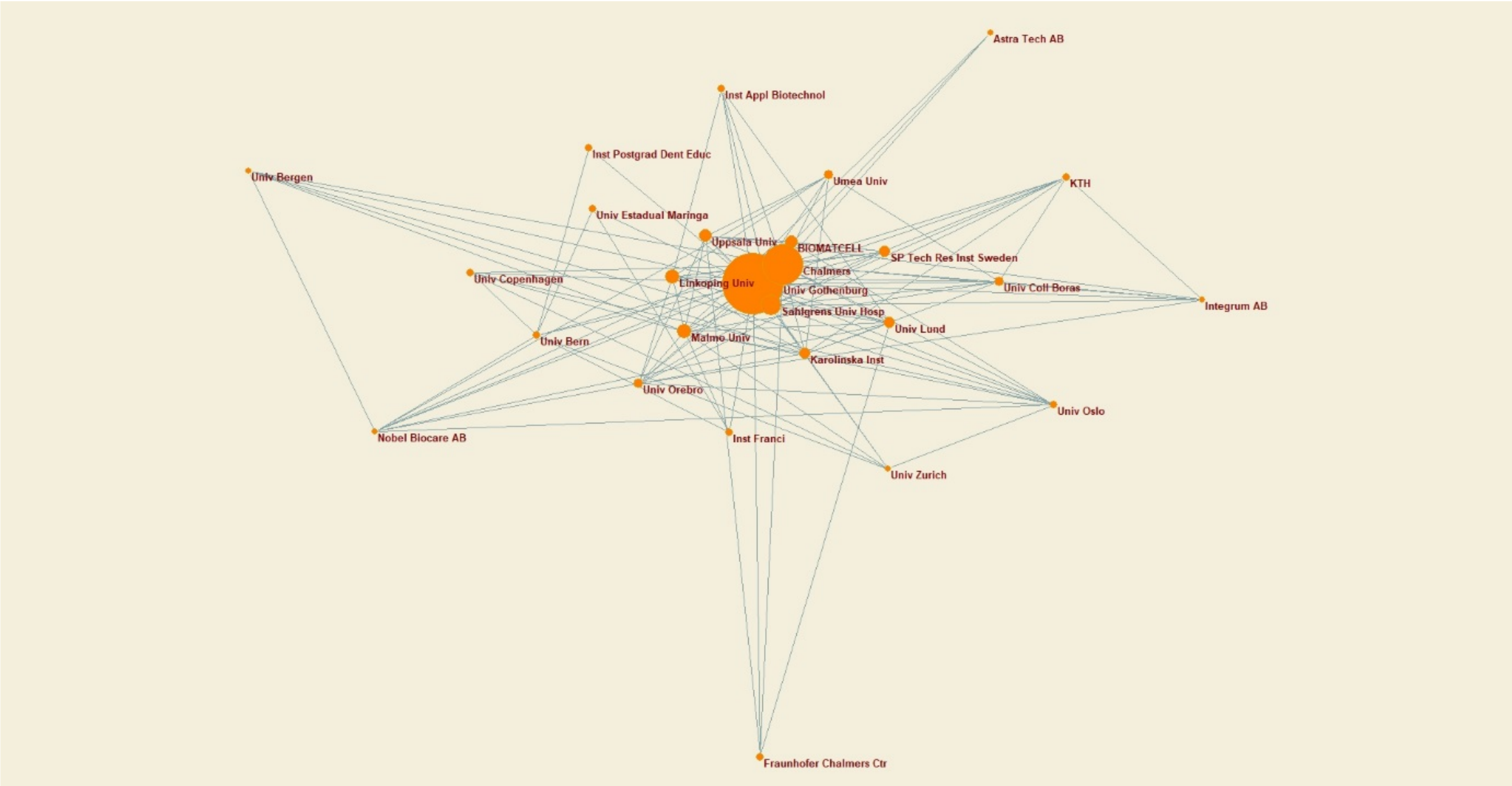

Figure 9. Pajek map over 27 collaborating institutions, the Local view.

Table 20. The collaboration between 27 organisations, the Local view.

# papers	Institution A	Institution B
119	Chalmers	Univ Gothenburg
62	Sahlgrens Univ Hosp	Univ Gothenburg
48	Chalmers	Sahlgrens Univ Hosp
43	Linkoping Univ	Univ Gothenburg
34	BIOMATCELL	Univ Gothenburg
32	Malmo Univ	Univ Gothenburg
30	Univ Gothenburg	Uppsala Univ
24	Karolinska Inst	Univ Gothenburg
23	SP Tech Res Inst Sweden	Univ Gothenburg
16	Univ Estadual Maringa	Univ Gothenburg
16	Chalmers	Malmo Univ
16	Chalmers	Univ Coll Boras
16	Umea Univ	Univ Gothenburg
15	Univ Bern	Univ Gothenburg
14	Univ Coll Boras	Univ Gothenburg
13	Inst Franci	Univ Gothenburg
13	Univ Copenhagen	Univ Gothenburg
12	Univ Gothenburg	Univ Orebro
12	Inst Postgrad Dent Educ	Univ Gothenburg
11	BIOMATCELL	SP Tech Res Inst Sweden
11	Univ Lund	Univ Gothenburg
11	Univ Gothenburg	UNIV LUND
10	KTH	Univ Gothenburg
10	Inst Appl Biotechnol	Univ Gothenburg
10	Univ Gothenburg	Univ Oslo
10	Univ Gothenburg	Univ Zurich
9	Chalmers	Karolinska Inst
9	Chalmers	KTH
9	Chalmers	Integrum AB
9	Sahlgrens Univ Hosp	Univ Coll Boras
8	Karolinska Inst	KTH
8	Nobel Biocare AB	Univ Gothenburg
7	Chalmers	Univ Bergen
7	Astra Tech AB	Univ Gothenburg
7	Chalmers	Univ Lund
6	Malmo Univ	Univ Bergen
6	Chalmers	Linkoping Univ
5	Karolinska Inst	Sahlgrens Univ Hosp
5	Univ Bergen	Univ Gothenburg
5	BIOMATCELL	Chalmers
5	Chalmers	SP Tech Res Inst Sweden
5	Astra Tech AB	Chalmers

On the national level we assess how international research is. The global pattern of collaboration reveals by and large what may be expected; more intense collaboration with European and North American actors, some collaboration with Asia and South America (Brazil) and random collaborations with Africa. Somewhat unexpectedly, the Chinese collaboration seems very weak and Asian collaboration concerns foremost Japan (Figure 10, Table 21). Another deviation from the expected is that the collaboration with Nordic countries is not as strong as one may expect – geographical distance usually has a stronger influence. The strong collaboration with England and Germany, however, adheres to the norm.

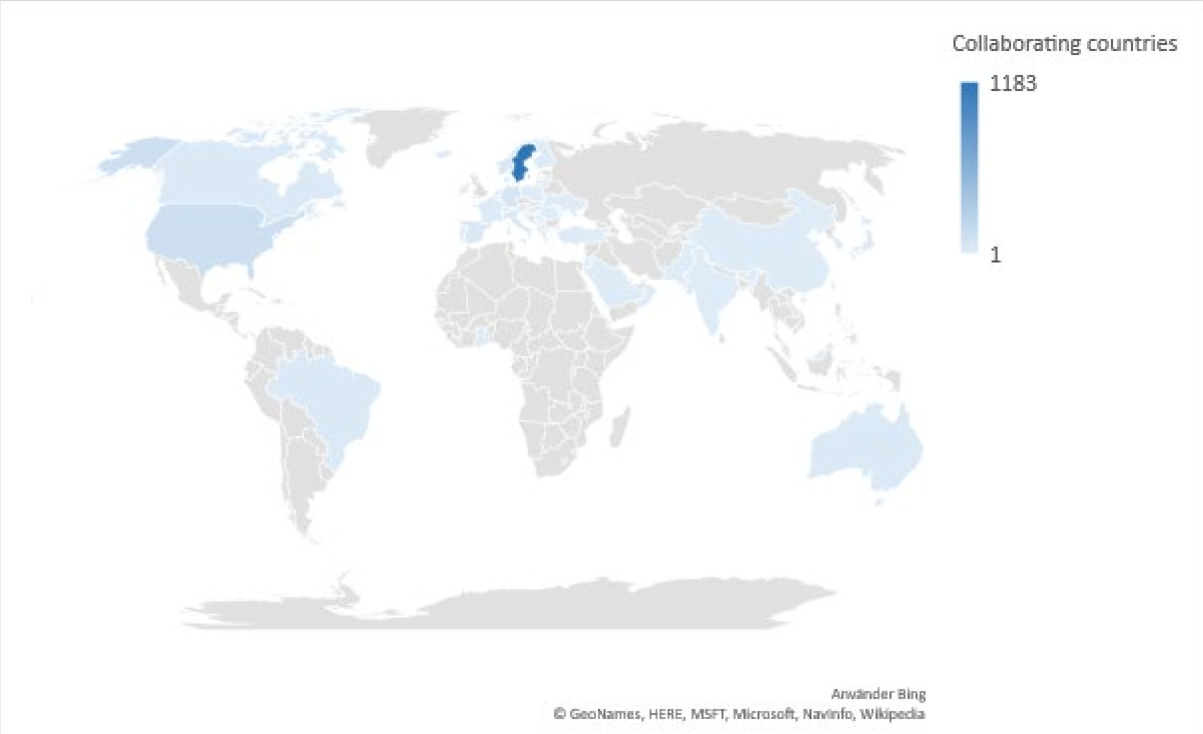

Figure 10. Collaborating countries, all 51 countries, the Local view.

Table 21. The distribution of collaborative countries occurring at least ten times, the Local view.

Country	# papers
Sweden	1249
USA	119
England	61
Germany	59
Switzerland	48
Italy	48
Norway	39
Japan	33
Spain	30
Belgium	28
Netherlands	27
Denmark	24
Brazil	23
South Korea	22

Australia	21
Canada	18
France	13
Finland	11
Austria	10

The cognitive content on the Local level

Though we grasp the evolution of collaboration, we don't know what kind of research themes each institution focuses on, or what kind of research themes give rise to collaboration. The next issue is therefore to map the cognitive content. As established, the bulk of papers pertain to the last two decades, hence the mapping basically mirrors that period. Applying the same methods as previously, citation links between papers were computed and applied as input to the clustering routine of Pajek. A total of 738 papers joined by 1,920 links gave rise to a network with the average degree = 5.20. This time the cluster solution comprised 96 clusters of various sizes (Table 22).

Table 22. The distribution of cluster sizes. The Local view.

# papers	Frequency	Cum. # papers	Cum % papers
44	1	44	6
43	1	87	12
37	1	124	17
35	1	159	22
34	1	193	26
33	1	226	31
30	1	256	35
29	1	285	39
28	1	313	42
22	1	335	45
21	1	356	48
20	1	376	51
19	2	414	56
15	2	444	60
14	1	458	62
13	1	471	64
12	1	483	65
9	3	510	69
8	2	526	71
7	3	547	74
6	1	553	75
5	7	588	80
4	5	608	82
3	18	662	90
2	38	738	100

Setting a threshold for the minimal cluster size to twelve, 65 percent of all papers related by citations were included in this analysis. In this case we need some more information than previously as we are interested in the cluster composition also from an organisational-collaborative perspective. In Table 23, five facts describing 19 selected clusters with a minimal size of 12 are presented:

1. Size (number of papers)
2. Mean publication year
3. Labels derived from titles
4. The number of affiliations to CUT and UG
5. The average degree of a cluster.

Paragraph 4 needs commenting: counting the total number of affiliations made to respective institution, CUT or UG, approximates which of the two institutions has more or less influence on a certain cluster. Some clusters may warrant special attention, why comprehensive bibliographic information is given in *Appendix 7*.

Table 23. 19 clusters with a minimal size of twelve papers. The Local view.

Cluster	Size	Avg. degree	Mean PY	Label	CUT	UG
2	44	5.32	2012	Implants	11	39
16	43	5.44	2009	Oral implants	1	42
5	37	5.68	1999	Implanted materials and reactions	3	36
6	35	3.09	2002	Bone augmentation; experimental studies	0	34
3	34	4.53	2002	Implants	12	26
21	33	4.30	2005	Oral implants	1	30
8	30	5.67	2007	Implants and surfaces	28	5
1	29	6.90	2011	Tissue engineering; scaffolds, cellulose	28	12
12	28	3.71	2007	Osseointegration	14	16
7	22	2.55	2007	Titanium implants	5	19
11	21	2.38	1998	Blood protein interactions with surfaces	5	16
22	20	3.30	2011	Oral implants	0	20
9	19	2.95	1997	Oral implants	7	12
14	19	2.32	2005	Oral implants	1	18
18	15	4.27	2009	Oral implants	0	15
29	15	2.67	2010	Orthopaedic implants; prostheses	2	13
13	14	2.86	2012	Oral implants; titanium implants	1	13
20	13	2.31	1994	Titanium implants	4	9
28	12	2.67	1998	Biomechanical models	8	4

On the sequent pages, the network structure of each cluster is presented with titles of papers. The objective of this presentation is to facilitate a more detailed interpretation of this sub-set of papers connected by citations. Studying these networks, it becomes obvious that some clusters are more loosely bound than others. As a measure of cluster coherence, we use the average degree. From Table 23 we can conclude that the variation of the average degree of clusters is large, ranging from 2.31 to 6.9. We should also expect some topic drift, i.e. the perceived subject inconsistency of a cluster. This could be subjectively assessed when comparing the intellectual content of titles representing papers. As mentioned, one common cause of topic drift in a citation network is the frequent citation of method papers with a broad applicability. An example of this is seen in Cluster 12 where paper 254, *Response of rat osteoblast-like cells to microstructured model surfaces in vitro*, cites paper 364, *Design and microstructuring of PDMS surfaces for improved marine biofouling resistance* (cf. Figure 19 and Table 32). Clearly, Marine biofouling has little to do with the bone cells in a rat. In this case, however, the method for preparation of samples was described in the latter paper, making an intellectual connection with the former. A method for studying the underlying networks of clusters may be suggested. Taking cluster 2 as an example, we may start by noting some descriptive information. From Table 23 we can conclude that not only is this cluster the largest but also one of the more coherent clusters, with an average degree > 5. Looking at the graph in Figure 11, we can identify those nodes (papers) that have a central position, that is, are connected with lines to several other papers. For instance, we can appreciate that node 1210: *The correlation between gene expression of proinflammatory markers and bone formation during osseointegration with titanium implants* have lines to 16 other nodes {3, 9, 71, 428, 802, 811, 836, 895, 904, 968, 1040, 1041, 1068, 1073, 1083, 1184}. Consulting Table 24, we can identify the titles of these papers and subsequently assess the cognitive surrounding of paper 1210, which in this example may be interpreted as a research theme of bone healing within the larger the context of implants.

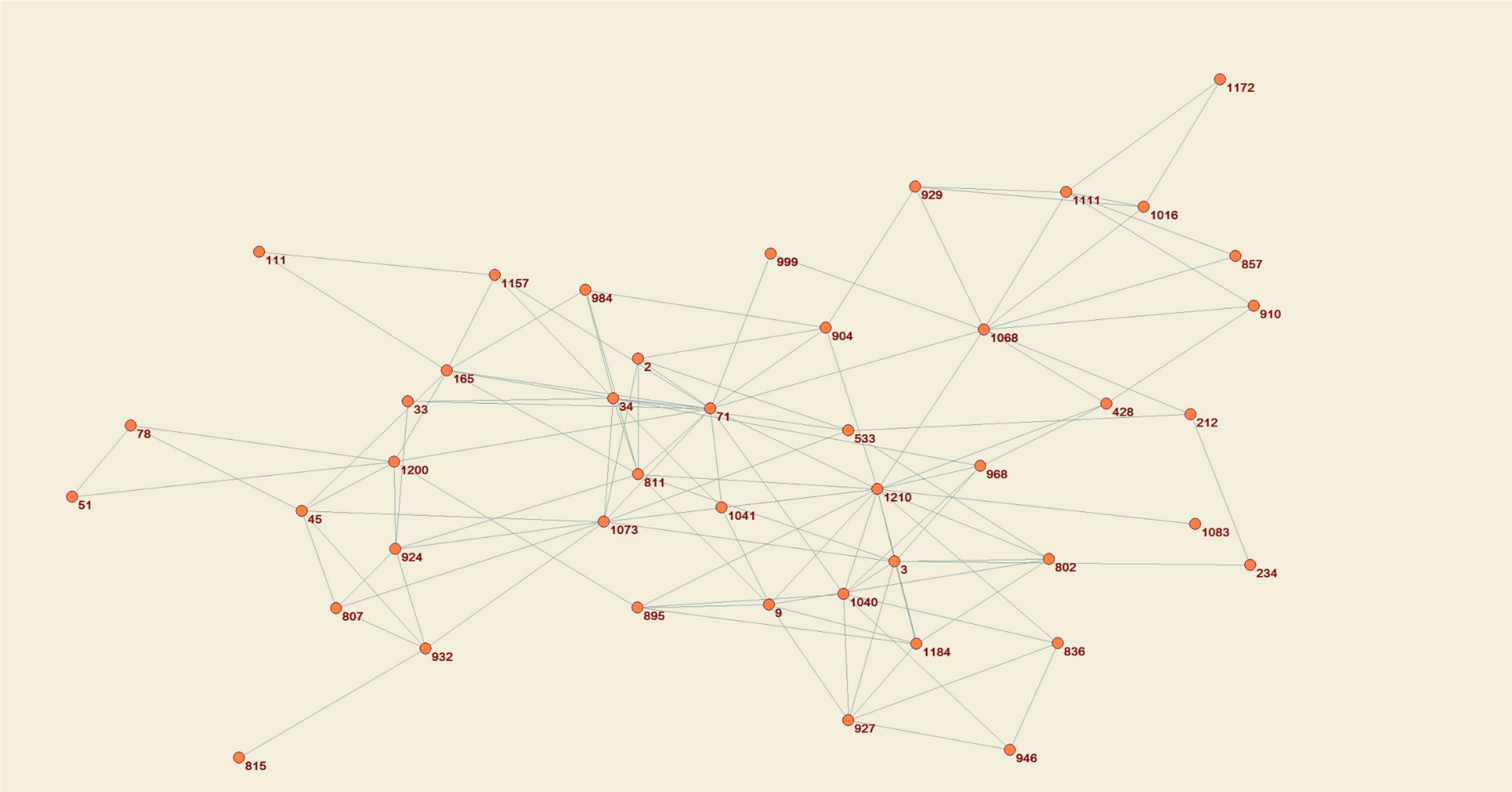

Figure 11.Cluster 2: Implants. The Local view.

