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Analysis of trends in Orthopedic Prosthetics

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Abstract:

This article uses concepts from technology management applied to health to identify and analyze the trends in new orthopedic implants. Using the technological information extracted from scientific articles and patents indexed between 2000 and 2014 in the Web of Science and Derwent Innovations Index databases, respectively, we created a taxonomy to take account of these trends. (Bio) mechanical and orthopedic engineering technologies (60%), (nano) biomaterials technologies (20%), and (bio)chemical and (bio) pharmaceutical technologies (16%) represent the current trends in orthopedic prosthetics. The last two categories together correspond to the application of nanobiotechnology to new biomaterials for implants (32%) and indicate the future trends in orthopedic prosthetics. Technologies for testing and diagnostics account for just 4% of the total. These data are strategic, in that they indicate the development and production of new orthopedic technologies for the health sector in a global market for orthopedic implants expected to be worth some US$ 41.8 billion in 2016

Introduction:

The opening of many countries' economies and the globalization seen in the early 1990s prompted companies and research institutions to view competitiveness as an indicator of economic development. For the World Economic Forum, competitiveness is defined as the set of institutions, policies, and factors that determine the level of productivity of a country [1].

Obtaining technological information is crucial for organizations to build knowledge, because it provides strategic indicators essential for the development and production of new healthcare technologies. The information and knowledge contained in a technology can be extracted from scientific articles and patents related to this technology. Patents contain information on recently launched, protected technology that will potentially be launched on the market. It has become common practice to use patents as indicators of the results of inventive activity [2].

Analyzing patents therefore offer strategic intelligence on a given technology, which could reveal competitive advantages based on the profile and identification of the leading actors in its development. The number of patents granted to these actors – which could be a company or even a country – reflects the strength of their technological activity [2].

Of all the different sectors of industry, health is one of the most promising from the perspective of technological convergence. This is defined as the merging of two or more areas of technology to form a new area of knowledge. This new transdisciplinary area is formed where its constitutive fields interface with one another, and leads to the emergence of new industries with great innovative potential [3].

Understanding the demographic and epidemiological profile of diseases is fundamental to comprehending health and disease processes in the world, yielding strategic indicators for the health industry. For instance, there are over 50 million fractures every year around the world, mostly from accidents, falls, or activities that could cause lesions. Of these fractures, 51% occur in people under 45 years of age, 21% in adults aged 45-64, and 29% in people aged 65 or over. In the older age bracket, osteoporosis is a major cause of the rising demand for fracture repairs. Around the world, nine million osteoporotic fractures occur every year. In Europe alone, there is one osteoporotic fracture every 30 seconds [4].

Osteoarthritis is the principal debilitating clinical condition, accounting for the functional incapacity of around 15% of the world's adult population [5]. Its progression leads to functional incapacity or limitation due to pain, reduced range of motion, stiffness, and resulting muscular weakness. The partial or total loss of a joint leads to bone deformation caused by friction in bone-on-bone contact. When medical treatment designed to contain joint and bone degeneration fails, arthroplasty is recommended to replace the joint with an implant [6,7,8].

Orthopedic prostheses constitute the majority of all implantable devices, whose total cost sums around US$ 10 billion. In view of the advanced development of biomaterials, clinical applications, and designs, the global orthopedic implant industry should be worth US$ 41.8 billion in 2016 [9].

In view of these facts, orthopedic implants could be seen as strategic because of the size of the market, their importance to health, and their capacity to foster the development of new knowledge through technological convergence.

The aim of this article is to analyze the technological information contained in scientific articles and patents with a view to identifying current and future technological trends for orthopedic implants. These trends are strategic for the development and production of new orthopedic technologies for the health sector both in economic terms and in terms of healthcare.

As well as this introduction, the article covers the technologies contained in the latest orthopedic implants (section 2), then sets forth the methodology used to identify the different groups of technologies (section 3). In section 4 the findings are presented together with a discussion of which technologies represent trends. Finally, section 5 offers some conclusions from the perspective of the trends and their importance to the health sector.

New Orthopedic Implants:

Orthopedic prostheses or implants constitute all implantable medical products with orthopedic purposes, and are used as joint replacements, artificial bones, in ligament surgery, and in maintaining spinal function in human beings [10].

Bone regeneration is required for many orthopedic conditions, especially in the cases of defects caused by fractures, nonunions, and bone loss due to neoplasia or infection processes, significantly impairing the quality of life of the people they affect. As the main reason for the failure of treatment is inadequate tissue-material interaction, improving biomaterials is seen as the key to the success and durability of implants and their capacity to restore movement [11].

Biomaterials are any biological or synthetic materials designed to interface with biological systems to assess, treat, augment or replace any tissue, organ or function of the body. They are used to make implants, devices or systems that come into contact with living biological systems and tissue in order to repair tissue loss and restore functions impaired by degenerative processes or traumas [12,13].