Table 24. Cluster 2: Implants. The Local view.

Nr.	Titles
2	Biomechanical, histological, and ultrastructural analyses of laser micro- and nano-structured titanium alloy implants: A study in rabbit
3	In vivo gene expression in response to anodically oxidized versus machined titanium implants
9	Integrin and chemokine receptor gene expression in implant-adherent cells during early osseointegration
33	Calcium Aluminate Coated and Uncoated Free Form Fabricated CoCr Implants: A Comparative Study in Rabbit
34	Morphological Studies on Machined Implants of Commercially Pure Titanium and Titanium Alloy (Ti6Al4V) in the Rabbit
45	Electron Beam-Melted, Free-Form-Fabricated Titanium Alloy Implants: Material Surface Characterization and Early Bone Response in Rabbits
51	Bone response to free form-fabricated hydroxyapatite and zirconia scaffolds: a histological study in the human maxilla
71	Technique for preparation and characterization in cross-section of oral titanium implant surfaces using focused ion beam and transmission electron microscopy
78	Bone ingrowth in zirconia and hydroxyapatite scaffolds with identical macroporosity
111	A novel method for producing electron transparent films of interfaces between cells and biomaterials
165	A novel tool for high-resolution transmission electron microscopy of intact interfaces between bone and metallic implants
212	Implantation of hydrophilic and hydrophobic titanium discs in rat tibia: cellular reactions on the surfaces during the first 3 weeks in bone
234	Novel in vivo method for evaluation of healing around implants in bone
428	An in-vivo method for biomechanical characterization of bone-anchored implants
533	Bone response to surface-modified titanium implants - studies on electropolished implants with different oxide thicknesses and morphology
802	Interactions between monocytes, mesenchymal stem cells, and implants evaluated using flow cytometry and gene expression
807	Osseointegration of 3D printed microalloyed CoCr implantsAddition of 0.04% Zr to CoCr does not alter bone material properties
811	A multiscale analytical approach to evaluate osseointegration
815	Multiscale characterization of cortical bone composition, microstructure, and nanomechanical properties in experimentally induced osteoporosis
836	Tissue dynamics and regenerative outcome in two resorbable non-cross-linked collagen membranes for guided bone regeneration: A preclinical molecular and histological study in vivo
857	Magnesium release from mesoporous carriers on endosseus implants does not influence bone maturation at 6 weeks in rabbit bone
895	Inflammatory cell response to ultra-thin amorphous and crystalline hydroxyapatite surfaces
904	Direct communication between osteocytes and acid-etched titanium implants with a sub-micron topography
910	Stem cell homing using local delivery of plerixafor and stromal derived growth factor-1alpha for improved bone regeneration around Ti-implants
924	Long-term osseointegration of 3D printed CoCr constructs with an interconnected open-pore architecture prepared by electron beam melting
927	Guided bone regeneration is promoted by the molecular events in the membrane compartment

Table 24 continued.

929	The effect of alendronate on biomineralization at the bone/implant interface
932	3D printed Ti6Al4V implant surface promotes bone maturation and retains a higher density of less aged osteocytes at the bone-implant interface
946	Guided bone regeneration using resorbable membrane and different bone substitutes: Early histological and molecular events
968	Bone response to a novel Ti-Ta-Nb-Zr alloy
984	Ultrastructural evaluation of shrinkage artefacts induced by fixatives and embedding resins on osteocyte processes and pericellular space dimensions
999	Ex vivo alendronate localization at the mesoporous titania implant/bone interface
1016	In vitro evaluation of human fetal osteoblast response to magnesium loaded mesoporous TiO2 coating
1040	Molecular and structural patterns of bone regeneration in surgically created defects containing bone substitutes
1041	Hydroxyapatite coating affects the Wnt signaling pathway during pen-implant healing in vivo
1068	Raloxifene and alendronate containing thin mesoporous titanium oxide films improve implant fixation to bone
1073	Long-term biocompatibility and osseointegration of electron beam melted, free-form-fabricated solid and porous titanium alloy: Experimental studies in sheep
1083	The effects of a systemic single dose of zoledronic acid on post-implantation bone remodelling and inflammation in an ovariectomised rat model
1111	In vivo biomechanical stability of osseointegrating mesoporous TiO2 implants
1157	Ultrastructural analysis of implant-soft tissue interface on a three dimensional tissue-engineered oral mucosal model
1172	Mesoporous titanium dioxide coating for metallic implants
1184	The stimulation of an osteogenic response by classical monocyte activation
1200	Free form fabricated features on CoCr implants with and without hydroxyapatite coating in vivo: a comparative study of bone contact and bone growth induction
1210	The correlation between gene expression of proinflammatory markers and bone formation during osseointegration with titanium implants

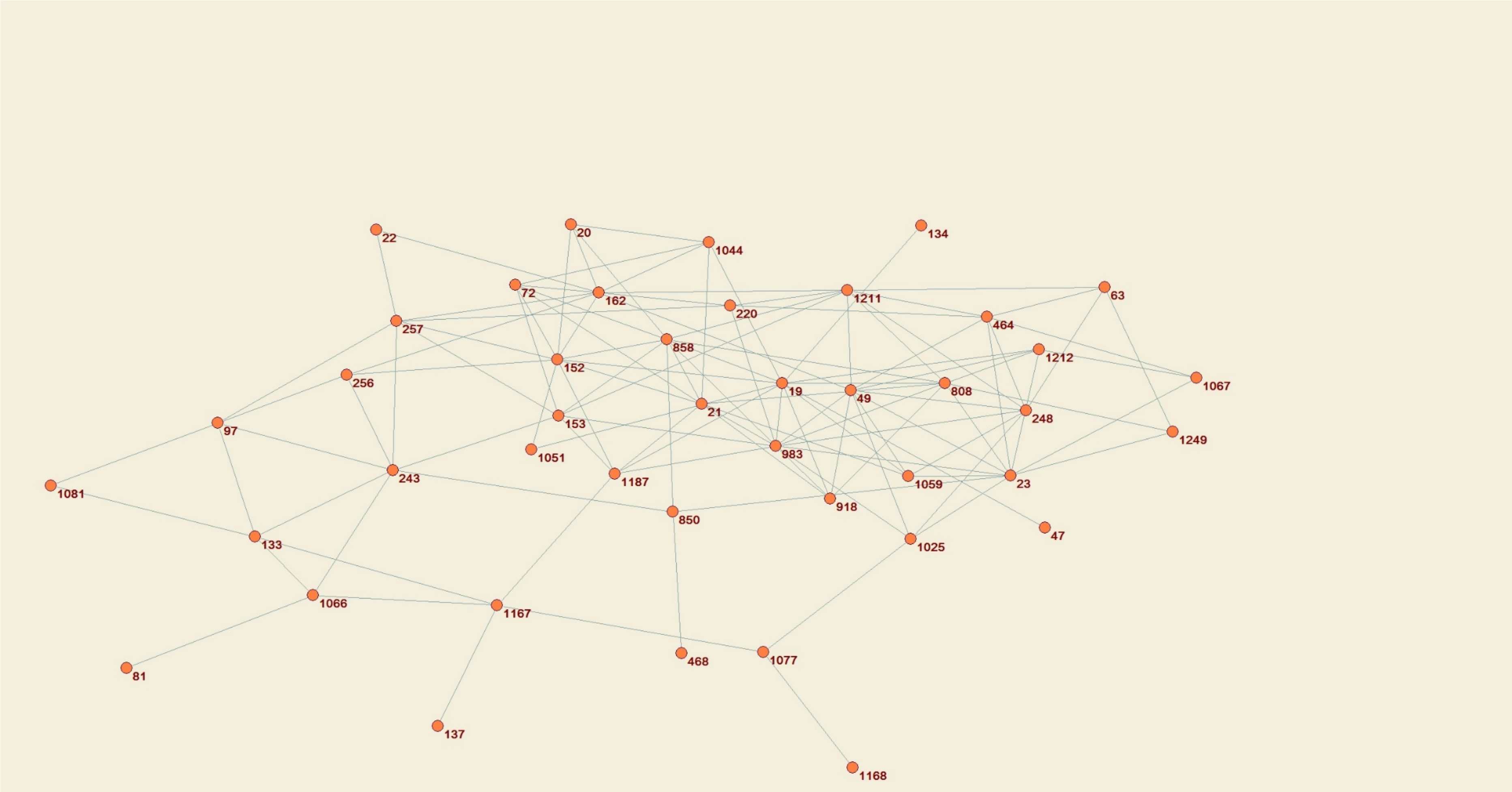

Figure 12. Cluster 16: Oral implants. The Local view.

Table 25.Cluster 16: Oral implants. The Local view.

Nr.	Title
19	A prospective, randomized-controlled clinical trial to evaluate bone preservation using implants with different geometry placed into extraction sockets in the maxilla
20	Factors influencing ridge alterations following immediate implant placement into extraction sockets
21	Bone dimensional variations at implants placed in fresh extraction sockets: a multilevel multivariate analysis
22	Analysis of the socket bone wall dimensions in the upper maxilla in relation to immediate implant placement
23	Dynamics of Bio-Oss (R) Collagen incorporation in fresh extraction wounds: an experimental study in the dog
47	Ridge alterations following tooth extraction with and without flap elevation: an experimental study in the dog
49	Ridge preservation with the use of Bio-Oss (R) collagen: A 6-month study in the dog
63	Effect of a xenograft on early bone formation in extraction sockets: an experimental study in dog
72	Implants in fresh extraction sockets: a prospective 5-year follow-up clinical study
81	Immediate functional loading of implants in single tooth replacement: a prospective clinical multicenter study
97	Healing at fluoride-modified implants placed in wide marginal defects: an experimental study in dogs
133	Bone healing at implants with a fluoride-modified surface: an experimental study in dogs
134	Immediate implant placement with transmucosal healing in areas of aesthetic priority: A multicentre randomized-controlled clinical trial I. Surgical outcomes
137	The role of whole blood in thrombin generation in contact with various titanium surfaces
152	Modeling of the buccal and lingual bone walls of fresh extraction sites following implant installation
153	Tissue modeling following implant placement in fresh extraction sockets
162	Bone tissue formation adjacent to implants placed in fresh extraction sockets: an experimental study in dogs
220	The influence of a biomaterial on the closure of a marginal hard tissue defect adjacent to implants - An experimental study in the dog
243	De novo alveolar bone formation adjacent to endosseous implants - A model study in the dog
248	Healing of human extraction sockets filled with Bio-Oss((R))
256	Appositional bone formation in marginal defects at implants - An experimental study in the dog
257	The jumping distance revisited - An experimental study in the dog
464	Healing around implants placed in bone defects treated with BiO-Oss(R) - An Experimental study in the dog
468	Healing at implants with and without primary bone contact - An experimental study in dogs
808	Effect of socket grafting with deproteinized bone mineral: An RCT on dimensional alterations after 6 months
850	Guided bone regeneration of non-contained mandibular buccal bone defects using deproteinized bovine bone mineral and a collagen membrane: an experimental in vivo investigation
858	The effect of placing a bone replacement graft in the gap at immediately placed implants: a randomized clinical trial
918	The alveolar process following single-tooth extraction: a study of maxillary incisor and premolar sites in man

Table 25 continued.

983	Ridge alterations following grafting of fresh extraction sockets in man A randomized clinical trial
1025	Ridge preservation with the use of deproteinized bovine bone mineral
1044	Implants placed in fresh extraction sockets in the maxilla: clinical and radiographic outcomes from a 3-year follow-up examination
1051	Soft and hard tissue alterations around implants placed in an alveolar ridge with a sloped configuration
1059	Biphasic alloplastic graft used to preserve the dimension of the edentulous ridge: an experimental study in the dog
1066	Effect of immediate functional loading on osseointegration of implants used for single tooth replacement. A human histological study
1067	Early healing in alveolar sockets grafted with titanium granules. An experimental study in a dog model
1077	Bone tissue in different parts of the edentulous maxilla and mandible
1081	Spontaneously formed nanostructures on titanium surfaces
1167	Osseointegration in periodontitis susceptible individuals
1168	The alveolar process of the edentulous maxilla in periodontitis and non-periodontitis subjects
1187	Dimension of the facial bone wall in the anterior maxilla: a cone-beam computed tomography study
1211	Bio-Oss (R) Collagen in the buccal gap at immediate implants: a 6-month study in the dog
1212	Socket grafting with the use of autologous bone: an experimental study in the dog
1249	beta-tricalcium phosphate in the early phase of socket healing: an experimental study in the dog

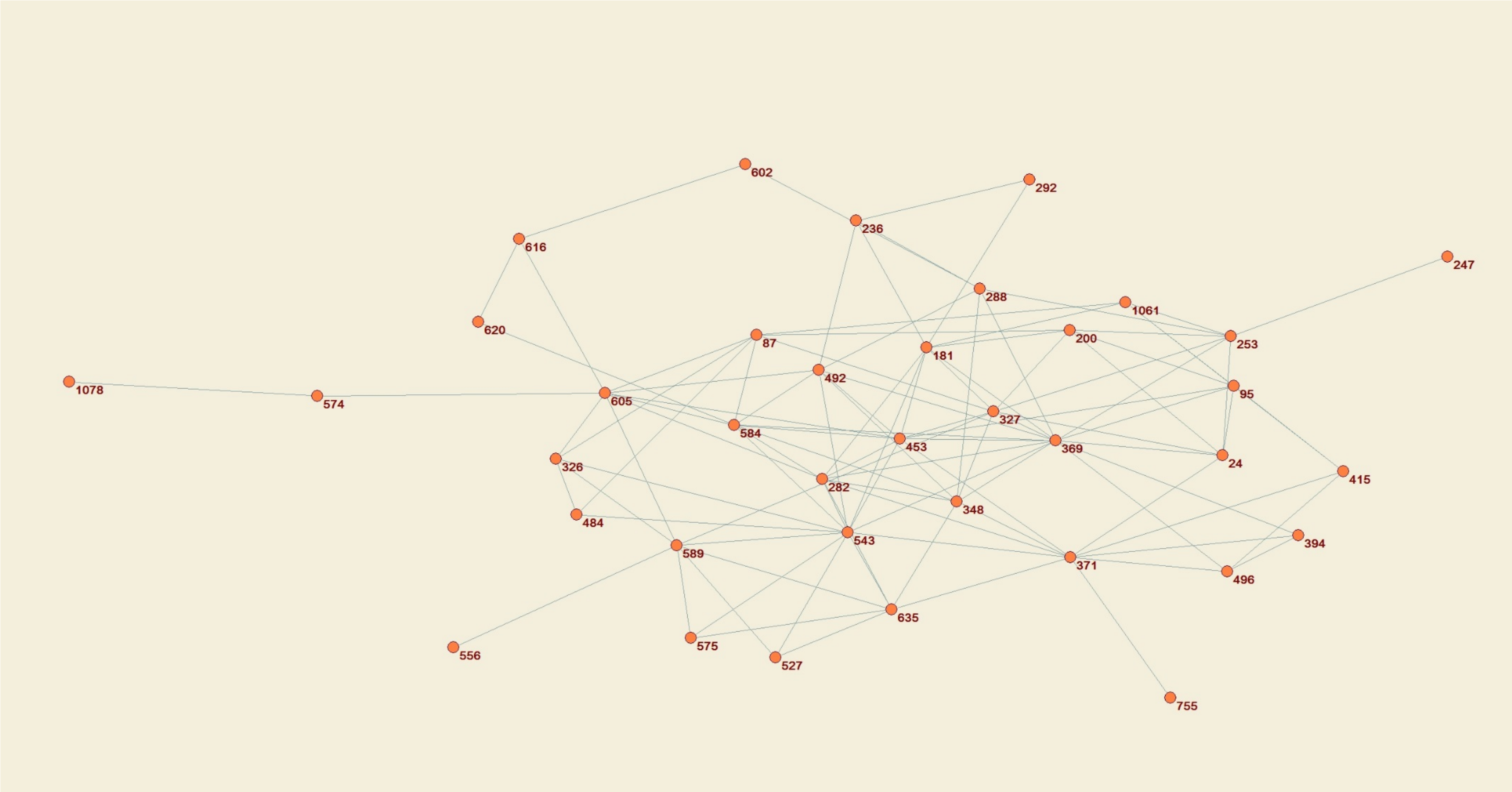

Figure 13. Cluster 5: Implanted materials and reactions. The Local view.

Table 26. Cluster 5: Implanted materials and reactions. The Local view.

NR.	Title
24	In Vivo Evaluation of Noble Metal Coatings
87	Fibrous capsule formation around titanium and copper
95	Effect of molecular mobility of polymeric implants on soft tissue reactions: An in vivo study in rats
181	The inflammatory cell influx and cytokines changes during transition from acute inflammation to fibrous repair around implanted materials
200	In vivo cytokine secretion and NF-kappa B activation around titanium and copper implants
236	Adhesion, apoptosis and cytokine release of human mononuclear cells cultured on degradable poly(urethane urea), polystyrene and titanium in vitro
247	IL-1 alpha, IL-1 beta and TNF-alpha secretion during in vivo/ex vivo cellular interactions with titanium and copper (vol 24, pg 461, 2003)
253	IL-1 alpha, IL-1 beta and TNF-alpha secretion during in vivo/ex vivo cellular interactions with titanium and copper
282	H2O2 production by cells on titanium and polystyrene surfaces using an in vivo model of exudate and surface related cell function
288	Apoptosis and cytokine release in human monocytes cultured on polystyrene and fibrinogen-coated polystyrene surfaces
292	Studies of polyurethane urea bands for ACL reconstruction
326	Tissue response to hafnium
327	In vivo/ex vivo cellular interactions with titanium and copper
348	Secretion of IL-1 and H2O2 by human mononuclear cells in vitro
369	In vivo cell recruitment, cytokine release and chemiluminescence response at gold, and thiol functionalized surfaces
371	Inflammatory cell recruitment, distribution, and chemiluminescence response at IgG precoated- and thiol functionalized gold surfaces
394	Ellipsometric studies in vitro on kinetics of rat complement activation
415	Complement activation and inflammation triggered by model biomaterial surfaces
453	Cell and soft tissue interactions with methyl- and hydroxyl-terminated alkane thiols on gold surfaces
484	Immunohistochemical studies on the distribution of albumin, fibrinogen, fibronectin, IgG and collagen around PTFE and titanium implants
492	Monocyte activation on titanium-sputtered polystyrene surfaces in vitro: The effect of culture conditions on interleukin-1 release
496	Complement activation on thiol-modified gold surfaces
527	Leukocyte accumulation and leukotriene-b-4 release in response to polyglactin-910 and expanded polytetrafluoroethylene in hollow chambers in the rat
543	Distribution of cells in soft-tissue and fluid space around hollow and solid implants in the rat
556	Inflammatory cells and mediators in the silicone chamber model for nerve regeneration
574	Commercially pure titanium and ti6al4v implants with and without nitrogen-ion implantation - surface characterization and quantitative studies in rabbit cortical bone
575	Implant exudate leukocyte response to antiinflammatory drug-treatment
584	A quantitative comparison of the cell response to commercially pure titanium and ti-6al-4v implants in the abdominal-wall of rats

Table 26 continued.

589	Leukotriene-b4, interleukin-1 and leukocyte accumulation in titanium and ptfe chambers after implantation in the rat abdominal-wall
602	The wear behavior of ion-implanted ti-6al-4v against uhmw polyethylene
605	Difference in tissue-response to nitrogen-ion-implanted titanium and cp titanium in the abdominal-wall of the rat
616	Wear of ion-implanted pure titanium against uhmwpe
620	Ultrastructural differences of the interface zone between bone and ti 6al 4v or commercially pure titanium
635	Hollow implants in soft-tissues allowing quantitative studies of cells and fluid at the implant interface
755	The blood compatibility challenge. Part 2: Protein adsorption phenomena governing blood reactivity
1061	Early inflammatory response in soft tissues induced by thin calcium phosphates
1078	A novel technique for tailored surface modification of dental implants a step wise approach based on plasma immersion ion implantation

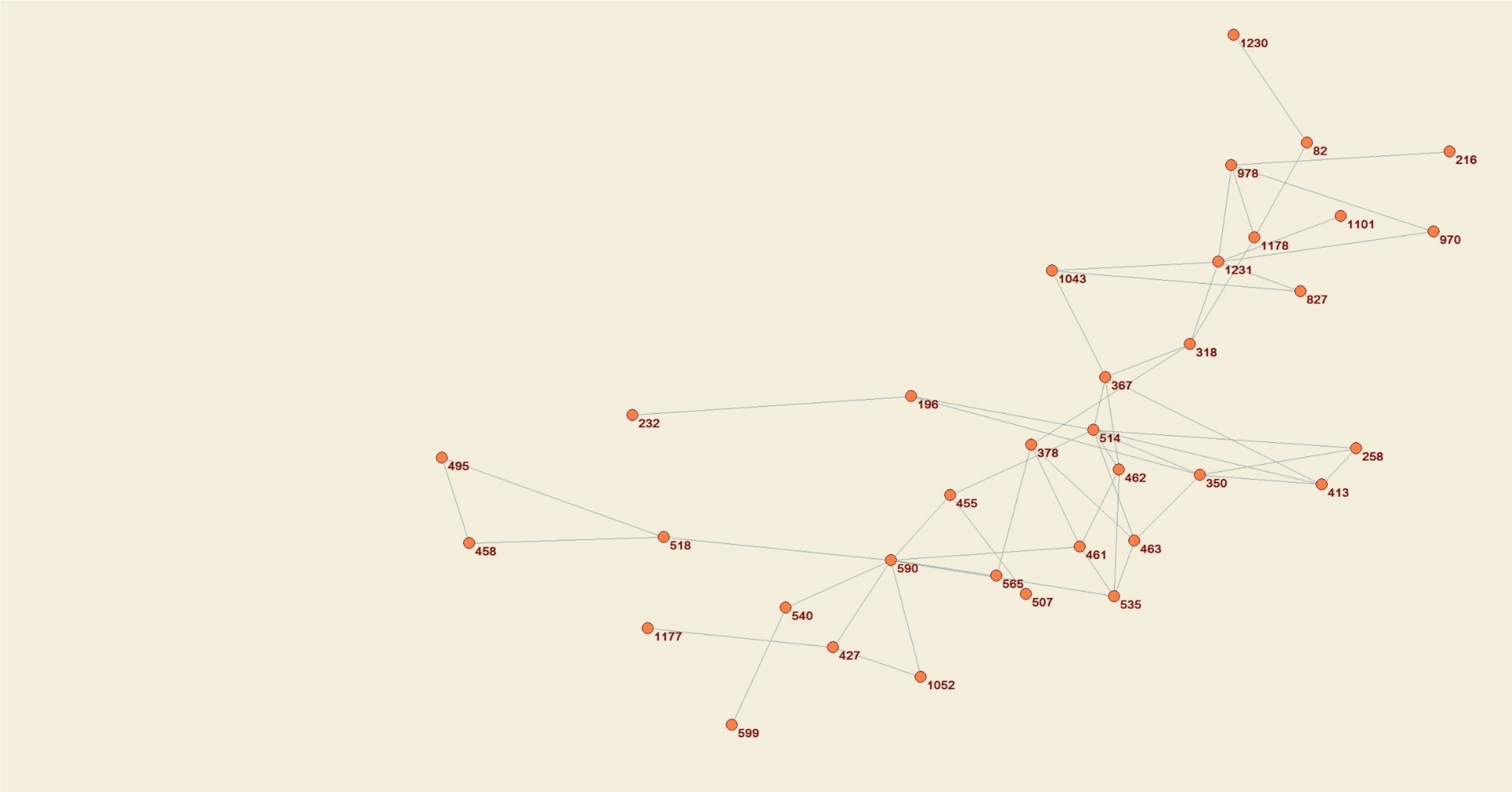

Figure 14. Cluster 6. Bone augmentation; experimental studies. The Local view.

Table 27. Cluster 6.Bone augmentation; experimental studies. The Local view.

Nr	Title
82	Back-scattered electron imaging and elemental microanalysis of retrieved bone tissue following maxillary sinus floor augmentation with calcium sulphate
196	Bone morphology and vascularization of untreated and guided bone augmentation-treated rabbit calvaria: evaluation of an augmentation model
216	A comparative study of barrier membranes as graft protectors in the treatment of localized bone defects - An experimental study in a canine model
232	Influence of preimplant surgical intervention and implant placement on bone wound healing
258	Bone augmentation by means of a stiff occlusive titanium barrier - A study in rabbits and humans
318	A clinical histologic study of bovine hydroxyapatite in combination with autogenous bone and fibrin glue for maxillary sinus floor augmentation - Results after 6 to 8 months of healing
350	Influence of decortication of the donor bone on guided bone augmentation - An experimental study in the rabbit skull bone
367	Augmentation of calvarial tissue using nonpermeable silicone domes and bovine bone mineral - An experimental study in the rat
378	Effects of barrier membranes on bone resorption and implant stability in onlay bone grafts - An experimental study
413	Influence of barrier occlusiveness on guided bone augmentation - An experimental study in the rat
427	Histological morphology of the e-PTFE/tissue interface in humans subjected to guided bone regeneration in conjunction with oral implant treatment
455	Measurements of stability changes of titanium implants with exposed threads subjected to barrier membrane induced bone augmentation – An experimental study in the rabbit tibia
458	Importance of delivery systems for growth-stimulatory factors in combination with osteopromotive membranes. An experimental study using rhBMP-2 in rat mandibular defects
461	Bone augmentation at titanium implants using autologous bone grafts and a bioresorbable barrier - An experimental study in the rabbit tibia
462	Augmentation of skull bone using a bioresorbable barrier supported by autologous bone grafts - An intra-individual study in the rabbit
463	Morphological and dimensional changes after barrier removal in bone formed beyond the skeletal borders at titanium implants - A kinetic study in the rabbit tibia
495	Effects of different osteopromotive membrane porosities on experimental bone neogenesis in rats
507	Anchorage of tio2-blasted, ha-coated, and machined implants - an experimental-study with rabbits
514	Augmentation of intramembranous bone beyond the skeletal envelope using an occlusive titanium barrier - an experimental-study in the rabbit
518	Healing of mandibular defects with different biodegradable and non-biodegradable membranes - an experimental-study in rats
535	The use of a new bioresorbable barrier for guided bone regeneration in connection with implant installation - case-reports
540	Healing of implant dehiscence defects with and without expanded polytetrafluoroethylene membranes - a controlled clinical and histological study
565	The role of early versus late removal of gtam(r) membranes on bone-formation at oral implants placed into immediate extraction sockets - an experimental-study in dogs
590	Bone augmentation at fenestrated implants by an osteopromotive membrane technique
599	A removal torque and histomorphometric study of commercially pure niobium and titanium implants in rabbit bone
827	Histomorphometric analyses of area fraction of different ratios of Bio-Oss((R)) and bone prior to grafting procedures - An in vitro study to demonstrate a baseline

Table 27 continued.

970	Bone tissue modelling and remodelling following guided bone regeneration in combination with biphasic calcium phosphate materials presenting different microporosity
978	Comparative maxillary bone-defect healing by calcium-sulphate or deproteinized bovine bone particles and extra cellular matrix membranes in a guided bone regeneration setting: an experimental study in rabbits
1043	A randomized and controlled clinical trial of two different compositions of deproteinized bovine bone and autogenous bone used for lateral ridge augmentation
1052	Early biocompatibility of poly (ethylene glycol) hydrogel barrier materials for guided bone regeneration. An in vitro study using human gingival fibroblasts (HGF-1)
1101	A 6-month histological analysis on maxillary sinus augmentation with and without use of collagen membranes over the osteotomy window: randomized clinical trial
1177	Lateral bone augmentation with newly developed ss-tricalcium phosphate block: an experimental study in the rabbit mandible
1178	Intramembraneous bone tissue responses to calcium sulfate: an experimental study in the rabbit maxilla
1230	Back-scattered electron imaging and elemental analysis of retrieved bone tissue following sinus augmentation with deproteinized bovine bone or biphasic calcium phosphate
1231	Histological and histomorphometrical analyses of biopsies harvested 11 years after maxillary sinus floor augmentation with deproteinized bovine and autogenous bone

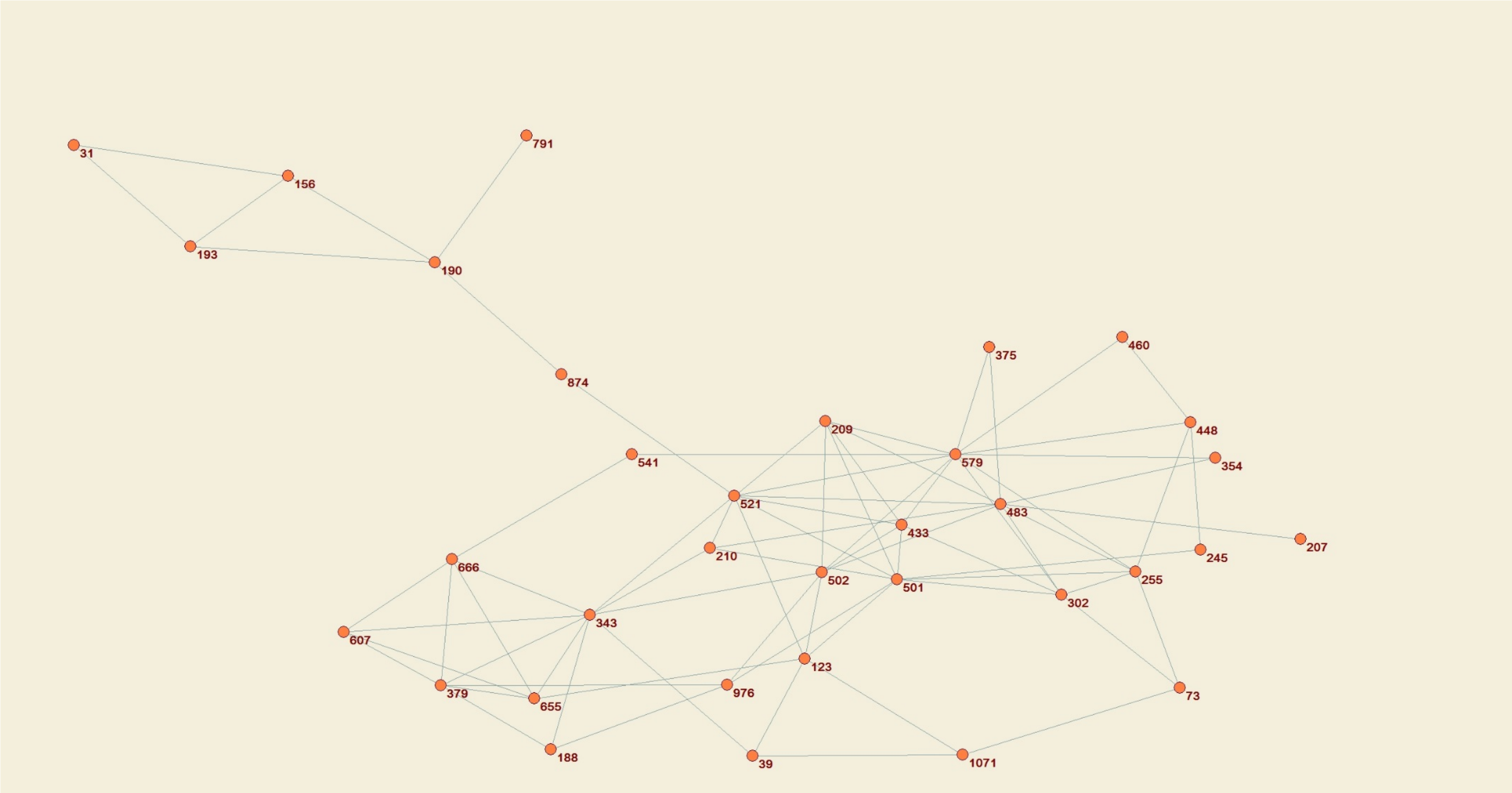

Figure 15. Cluster 3: Implants. The Local view.

Table 28. Cluster 3: Implants. The Local view.

NR.	Title
31	Does Longstanding Nicotine Exposure Impair Bone Healing and Osseointegration? An Experimental Study in Rabbits
39	Nucleation and growth of calcium phosphates in the presence of fibrinogen on titanium implants with four potentially bioactive surface preparations. An in vitro study
73	Bone reaction to nano hydroxyapatite modified titanium implants placed in a gap-healing model
123	Formation of calcium phosphates on titanium implants with four different bioactive surface preparations. An in vitro study
156	Effect of systemic administration of nicotine on healing in osseous defects. An experimental study in rabbits. Part II
188	The effect of limited lateral resolution in the measurement of implant surface roughness: A computer simulation
190	The impact of nicotine on osseointegration - An experimental study in the femur and tibia of rabbits
193	The impact of nicotine on bone healing and osseointegration - An experimental study in rabbits
207	Improved tibial cutting accuracy in knee arthroplasty
209	Titanium release from implants prepared with different surface roughness - An in vitro and in vivo study
210	Variation in surface texture measurements
245	Biological behavior of sol-gel coated dental implants
255	An in vivo study of bone response to implants topographically modified by laser micromachining
302	The importance of surface texture for bone integration of screw shaped implants: An in vivo study of implants patterned by photolithography
343	Surface roughness parameters as predictors of anchorage strength in bone: a critical analysis
354	Chemical and topographical surface analysis of five different implant abutments
375	Surface characterization, protein adsorption, and initial cell-surface reactions on glutathione and 3-mercapto-1,2,-propanediol immobilized to gold
379	The relation between surface roughness and interfacial shear strength for bone-anchored implants. A mathematical model
433	A histomorphometric evaluation of screw-shaped implants each prepared with two surface roughnesses
448	Short- and long-term animal studies with a plasma-sprayed calcium phosphate-coated implant
460	Bone tissue reactions to an electrophoretically applied calcium phosphate coating
483	Characterizing three-dimensional topography of engineering and biomaterial surfaces by confocal laser scanning and stylus techniques
501	Torque and histomorphometric evaluation of cp titanium screws blasted with 25- and 75-mu m-sized particles of Al2O3
502	Experimental study of turned and grit-blasted screw-shaped implants with special emphasis on effects of blasting material and surface topography
521	An animal study of cp titanium screws with different surface topographies
541	Quantitative comparison of screw-shaped commercially pure titanium and zirconium implants in rabbit tibia
579	An optical 3-dimensional technique for topographical descriptions of surgical implants
607	Qualitative interfacial study between bone and tantalum, niobium or commercially pure titanium

Table 28 continued.

655	An ultrastructural characterization of the interface between bone and sputtered titanium or stainless-steel surfaces
666	Interface analysis of titanium and zirconium bone implants
791	Implant-associated gene expression in the jaw bone of smokers and nonsmokers: A human study using quantitative qPCR
874	Pectin nanocoating of titanium implant surfaces - an experimental study in rabbits
976	Simulation of the mechanical interlocking capacity of a rough bone implant surface during healing
1071	Osteogenesis-inducing calcium phosphate nanoppaper precursors applied to titanium surfaces

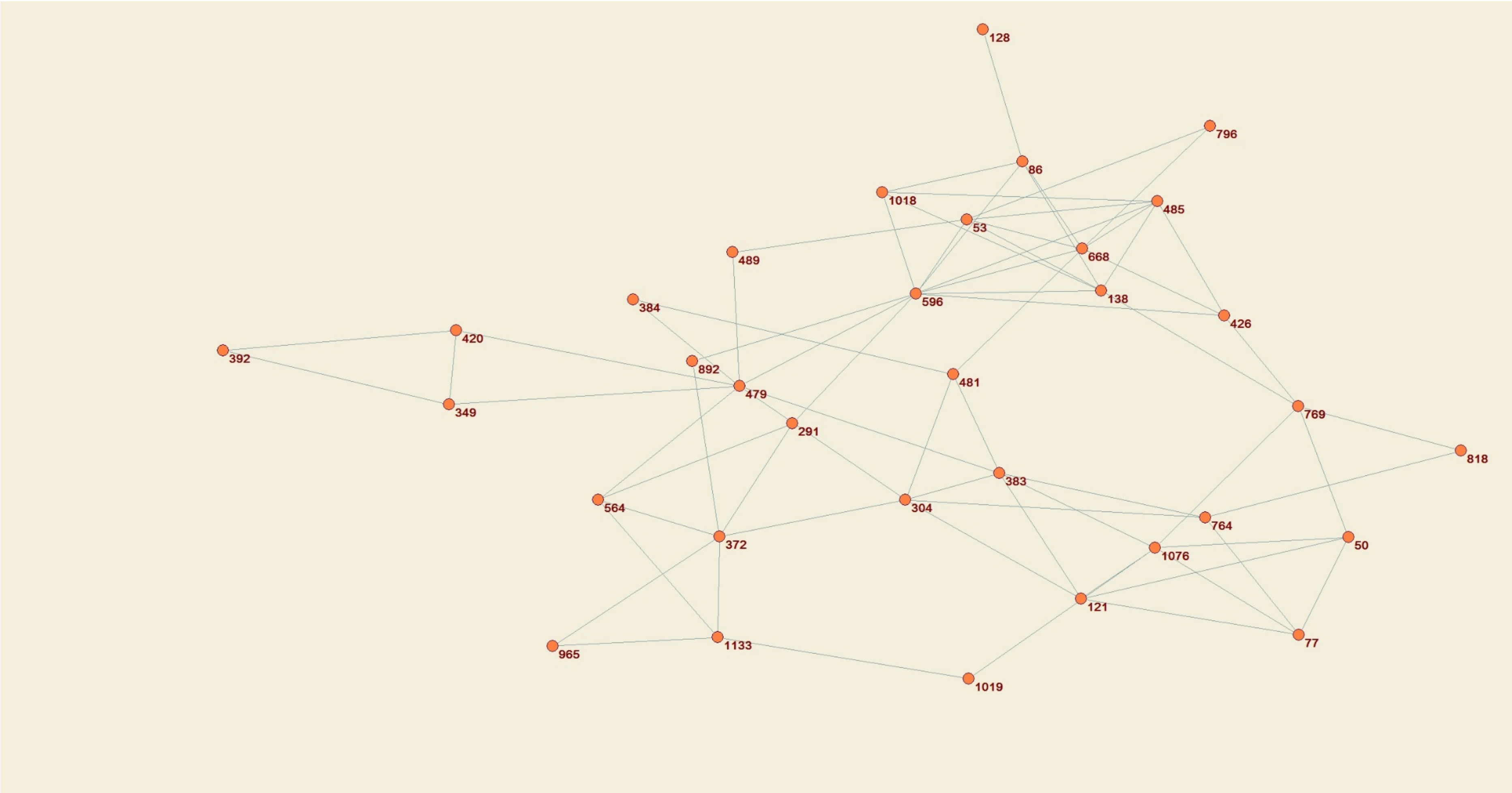

Figure 16. Cluster 21: Oral implants. The Local view.

Table 29. Cluster 21: Oral implants. The Local view.

NR.	Title
50	Spontaneous progression of ligatured induced peri-implantitis at implants with different surface characteristics. An experimental study in dogs II: histological observations
53	Subcrestal placement of two-part implants
77	Spontaneous progression of peri-implantitis at different types of implants. An experimental study in dogs. I: clinical and radiographic observations
86	The mucosal barrier at implant abutments of different materials
121	Spontaneous progression of ligature induced peri-implantitis at implants with different surface roughness: an experimental study in dogs
128	Peri-implant hard and soft tissue integration to dental implants made of titanium and gold
138	Morphogenesis of the peri-implant mucosa: an experimental study in dogs
291	Long-term follow-up of osseointegrated titanium implants using clinical, radiographic and microbiological parameters
304	Re-osseointegration after treatment of peri-implantitis at different implant surfaces - An experimental study in the dog
349	The soft tissue response to contaminated and cleaned titanium surfaces using CO2 laser, citric acid and hydrogen peroxide - An experimental study in the rat abdominal wall
372	Microbial findings at failing implants
383	Resolution of peri-implantitis following treatment - An experimental study in the dog
384	Chemical treatment of machined titanium surfaces - An in vitro study
392	Temperature increases during surface decontamination of titanium implants using CO2 laser
420	An XPS and SEM evaluation of six chemical and physical techniques for cleaning of contaminated titanium implants
426	Soft tissue response to plaque formation at different implant systems. A comparative study in the dog
479	The effect of antimicrobial therapy on periimplantitis lesions - An experimental study in the dog
481	Guided bone regeneration in the treatment of periimplantitis
485	The peri-implant hard and soft tissues at different implant systems - A comparative study in the dog
489	Bacterial colonization on internal surfaces of Branemark System(R) implant components
564	A longitudinal microbiological study on osseointegrated titanium implants in partially edentulous patients
596	The soft tissue barrier at implants and teeth
668	Light and transmission electron-microscopy used to study the tissue morphology close to implants
764	Re-osseointegration following reconstructive surgical therapy of experimental peri-implantitis. A pre-clinical in vivo study
769	Peri-implantitis and its prevention
796	Peri-implant tissue healing at implants with different designs and placement protocols: An experimental study in dogs
818	Long-term outcome of surgical treatment of peri-implantitis. A 2-11-year retrospective study
892	Treatment of peri-implantitis: clinical outcome of chloramine as an adjunctive to non-surgical therapy, a randomized clinical trial

Table 29 continued.

965	Effect of cleansing of biofilm formed on titanium discs
1018	Morphogenesis of peri-implant mucosa revisited: an experimental study in humans
1019	Microbiota in experimental periodontitis and peri-implantitis in dogs
1076	Experimental periodontitis and peri-implantitis in dogs
1133	Clinical and microbiological characteristics of peri-implantitis cases: a retrospective multicentre study

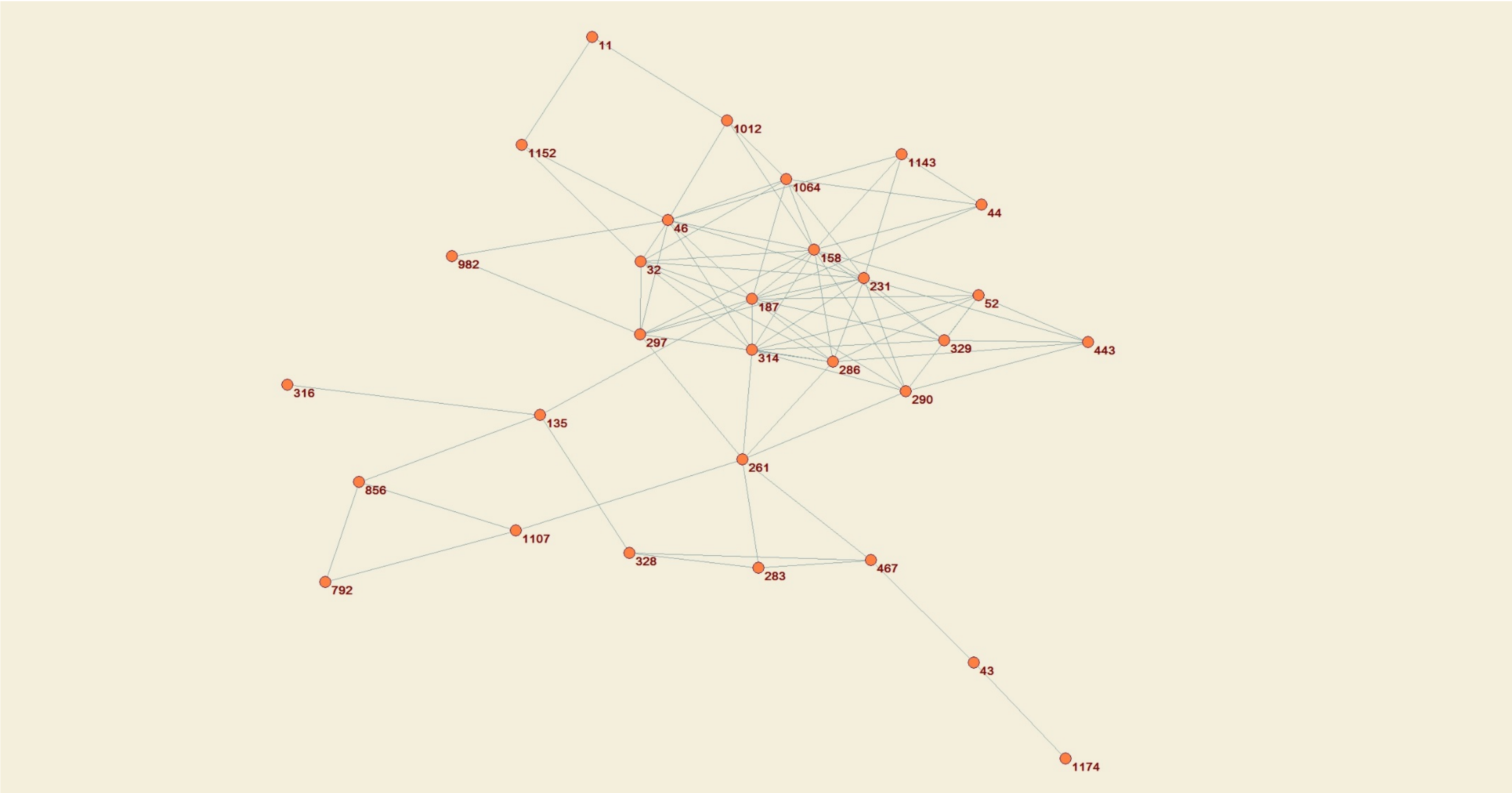

Figure 17. Cluster 8. Implants and surfaces. The Local view.

Table 30. Cluster 8. Implants and surfaces. The Local view.

NR.	Title
11	Surface Characterization of Commercial Oral Implants on the Nanometer Level
32	Resonance frequency measurements in vivo and related surface properties of magnesium-incorporated, micropatterned and magnesium-incorporated TiUnite((R)), Osseotite((R)), SLA((R)) and TiOblast((R)) implants
43	Human articular chondrocytes on macroporous gelatin microcarriers form structurally stable constructs with blood-derived biological glues in vitro
44	XPS, AES and SEM analysis of recent dental implants
46	The roles of surface chemistry and topography in the strength and rate of osseointegration of titanium implants in bone
52	An in vitro comparison of possibly bioactive titanium implant surfaces
135	Inflammatory response to titanium surfaces with fibrinogen and catalase coatings: an in vitro study
158	Oxidized, bioactive implants are rapidly and strongly integrated in bone. Part 1 - experimental implants
187	The bone response of oxidized bioactive and non-bioactive titanium implants
231	The significance of the surface properties of oxidized titanium to the bone response: special emphasis on potential biochemical bonding of oxidized titanium implant
261	Bone formation after 4 weeks around blood-plasma-modified titanium implants with varying surface topographies: an in vivo study
283	Ex vivo PMA-induced respiratory burst and TNF-alpha secretion elicited from inflammatory cells on machined and porous blood plasma clot-coated titanium
286	Resonance frequency and removal torque analysis of implants with turned and anodized surface oxides
290	Qualitative and quantitative observations of bone tissue reactions to anodised implants
297	Characteristics of the surface oxides on turned and electrochemically oxidized pure titanium implants up to dielectric breakdown: the oxide thickness, micropore configurations, surface roughness, crystal structure and chemical composition
314	The electrochemical oxide growth behaviour on titanium in acid and alkaline electrolytes
316	In vitro study of monocyte viability during the initial adhesion to albumin- and fibrinogen-coated surfaces
328	On the formation of fibrous capsule and fluid space around machined and porous blood plasma clot coated titanium
329	Oxidized implants and their influence on the bone response
443	Bone response to surface modified titanium implants - studies on the tissue response after 1 year to machined and electropolished implants with different oxide thicknesses
467	Influence of fibrin sealant (Tisseel(R)) on osteochondral defect repair in the rabbit knee
792	Effects of implant-delivered insulin on bone formation in osteoporotic rats
856	Insulin released from titanium discs with insulin coatingsKinetics and biological activity
982	Inflammatory cytokine release is affected by surface morphology and chemistry of titanium implants
1012	Local release of magnesium from mesoporous TiO2 coatings stimulates the pen-implant expression of osteogenic markers and improves osteoconductivity in vivo
1064	Experimental evidence for interfacial biochemical bonding in osseointegrated titanium implants
1107	Effects of locally administered insulin on bone formation in non-diabetic rats

Table 30 continued.

1143	The effect of calcium ion concentration on the bone response to oxidized titanium implants
1152	Effect of Si addition on Ca- and P-impregnated implant surfaces with nanometer-scale roughness: an experimental study in dogs
1174	Cell expansion of human articular chondrocytes on macroporous gelatine scaffolds-impact of microcarrier selection on cell proliferation

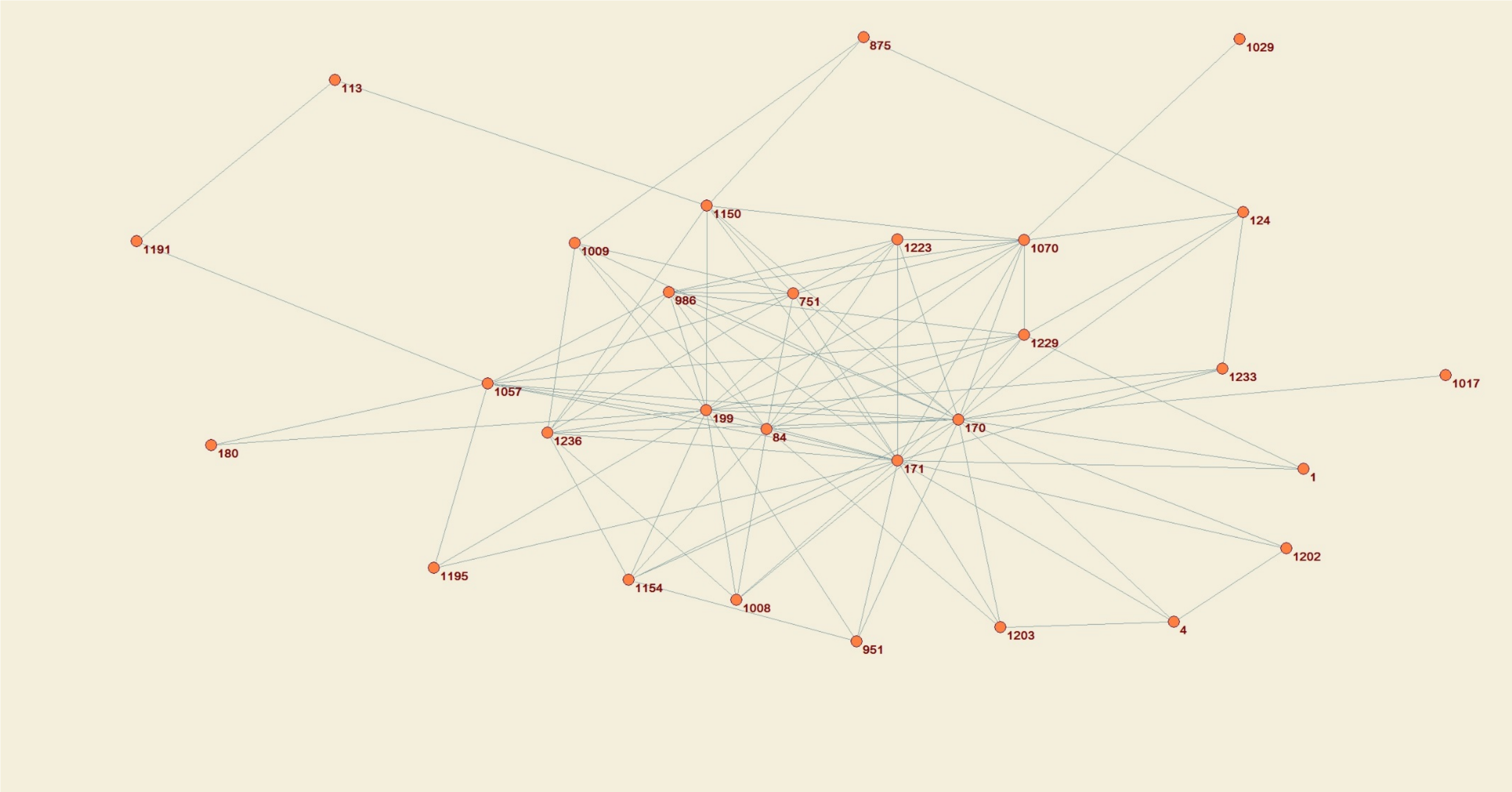

Figure 18. Cluster 1: Tissue engineering; scaffolds, cellulose. The local view.

Table 31. Cluster 1: Tissue engineering; scaffolds, cellulose. The Local view.

NR.	Title
1	Intravital fluorescent microscopic evaluation of bacterial cellulose as scaffold for vascular grafts
4	Real-time measurements of coagulation on bacterial cellulose and conventional vascular graft materials
84	Engineering microporosity in bacterial cellulose scaffolds
113	Effect of cell seeding concentration on the quality of tissue engineered constructs loaded with adult human articular chondrocytes
124	Bacterial cellulose as a potential meniscus implant
170	Mechanical properties of bacterial cellulose and interactions with smooth muscle cells
171	In vivo biocompatibility of bacterial cellulose
180	Surface-engineered bacterial cellulose as template for crystallization of calcium phosphate
199	Bacterial cellulose as a potential scaffold for tissue engineering of cartilage
751	Biofabrication of bacterial nanocellulose scaffolds with complex vascular structure
875	Increased lipid accumulation and adipogenic gene expression of adipocytes in 3D bioprinted nanocellulose scaffolds
951	Neuronal Networks on Nanocellulose Scaffolds
986	Novel bilayer bacterial nanocellulose scaffold supports neocartilage formation in vitro and in vivo
1008	Biosynthesis and in vitro evaluation of macroporous mineralized bacterial nanocellulose scaffolds for bone tissue engineering
1009	Adipogenic differentiation of stem cells in three-dimensional porous bacterial nanocellulose scaffolds
1017	3D Culturing and differentiation of SH-SY5Y neuroblastoma cells on bacterial nanocellulose scaffolds
1029	Towards mechanical integrity of tissue-engineered ear cartilage
1057	Description of a novel approach to engineer cartilage with porous bacterial nanocellulose for reconstruction of a human auricle
1070	Mechanical evaluation of bacterial nanocellulose as an implant material for ear cartilage replacement
1150	Mechanical stimulation of fibroblasts in micro-channeled bacterial cellulose scaffolds enhances production of oriented collagen fibers
1154	In situ Imaging of Collagen Synthesis by Osteoprogenitor Cells in Microporous Bacterial Cellulose Scaffolds
1191	Influence of pore size on the redifferentiation potential of human articular chondrocytes in poly(urethane urea) scaffolds
1195	Bacterial cellulose modified with xyloglucan bearing the adhesion peptide RGD promotes endothelial cell adhesion and metabolism - a promising modification for vascular grafts
1202	An in vitro study of blood compatibility of vascular grafts made of bacterial cellulose in comparison with conventionally-used graft materials
1203	Bacterial cellulose as a potential vascular graft: Mechanical characterization and constitutive model development
1223	Tissue-engineered conduit using urine-derived stem cells seeded bacterial cellulose polymer in urinary reconstruction and diversion
1229	Behavior of human chondrocytes in engineered porous bacterial cellulose scaffolds
1233	Electromagnetically Controlled Biological Assembly of Aligned Bacterial Cellulose Nanofibers

Table 31.continued.

1236	Microporous bacterial cellulose as a potential scaffold for bone regeneration

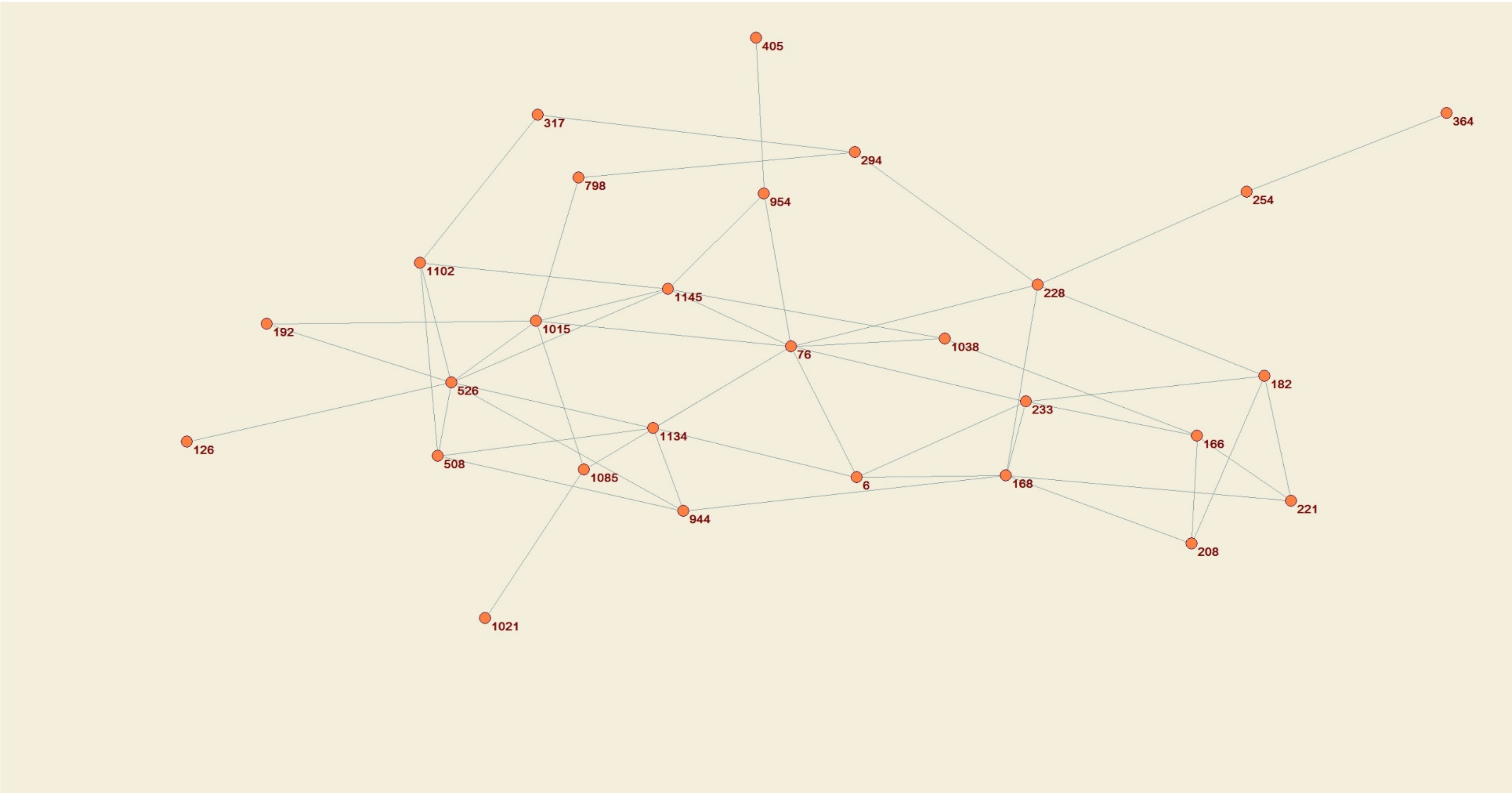

Figure 19. Cluster 12. Osseointegration. The Local view.

Table 32. Cluster 12: Osseointegration. The Local view.

NR.	Title
6	Improving osseointegration of dental implants
76	Nano hydroxyapatite structures influence early bone formation
126	Comparison of histomorphometrical data obtained with two different image analysis methods
166	Study of Staphylococcus aureus adhesion on a novel nanostructured surface by chemiluminometry
168	Osteoprogenitor response to semi-ordered and random nanotopographies
182	In vitro and in vivo response to nanotopographically-modified surfaces of poly(3-hydroxybutyrate-co-3-hydroxyvalerate) and polycaprolactone
192	A descriptive study on retrieved non-threaded and threaded implant designs
208	Changes in fibroblast morphology in response to nano-columns produced by colloidal lithography
221	Fibroblast response to a controlled nanoenvironment produced by colloidal lithography
228	Quantitative assessment of the response of primary derived human osteoblasts and macrophages to a range of nanotopography surfaces in a single culture model in vitro
233	Nanoscale features influence epithelial cell morphology and cytokine production
254	Response of rat osteoblast-like cells to microstructured model surfaces in vitro
294	The effect of titanium surface roughness on the adhesion of monocytes and their secretion of TNF-alpha and PGE(2)
317	Histologic evaluation of the bone integration of TiO2 blasted and turned titanium microimplants in humans
364	Design and microstructuring of PDMS surfaces for improved marine biofouling resistance
405	In vitro real-time characterization of cell attachment and spreading
508	Cutting directions of bone with biomaterials in-situ does influence the outcome of histomorphometrical quantifications
526	Importance of ground section thickness for reliable histomorphometrical results
798	Inflammatory cytokine release from human peripheral blood mononuclear cells exposed to polyetheretherketone and titanium-6 aluminum-4 vanadium in vitro
944	Improved osseointegration and interlocking capacity with dual acid-treated implants: a rabbit study
954	Using QCM-D to study the adhesion of human gingival fibroblasts on implant surfaces
1015	Enhanced bone healing around nanohydroxyapatite-coated polyetheretherketone implants: An experimental study in rabbit bone
1021	Enhancement of CRF-PEEK osseointegration by plasma-sprayed hydroxyapatite: A rabbit model
1038	Biofilm formation on nanostructured hydroxyapatite- coated titanium

Table 32 continued.

1085	**Nano-hydroxyapatite-coated PEEK implants: A pilot study in rabbit bone**
1102	The histological evaluation of osseointegration of surface enhanced microimplants immediately loaded in conjunction with sinuslifting in humans
1134	Enhanced implant integration with hierarchically structured implants: a pilot study in rabbits
1145	The biological response to three different nanostructures applied on smooth implant surfaces

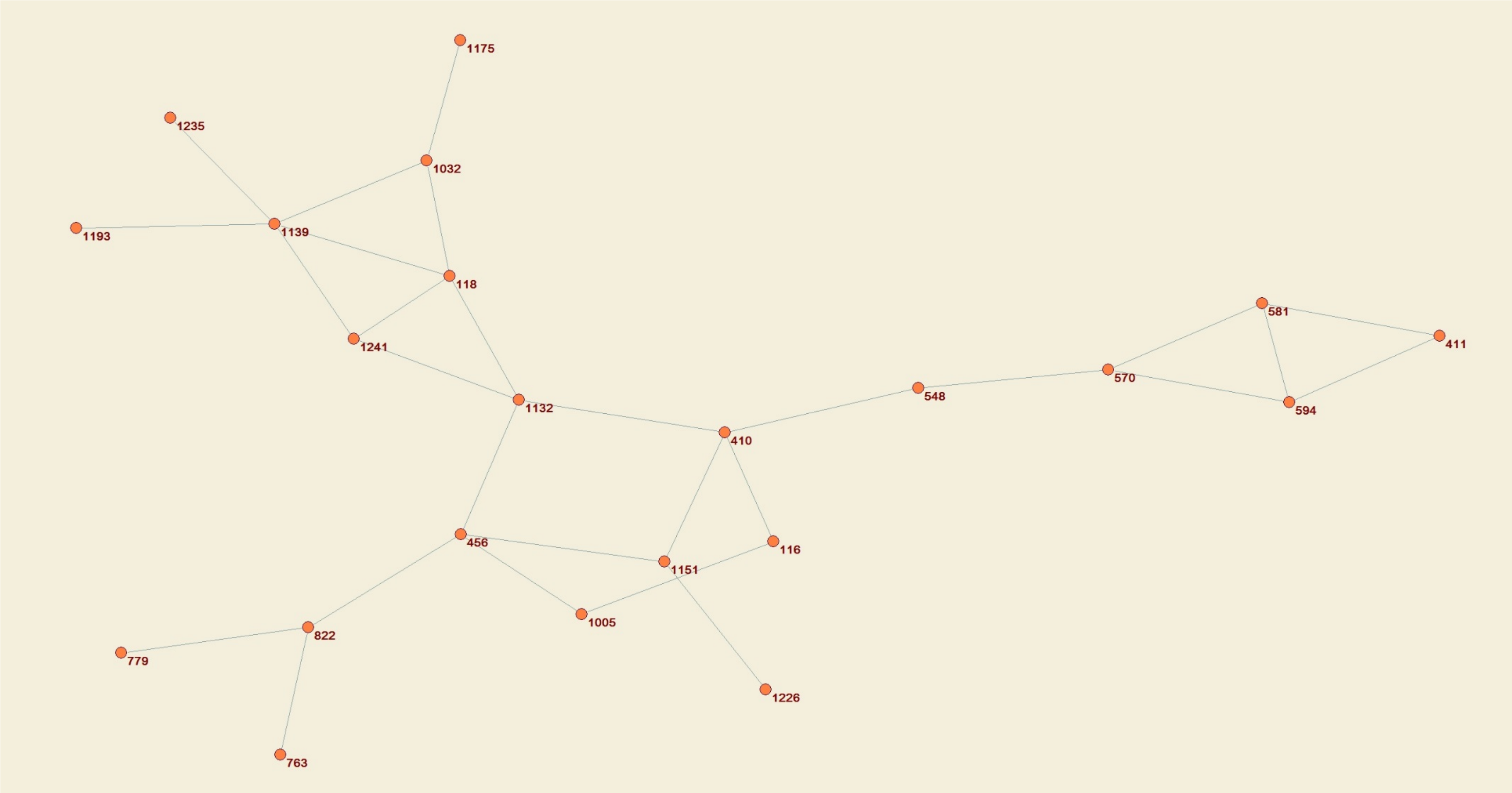

Figure 20. Cluster 7: Titanium implants. The Local view.

Table 33. Cluster 7: Titanium implants. The Local view.

NR.	Title
116	Callus formation and remodeling at titanium implants
118	A novel characteristic of porous titanium oxide implants
410	Integration of press-fit implants in cortical bone: A study on interface kinetics
411	Studies of the healing of bone grafts, and the incorporation of titanium implants in grafted bone: an experimental animal model
456	Biomechanical characterization of osseointegration during healing: An experimental in vivo study in the rat
548	Fluorapatite-coated implants in experimental arthritis - the response of rabbit trabecular bone
570	Tissue-response to titanium implants in experimental antigen-induced arthritis
581	Ultrastructure of the bone-titanium interface in rabbits
594	Structure of the bone-titanium interface in retrieved clinical oral implants
763	Loads on Transhumeral Amputees Using Osseointegrated Prostheses
779	Restoring Natural Forearm Rotation in Transradial Osseointegrated Amputees
822	Biomechanical Characterisation of Bone-anchored Implant Systems for Amputation Limb Prostheses: A Systematic Review
1005	Comparing and visualizing titanium implant integration in rat bone using 2D and 3D techniques
1032	Photocatalytically induced hydrophilicity influences bone remodelling at longer healing periods: a rabbit study
1132	Healing of complement activating Ti implants compared with non-activating Ti in rat tibia
1139	In vitro characterization and osteoblast responses to nanostructured photocatalytic TiO2 coated surfaces
1151	Local bisphosphonate release versus hydroxyapatite coating for stainless steel screw fixation in rat tibiae
1175	Histological and three-dimensional evaluation of osseointegration to nanostructured calcium phosphate-coated implants
1193	Metal plasma immersion ion implantation and deposition (MePIIID) on screw-shaped titanium implant: The effects of ion source, ion dose and acceleration voltage on surface chemistry and morphology
1226	Surface immobilized zoledronate improves screw fixation in rat bone: A new method for the coating of metal implants
1235	Sol-gel derived titania coating with immobilized bisphosphonate enhances screw fixation in rat tibia
1241	The effect of heat- or ultra violet ozone-treatment of titanium on complement deposition from human blood plasma

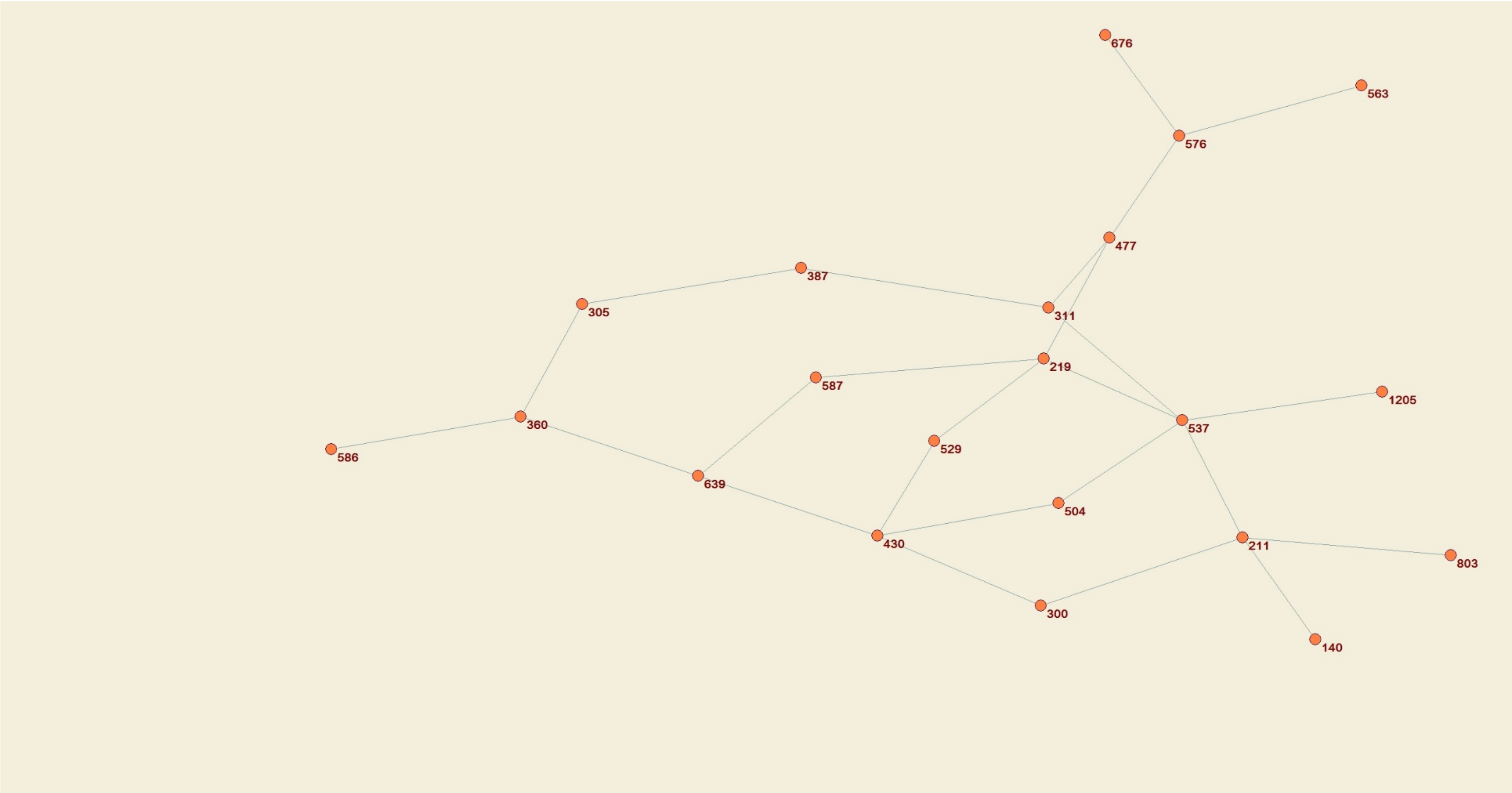

Figure 21. Cluster 11: Blood protein interactions with surfaces. The Local view.

Table 34.Cluster 11: Blood protein interactions with surfaces. The Local view.

NR.	Title
140	Molecular mobility of polymeric implants and acute inflammatory response: An experimental study in mice
211	The effect of substrate molecular mobility on surface induced immune complement activation and blood plasma coagulation
219	Thrombin, kallikrein and complement C5b-9 adsorption on hydrophilic and hydrophobic titanium and glass after short time exposure to whole blood
300	Acoustics of blood plasma on solid surfaces
305	Respiratory burst response of peritoneal leukocytes adhering to titanium and stainless steel
311	Cellular reactions and bone apposition to titanium surfaces with different surface roughness and oxide thickness cleaned by oxidation
360	Different kinetics of the respiratory burst response in granulocytes, induced by serum from blood coagulated in contact with polymer materials
387	Characterization of cellular response to thiol-modified gold surfaces implanted in mouse peritoneal cavity
430	Protein absorption and ellipsometry in biomaterial research
477	Platelet binding and protein adsorption to titanium and gold after short time exposure to heparinized plasma and whole blood
504	Blood protein interactions with chromium surfaces
529	Logarithmic growth of protein films
537	Titanium with different oxides - in-vitro studies of protein adsorption and contact activation
563	Surface modification of intravenous catheters to reduce local tissue-reactions
576	Pre-adsorption of a cellulose ether onto polymer surfaces - adsorption of adhesins and platelet activation
586	Adsorption of coagulation proteins from whole-blood on to polymer materials - relation to platelet activation
587	Kinetics supramolecular structure and equilibrium properties of fibrinogen adsorption at liquid solid interfaces
639	Molecular and supramolecular structure of adsorbed fibrinogen and adsorption-isotherms of fibrinogen at quartz surfaces
676	Covalent coupling of polysaccharides to silicon and silicon rubber surfaces
803	Curvature-dependent effects of nanotopography on classical immune complement activation
1205	Protein adsorption on thin films of carbon and carbon nitride monitored with in situ ellipsometry

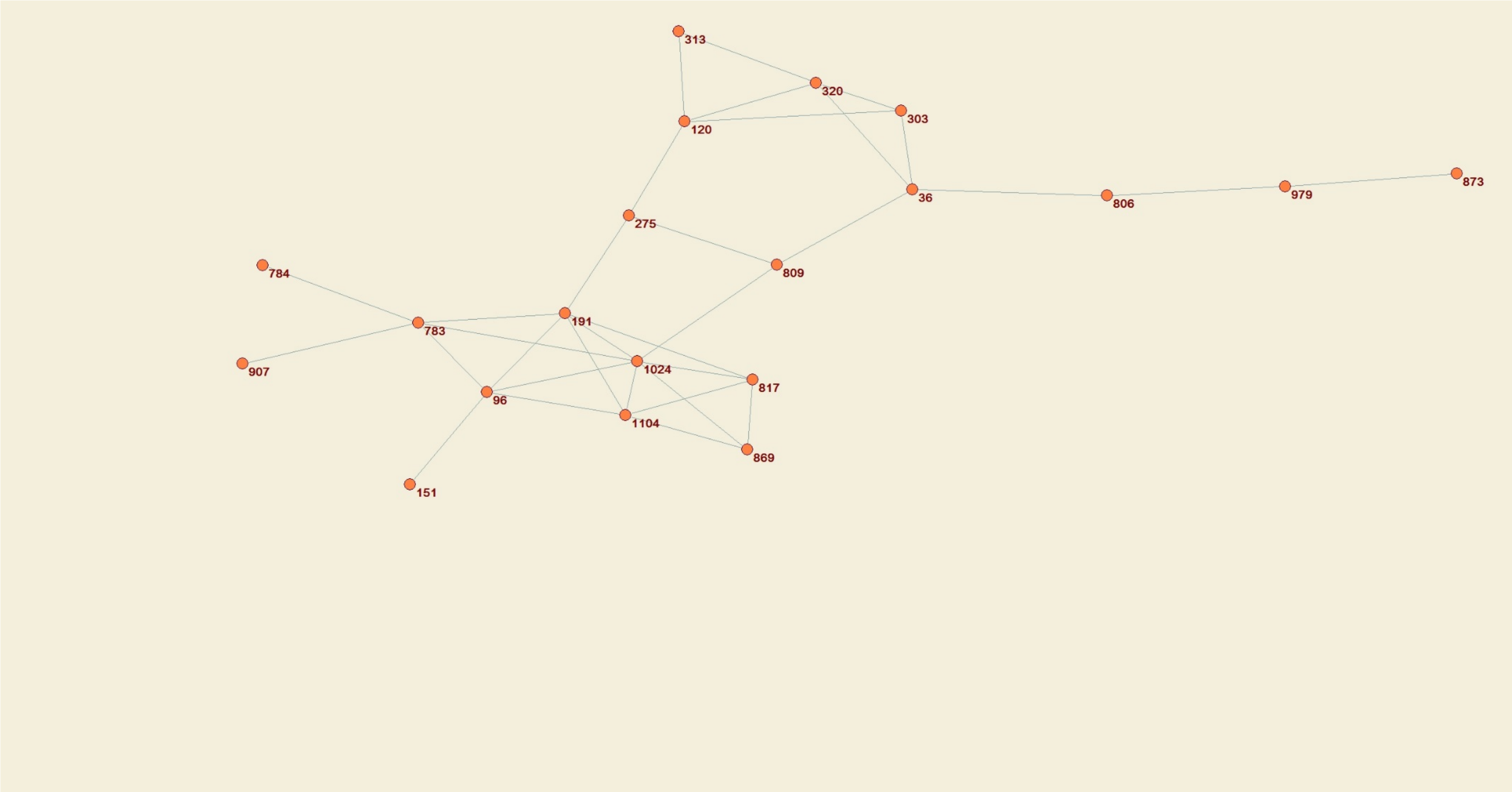

Figure 22. Cluster 22: Oral implants. The Local view.

Table 35. Cluster 22: Oral implants. The Local view.

NR.	Title
36	Survival and complication rates of implant-supported fixed partial dentures with cantilevers: a systematic review
96	Clinical characteristics at implants with a history of progressive bone loss
120	Bone level changes at axial- and non-axial-positioned implants supporting fixed partial dentures. A 5-year retrospective longitudinal study
151	Probe penetration in periodontal and peri-implant tissues: An experimental study in the beagle dog
191	Prevalence of subjects with progressive bone loss at implants
275	Outcome of implant therapy in relation to experienced loss of periodontal bone support - A retrospective 5-year study
303	Bone reactions adjacent to titanium implants subjected to static load of different duration. A study in the dog (III)
313	Bone reactions adjacent to titanium implants with different surface characteristics subjected to static load. A study in the dog (II)
320	Bone reactions adjacent to titanium implants subjected to static load - A study in the dog (I)
783	Long-term biological complications of dental implants placed either in pristine or in augmented sites: A systematic review and meta-analysis
784	Group 4 ITI Consensus Report: Risks and biologic complications associated with implant dentistry
806	Technical complications following implant-supported restorative therapy performed in Sweden
809	Marginal bone loss at implants with different surface characteristics - A 20-year follow-up of a randomized controlled clinical trial
817	Bone loss at implants and teeth in the same inter-proximal unit: A radiographic study
869	Bone loss at implants and teeth in thesame segment of the dentition in partially dentate subjects
873	Altered expectations on dental implant therapy; views of patients referred for treatment of peri-implantitis
907	Implant-supported single-tooth restorations. A 12-year prospective study
979	Patient-reported outcomes of dental implant therapy in a large randomly selected sample
1024	Mucosal inflammation and incidence of crestal bone loss among implant patients: a 10-year study
1104	A cross-sectional study on the prevalence of marginal bone loss among implant patients

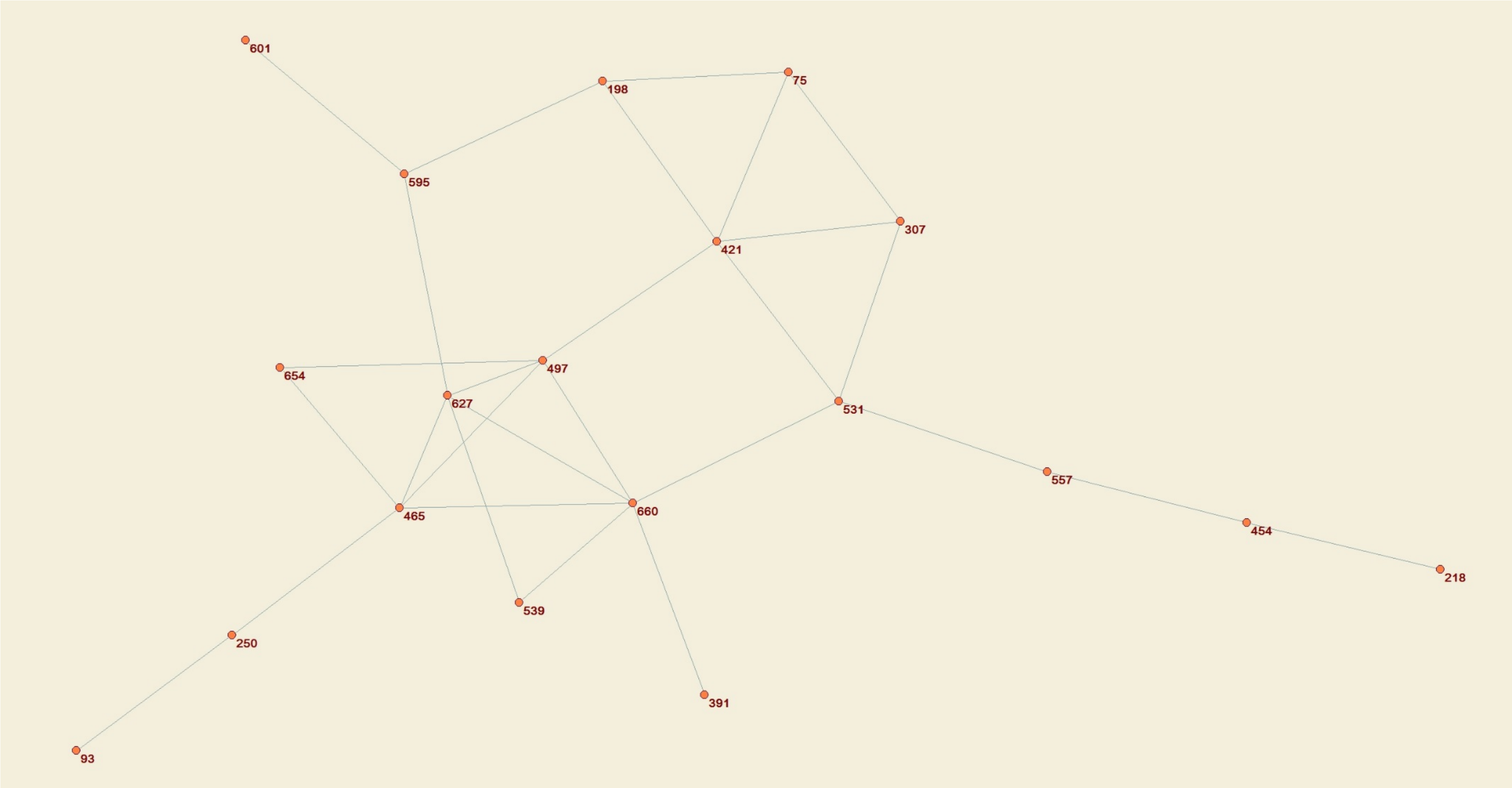

Figure 23. Cluster 9: Oral implants. The Local view.

Table 36. Cluster 9: Oral implants. The Local view.

NR.	Title
75	Influence of modifying and veneering the surface of ceramic abutments on cellular attachment and proliferation
93	Supported phospholipid bilayers as a platform for neural progenitor cell culture
198	The influence of surface topography of ceramic abutments on the attachment and proliferation of human oral fibroblasts
218	Influence of implant taper on the primary and secondary stability of osseointegrated titanium implants
250	Cell adhesion on supported lipid bilayers
307	Determining optimal surface roughness of TiO2 blasted titanium implant material for attachment, proliferation and differentiation of cells derived from human mandibular alveolar bone
391	Adsorption and coadsorption of water and glycine on TiO2
421	Attachment and proliferation of human oral fibroblasts to titanium surfaces blasted with TiO2 particles - A scanning electron microscopic and histomorphometric analysis
454	Mk II: The self-tapping Branemark implant: 5-year results of a prospective 3-center study
465	Glow discharge plasma treatment for surface cleaning and modification of metallic biomaterials
497	Bone response to surface-modified titanium implants: Studies on the early tissue response to machined and electropolished implants with different oxide thicknesses
531	A histomorphometric evaluation of bone-to-implant contact on machine-prepared and roughened titanium dental implants - a pilot-study in the dog
539	Site-specific adhesion of staphylococcus-epidermidis (rp12) in ti-al-v metal systems
557	Implant treatment in resorbed edentulous upper jaws - a 3-year follow-up-study on 70 patients
595	In vitro and in vivo experimental studies on single crystal sapphire dental implants
601	Histology of tissues surrounding single crystal sapphire endosseous dental implants An experimental study in the beagle dog
627	Biomaterial and implant surfaces - on the role of cleanliness, contamination, and preparation procedures
654	Characterization of surface-roughness in titanium dental implants measured with scanning tunneling microscopy at atmospheric-pressure
660	Surface science aspects on inorganic biomaterials

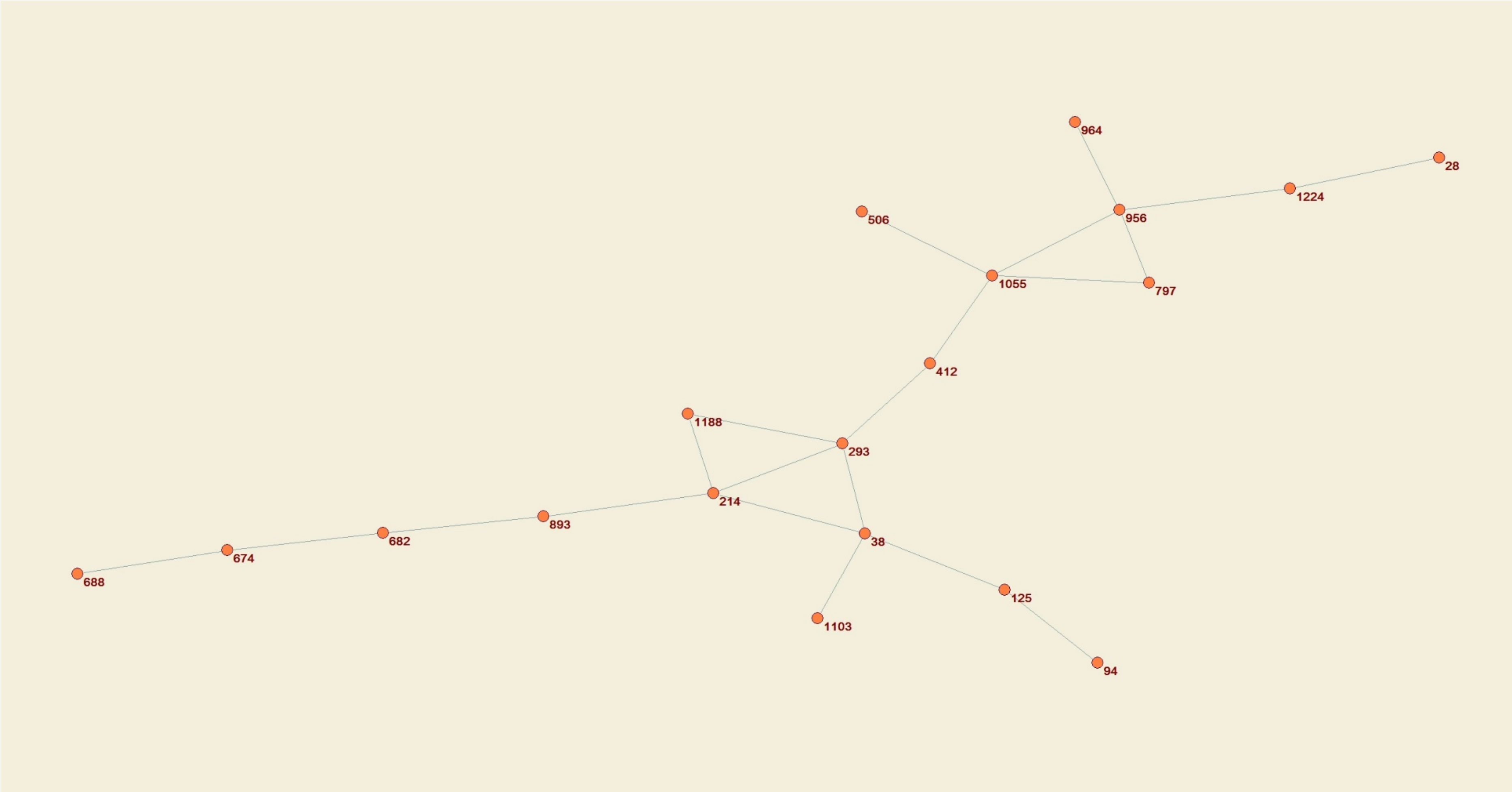

Figure 24. Cluster 14: Oral implants. The Local view.

Table 37. Cluster 14: Oral implants. The Local view.

NR.	Title
28	Vertical ridge augmentation of the atrophic posterior mandible with interpositional bloc grafts: bone from the iliac crest vs. bovine anorganic bone. Clinical and histological results up to one year after loading from a randomized-controlled clinical trial
38	Effects of different implant surfaces and designs on marginal bone-level alterations: a review
94	Short-term clinical results of Nobel Direct implants: a retrospective multicentre analysis
125	Direct loading of Nobel Direct (R) and Nobel Perfect (R) one-piece implants: a 1-year prospective clinical and radiographic study
214	Astra Tech and Branemark system implants: a 5-year prospective study of marginal bone reactions
293	Marginal bone reaction to oral implants: a prospective comparative study of Astra Tech and Branemark System implants
412	Inter- and intraobserver variability in radiographic bone level assessment at Branemark fixtures
506	Accuracy and precision in the radiographic diagnosis of clinical instability in branemark dental implants
674	Direct-current influence on bone-formation in titanium implants
682	Osseointegrated titanium fixtures in the treatment of edentulousness
688	Direct bone anchorage of external hearing-aids
797	Marginal bone level and survival of short and standard-length implants after 3 years: An Open Multi-Center Randomized Controlled Clinical Trial
893	An open, prospective, non-randomized, controlled, multicentre study to evaluate the clinical outcome of implant treatment in women over 60years of age with osteoporosis/osteopenia: 1-year results
956	Short implants compared to implants in vertically augmented bone: a systematic review
964	Therapeutic concepts and methods for improving dental implant outcomes Summary and consensus statements. The 4th EAO Consensus Conference 2015
1055	Implants of 6 mm vs. 11 mm lengths in the posterior maxilla and mandible: a 1-year multicenter randomized controlled trial
1103	Deposition of nanometer scaled calcium-phosphate crystals to implants with a dual acid-etched surface does not improve early tissue integration
1188	Sinus bone formation and implant survival after sinus membrane elevation and implant placement: a 1-to 6-year follow-up study
1224	Vertical augmentation with interpositional blocks of anorganic bovine bone vs. 7-mm-long implants in posterior mandibles: 1-year results of a randomized clinical trial

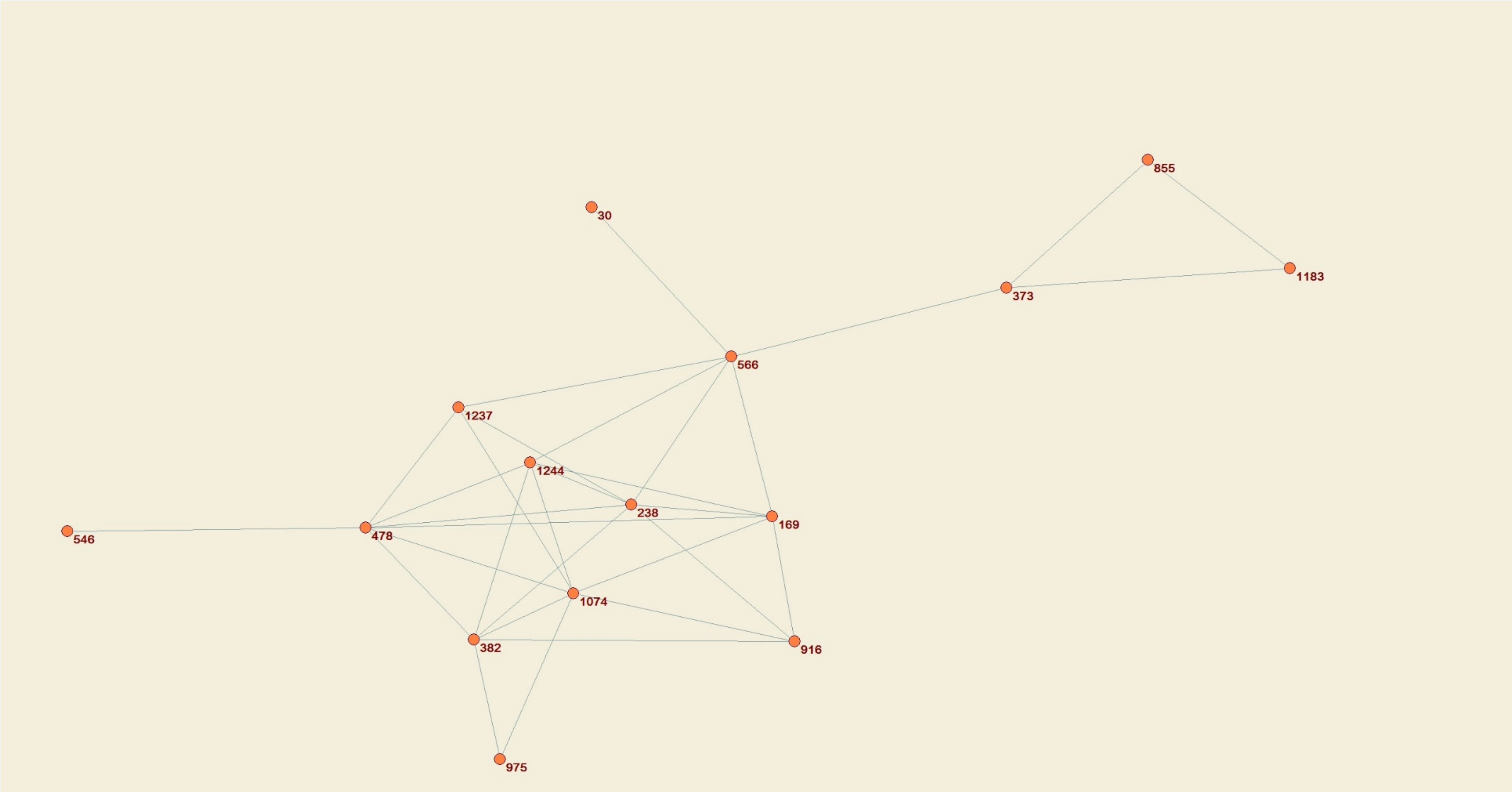

Figure 25. Cluster 18: Oral implants. The Local view.

Table 38. Cluster 18: Oral implants. The Local view.

NR	Title
30	Implant-supported fixed cantilever prosthesis in partially edentulous jaws: a cohort prospective study
169	Tissue alterations at implant-supported single-tooth replacements: a 1-year prospective clinical study
238	Peri-implant bone alterations in relation to inter-unit distances - A 3-year retrospective study
373	Single implants in the upper incisor region and their relationship to the adjacent teeth - An 8-year follow-up study
382	Implant supported single-tooth replacements compared to contralateral natural teeth - Crown and soft tissue dimensions
478	Recession of the soft tissue margin at oral implants - A 2-year longitudinal prospective study
546	The influence of the masticatory mucosa on the peri-implant soft-tissue condition
566	Radiological evaluation of marginal bone loss at tooth surfaces facing single branemark implants
855	Zirconia abutments for single-tooth implant restorations: a 10-to 11-year follow-up study
916	Three-Dimensional buccal bone anatomy and aesthetic outcome of single dental implants replacing maxillary incisors
975	Dimensions of the healthy gingiva and peri-implant mucosa
1074	Soft tissue topography and dimensions lateral to single implant-supported restorations. A cross-sectional study
1183	Zirconia abutments for single-tooth implant restorations: a retrospective and clinical follow-up study
1237	Bone alterations at implant-supported FDPs in relation to inter-unit distances: a 5-year radiographic study
1244	Peri-implant soft tissue and bone crest alterations at fixed dental prostheses: a 3-year prospective study

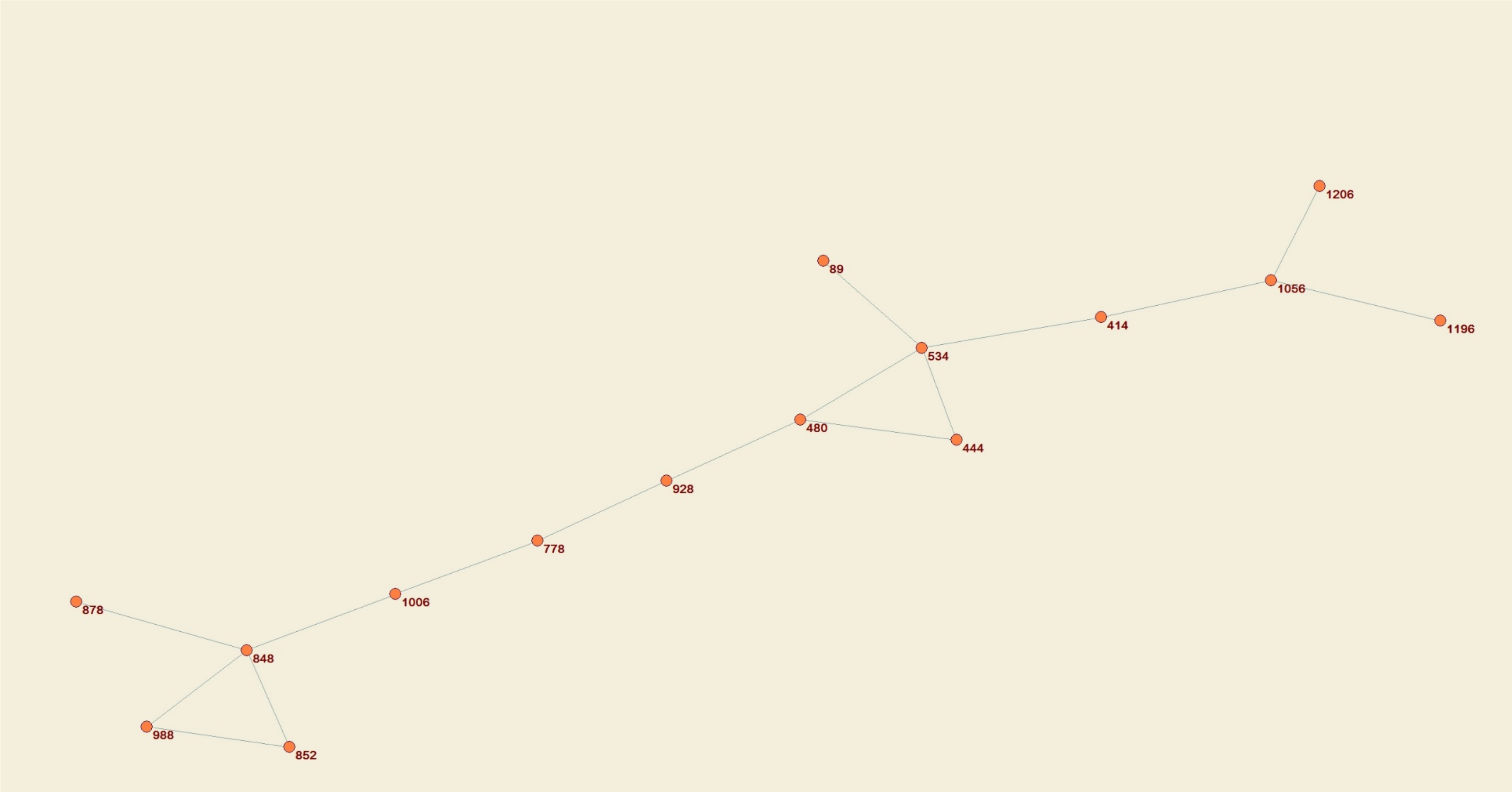

Figure 26. Cluster 29: orthopedic implants; prostheses. The Local view.

Table 39. Cluster 29: orthopedic implants; prostheses. The Local view.

NR.	Title
89	Five-year results from a randomized, controlled trial on early and delayed loading of implants supporting full-arch prosthesis in the edentulous maxilla
414	Measurements of bone and frame-work deformations induced by misfit of implant superstructures - A pilot study in rabbits
444	Failure patterns of four osseointegrated oral implant systems
480	A prospective 15-year follow-up study of mandibular fixed prostheses supported by osseointegrated implants - Clinical results and marginal bone loss
534	Fixed implant-supported prostheses in the edentulous maxilla - a 5-year follow-up report
778	Antibiofilm elastin-like polypeptide coatings: functionality, stability, and selectivity
848	Staphylococcal biofilm gene expression on biomaterials - A methodological study
852	Biofilm formation and antimicrobial susceptibility of staphylococci and enterococci from osteomyelitis associated with percutaneous orthopaedic implants
878	The clinical, radiological, microbiological, and molecular profile of the skin-penetration site of transfemoral amputees treated with bone-anchored prostheses
928	Engineered protein coatings to improve the osseointegration of dental and orthopaedic implants
988	A novel soft tissue model for biomaterial-associated infection and inflammation - Bacteriological, morphological and molecular observations
1006	Bacteria-material surface interactions: methodological development for the assessment of implant surface induced antibacterial effects
1056	The influence of stiffness of implant-abutment connection on load-deflection ratios of a screw-retained stiff cantilever beam. 3-D measurements in vitro
1196	Deflections of an implant-supported cantilever beam subjected to vertically directed loads. In vitro measurements in three dimensions using an optoelectronic method. II Analysis of methodological errors
1206	Deflections of an implant-supported cantilever beam subjected to vertically directed loads: in vitro measurements in three dimensions using an optoelectronic method. I. Experimental set-up

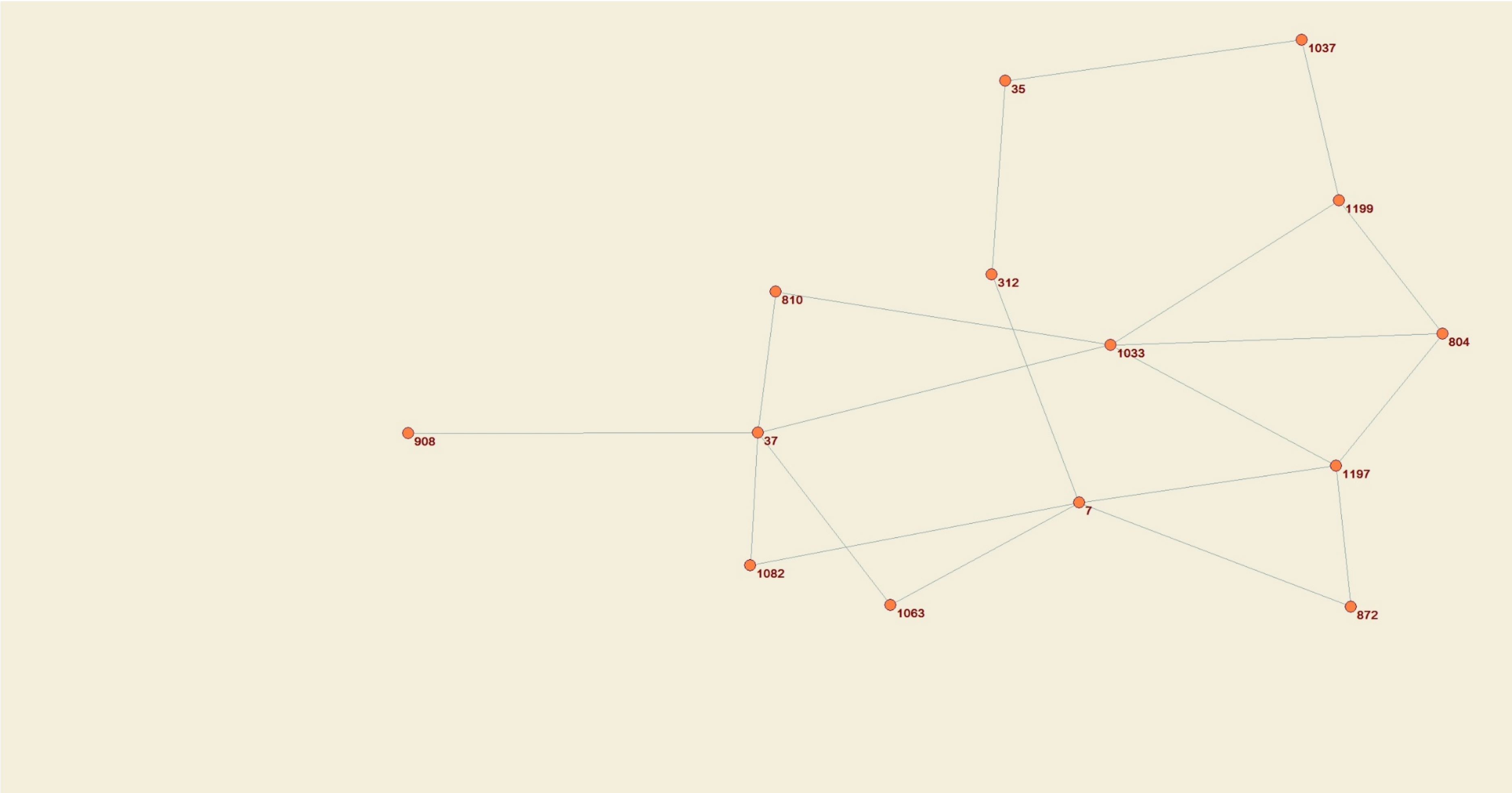

Figure 27. Cluster 13: Oral implants, titanium implants. The Local view.

Table 40. Cluster 13: Oral implants; titanium implants. The Local view.

NR.	Title
7	Titanium dioxide nanotubes enhance bone bonding in vivo
35	Semi-conducting properties of titanium dioxide surfaces on titanium implants
37	Effects of titanium surface topography on bone integration: a systematic review
312	Interactions between human whole blood and modified TiO2-surfaces: Influence of surface topography and oxide thickness on leukocyte adhesion and activation
804	Three-dimensional modeling of removal torque and fracture progression around implants
810	Biomechanical, histological, and computed X-ray tomographic analyses of hydroxyapatite coated PEEK implants in an extended healing model in rabbit
872	The influence of controlled surface nanotopography on the early biological events of osseointegration
908	Implant stability and bone remodeling up to 84days of implantation with an initial static strain. An invivo and theoretical investigation
1033	Understanding mechanisms and factors related to implant fixation; a model study of removal torque
1037	Electronic properties of anodized TiO2 electrodes and the effect on in vitro response
1063	Bone response to physical-vapour-deposited titanium dioxide coatings on titanium implants
1082	Evaluation of surface roughness as a function of multiple blasting processing variables
1197	Biomechanical, histological and ultrastructural analyses of laser micro- and nano-structured titanium implant after 6 months in rabbit
1199	Global biomechanical model for dental implants

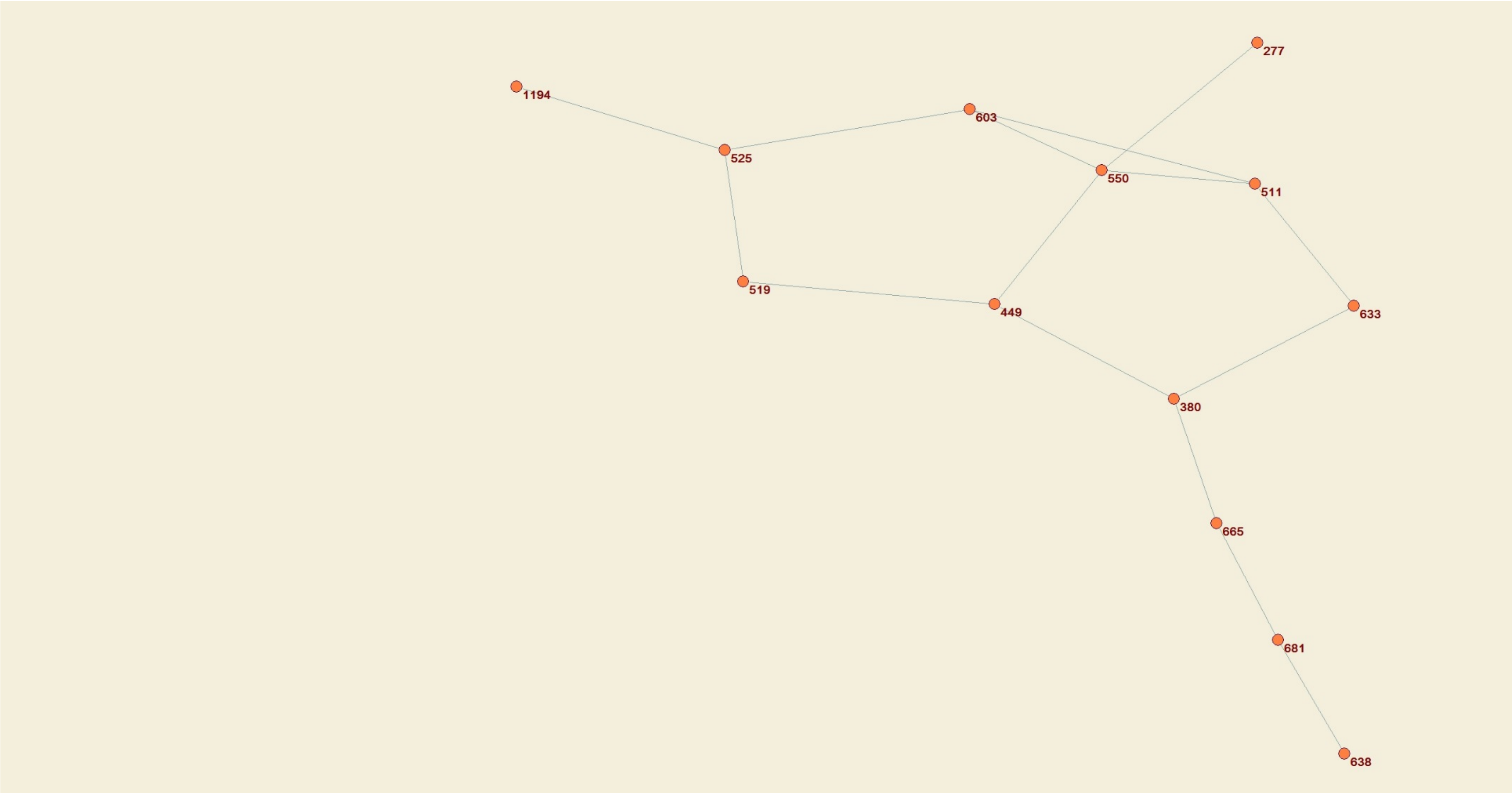

Figure 28. Cluster 20: Titanium implants. The Local view.

Table 41. Cluster 20: Titanium implants. The Local view.

Nr.	Title
277	Morphologic and immunohistochemical observations of tissues surrounding retrieved transvenous pacemaker leads
380	Surface analysis of failed oval titanium implants
449	Immunohistochemistry of soft tissues surrounding late failures of Branemark implants
511	Cast titanium as implant material
519	Immunohistochemical study of the soft-tissue around long-term skin-penetrating titanium implants
525	Electron-microscopic observations on the soft-tissue around clinical long-term percutaneous titanium implants
550	Method for immunolocalization of extracellular proteins in association with the implant soft-tissue interface
603	Method for ultrastructural studies of the intact tissue-metal interface
633	Surface spectroscopic characterization of titanium implants after separation from plastic-embedded tissue
638	Drug test chamber - a titanium implant for administration of biochemical agents to a standardized bone callus insitu
665	Accelerated oxide-growth on titanium implants during autoclaving caused by fluorine contamination
681	The interface zone of inorganic implants invivo - titanium implants in bone
1194	Integration between a percutaneous implant and the porcine small bowel

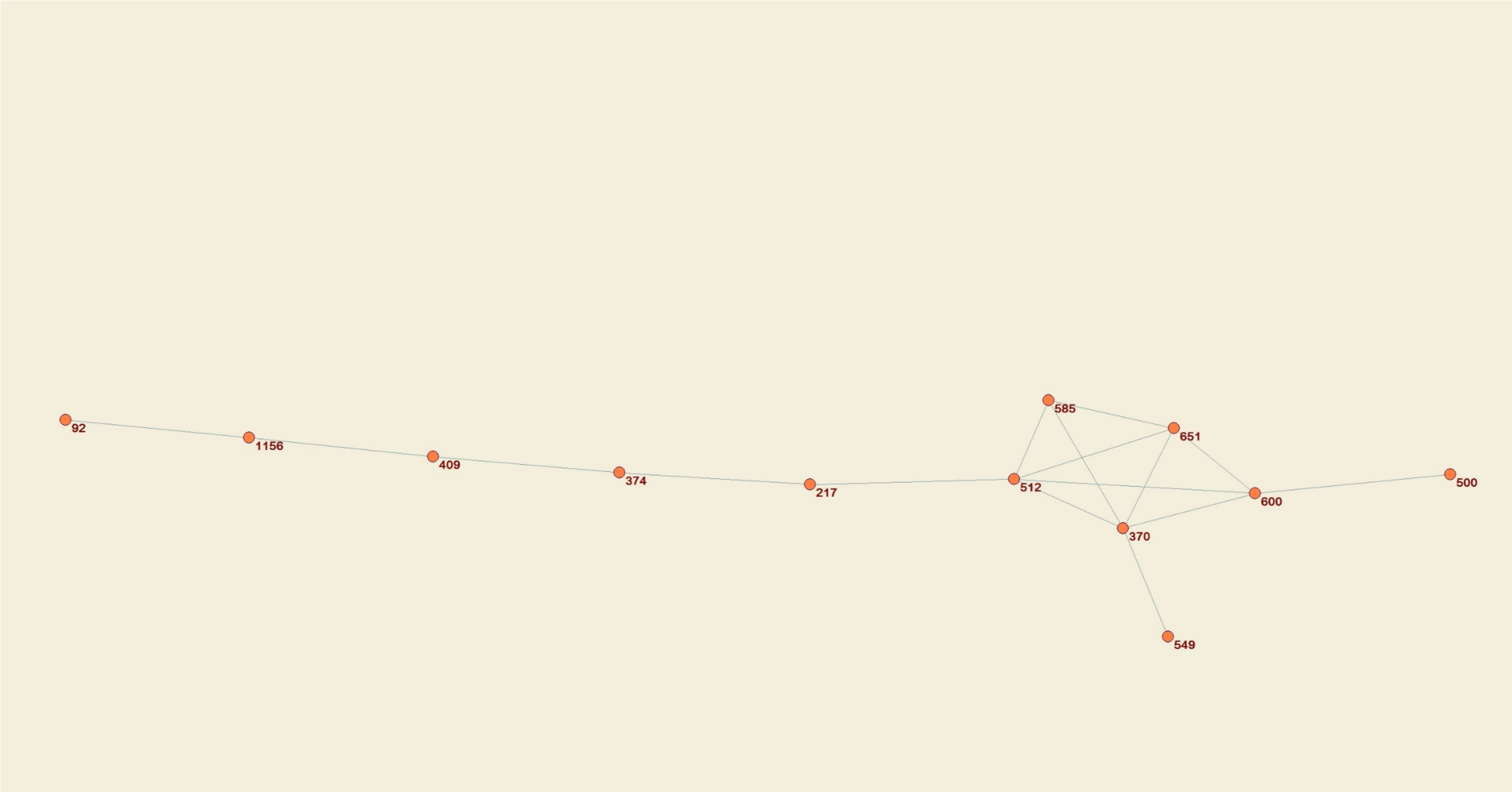

Figure 29. Cluster 28: Biomechanical models. The Local view.

Table 42. Cluster 28: Biomechanical models. The Local view.

NR.	Title
92	Bone level alterations at implants placed in the posterior segments of the dentition: outcome of submerged/non-submerged healing – A 5-year multicenter, randomized, controlled clinical trial
217	Area moments of inertia as a measure of the mandible stiffness of the implant patient
370	Total shoulder and relative muscle strength in the scapular plane
374	The implant neck: smooth or provided with retention elements - A biomechanical approach
409	The use of a conical fixture design for fixed partial prostheses. A preliminary report
500	Measurement of upper extremity orientation by video stereometry system
512	Structure and internal consistency of a shoulder model
549	On a model of the upper extremity
585	Towards a model for force predictions in the human shoulder
600	Biomechanical model of the human shoulder joint .2. The shoulder rhythm
651	Biomechanical model of the human shoulder .1. Elements
1156	Submerged and transmucosal healing yield the same clinical outcomes with two-piece implants in the anterior maxilla and mandible: interim 1-year results of a randomized, controlled clinical trial

High impact local papers

When counting citations of papers, we need to consider the so called citation window, acknowledging the influence of time on citation counts. Thus, we compute the ACR (cf. section Period 1: 1994-2004). Distributions of citations are commonly skewed to the right with high citation frequencies affecting the arithmetic mean. Hence, the median is a better description of central tendency and in this case it was 1.3 and the range 68.3. As can be concluded from Figure 25, the main bulk of ACRs is within the interval 0-5 (83 %) and the distribution is strongly lopsided.

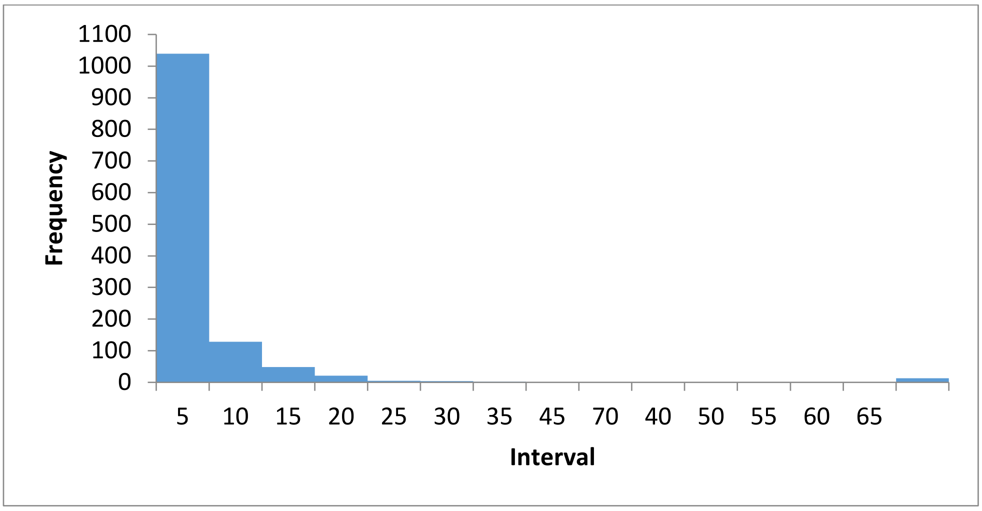

Figure 30. Histogram showing the distribution of annual citation rates. Local view.

Now we direct our interest towards those papers that can be found within the upper quartile of this distribution. We find 312 papers which may be studied with the intention of finding the more acclaimed research themes for the period of observation. Of these 312 papers, 229 were connected through a citation link, and following the previously used methods, a total of 15 clusters were generated. The resolution parameter *r* was set to 0.5 which resulted in cluster sizes between 2 and 49 and *Q* = 0.91. In Table 31 clusters with a minimal size of 5 are displayed with additional information:

- the number of cluster members (size),
- the label, i.e., the perceived subject content derived from title words and their frequencies,
- the average age calculated as the number of years from 2019,
- the total number of citations to the cluster in question, measuring the volume of citation impact, and
- the average annual citation rate (ACR).

As can be concluded from Table 39, the general focus is on oral implants. Most clusters relate to dental research and have the label Oral implants. Labels specifying the difference between these clusters would of course require a specialist from this field. We can see that the distribution of average ages ranges from 8 years to 25 years. The correlation between Average age and Average ACR is strongly negative (*r* = - 0.70) indicating the aging of some parts of the literature in terms of diminishing citation. The youngest clusters, Cluster 6 and Cluster 4 also have the highest average ACR. We conclude that the highest impact is directed towards research themes that basically involve oral implants, but we also have clusters with research themes that connect with tissue engineering and biomaterials, not specifically associated with dental research (Cluster 2 and Cluster 4).

Table 43. The distribution of clusters based on papers within the upper quartile of the distribution of ACRs, the Local view.

Cluster	Size	Label	Avg. age in years	Total cit.	Avg. ACR
1	49	Implants, titanium, surface	16	7190	9
2	34	Osseointegration, interface	10	2093	7
6	33	Oral implants	9	3468	11
7	27	Oral implants	13	3055	8
4	17	Bacterial cellulose - scaffolds	8	1687	11
8	17	Oral implants	18	2873	9
5	15	Oral implants	14	1767	8
3	14	Oral implants	14	2023	10
9	5	Oral implants	25	624	5

For the 312 selected papers, more bibliographic information, including citations, titles and addresses, is available in *Appendix 8*.

Summary

Growth, volume and impact

Calculating the growth rate of the literature of Medical technology, we found that the annual percent growth rate was five percent for both the first and the last period, and 13 percent for the middle period. Thus it seems that an increasing growth rate levelled out during the later five years.

Considering actors on the global level, for the first period we identified North American universities in the two top positions, *Harvard University* and *University of California System*, and on the third position *London University*. These three universities keep a top position through all three periods. In the third period the *Chinese Academy of Sciences* appear on the fourth rank position which implies a remarkable climb as this university is below the 25 most productive institutions in the first period, and on the 11th rank position in the second.

On the aggregate level of countries, China holds the 14th rank position in the first period and rapidly climbs to the second rank position during the second period and keeps that position during the third period. Unsurprisingly the USA holds the top position during all three periods. Sweden is on the list of the 25 most productive countries during all three periods and well above the other Scandinavian countries for all three periods. There is, however, a relative decline as Sweden falls from the ninth rank position in the first period to the 18th rank position during the second period and to the 20th rank position during the third period.

With regard to funding agencies, for all periods most funders are North American with *United States Department of Health Human Services* in top. In the second and third periods, the *National Natural Science Foundation of China* appears on the third rank position.

For the three consecutive periods of observation, we conclude that method papers generally have a great impact and also review articles. For the first period we noted a slow ageing scheme for some continuously cited seminal papers, and there seemed to be a balance between method and empirical research. The second period seemed somewhat biased towards empirical research and in the third period we saw a strong element of novel methods and techniques. Note that these impressions apply to the thin segment of top cited papers, as accounted for in the introduction section.

The cognitive structure of the field

With a point of departure in the set of top five percent cited papers, a cluster analysis based on citation links between papers was pursued with the aim of mapping the cognitive structure of the field over three consecutive periods. The cluster analysis from the first period resulted in a cluster solution with 29 clusters with a minimal size of 20, 77 percent of all highly cited papers were included and the average degree was 4.3. The corresponding figures for the second period were 55 clusters with a minimal size of 20, 86 percent of all highly cited papers and an average degree of 5.95, and for the last period, 47 clusters with a minimal size of 20, 60 percent of all highly cited papers and an average degree of 1.0. Conclusively, much deviating networks were generated. In particular, the interconnectedness in terms of average degree was much lower in the last period and the granularity considerably higher (cluster size and number of clusters). This may largely be explained by the shorter length of the observation period (five years). We conclude that the different periods provide us with quite different cognitive structures, though there are several common themes to be seen: bio-materials / tissue engineering, medical imaging, implants (oral and others) and health information. In the first period, medical imaging and bio-materials are pronounced themes and there are also more of an emphasis on bio-mechanics than in the other periods. In the second period, besides a much larger number of clusters, an emphasis on other research themes is seen: drug delivery, health information technology, targeting, brain-computer interface, surface features – nanoscale and nanoparticles. In the third period novel research themes like bioprinting, photo-thermal therapy and computer aided detection and diagnosis are added. In all, 131 clusters with much varying content lay ground for a detailed study of various research themes during the 25-year period of observation.

The local view

In this study, particular interest was directed towards research performed by CUT and UG and a separate set of papers was collected for this purpose. The oldest paper was from 1973 and the growth of papers showed an increasing but erratic trend over time. In total, 866 papers were assigned to UG and 401 to CUT, including overlapping papers. In the same set, 103 papers affiliated with SUH were identified. The strongest link of collaboration was between CUT and UG, followed by UG and SUH. Ten percent of the total number of papers for CUT and UG were generated in collaboration with each other. The trend of increasing collaboration over time was more accentuated for the combination CUT – UG. The collaboration network including external organisations was mapped on two levels: (1) organisational and (2) national. Results showed that most collaborations on the institutional level concerned Swedish universities and few private corporations. On the national level, the major part of collaboration take place with North America, England and Germany and we found less than expected collaborations with Scandinavian countries.

Applying a cluster analytical approach, citation links between papers were computed resulting in the association of 738 papers. The underlying network had an average degree of 5.20 and the cluster solution comprised a total of 96 clusters. Of these, 19 clusters with a minimal size of 12 were analysed. A thorough analysis was performed and the overall impression was that the cognitive structure reflected much less variation when compared with the global level and there was an emphasis on oral implants and dental research.

Focusing on a select set of high impact papers, 312 papers within the upper quartile of the distribution ACRs were identified and clustered on basis of citation links. Nine clusters with a minimum size of five were analysed. Most of these clusters focused on oral implants and dental research.