The ideal bone graft substitute would be osteogenic (producing bone tissue), osteoinducing (inducing the differentiation of stem cells into osteogenic bone cells), osteoconducting (allowing the bone tissue to migrate over the biomaterial at the tissue-material interface), biocompatible (capable of preventing inflammatory and immunogenic reactions), biodegradable/bioabsorbable (so that the material can be

substituted by growing bone), capable of providing structural support, easy to use clinically, and cost effective [14].

Different biomaterials can therefore be classified according to their properties: 1) osteoconducting (polymeric biomaterials, calcium phosphate and calcium sulphate ceramics); 2) osteoinducing (biomaterials deriving from gene therapy and tissue engineering that induce the differentiation of stem cells into osteogenic bone cells); 3) osteogenic (biomaterials that contain bone marrow aspirates); 4) combined materials (biomaterials with more than one of the above properties, such as composites) [14].

The latest biomaterials being used in implants have properties that set them apart from conventional biomaterials and promising potential clinical applications. Basically, these biomaterials have a surprising capacity to mimic the physiological behavior of bones, interacting with the human body without causing damage or major adverse reactions [11,15,16,17,18].

These technological advances have been obtained by merging nanotechnology with biotechnology: nanobiotechnology. Nanocoatings, nanofilms, and nanostructured surfaces fill fundamental gaps for tissue regeneration and bone repair. One of the main problems associated with implants is their limited biocompatibility, bone growth, and adhesion of the biomaterial to the human body. With tissue engineering and the use of nanomaterials, tissue-material interactions are becoming increasingly similar to the normal physiological reality.

Methodology:

We retrieved and analyzed data on patent applications using the Derwent Innovations Index and accessed the Web of Science database to find scientific articles on orthopedic prostheses. The period of study was 2000 to 2014.

It is essential to treat the data retrieved from patent documents and scientific articles to extract the technological information they contain and group it according to the technologies described. As these groups correspond to the information extracted from different documents, we had to create a taxonomy that represented the whole set in order to present the technological trends in orthopedic prostheses.

Selection and treatment of technological information extracted from patent documents

The search strategy was created using International Patent Classification (IPC) subclasses for orthopedic implants, materials used in such implants, biotechnology, and nanotechnology. The search strategy and procedure are presented below.

• Search for general implants: IP=(A61F-002/00 OR A61F-002/02 OR A61F-002/08 OR A61F-002/28 OR A61F-002/30 OR A61F-002/32 OR A61F-002/34 OR A61F- 002/36 OR A61F-002/38 OR A61F-002/40 OR A61F-002/42 OR A61F-002/44 OR A61F-002/46 OR A61F-002/54 OR A61F-002/56 OR A61F-002/58 OR A61F-002/60 OR A61F-002/62 OR A61F-002/64 OR A61F-002/66 OR A61F-002/68 OR A61F- 002/76 OR A61F-002/78 OR A61F-002/80 OR A61L-031/0054 OR A61L-031/02 OR A61L-031/04 OR A61L-031/06 OR A61L-031/08 OR A61L-031/10 OR A61L-031/12 OR A61L-031/14 OR A61L-031/16 OR A61L-031/18 OR A61L-033/00 OR A61L- 033/02 OR A61L-033/04 OR A61L-033/06 OR A61L-033/08 OR A61L-033/10 OR A61L-033/12 OR A61L-033/14 OR A61L-033/16 OR A61L-033/18)

• Search for orthopedic implants developed using biotechnology: IP=(C12N-001/00 OR C12N-001/00 OR C12N-003/00 OR C12N-007/00 OR C12N-009/00 OR C12N-011/00 OR C12N-013/00 OR C12N-013/00 OR C12N-015/00 OR C12N-005/00 OR C12N-005/02 OR C12N-005/06 OR C12N-005/08 OR C12N-005/10 OR C12N-005/12 OR C12N-005/16 OR C12N-005/18 OR C12N-005/20 OR C12N-005/24 OR C12N-005/26 OR C12N-005/26 OR C12N-005/28) AND (IPC for general implants)

• Search for orthopedic implants developed using nanotechnology: IP=(B82B-001/00 OR B82B-003/00 OR B82Y) OR MAN=(E05-U06 OR E27-B02A OR E27-B01A OR E27-B03A OR E31-U04 OR J01-C04 OR S05-Y02 OR N06-C09 OR U11-A14 OR U11-C13 OR U21-B01T OR X12-D01D OR X12-D07E2A) AND (IPC for general implants)

• Search for orthopedic implants developed using nanobiotechnology: IP=(C12N-001/00 OR C12N-001/00 OR C12N-003/00 OR C12N-007/00 OR C12N-009/00 OR C12N-011/00 OR C12N-013/00 OR C12N-013/00 OR C12N-015/00 OR C12N-005/00 OR C12N- 005/02 OR C12N-005/06 OR C12N-005/08 OR C12N-005/10 OR C12N-005/12 OR C12N-005/16 OR C12N-005/18 OR C12N-005/20 OR C12N-005/24 OR C12N-005/26 OR C12N-005/26 OR C12N-005/28) AND (IPC for general implants)AND (IPC for nanotechnology)

The technology groups identified were organized according to the following technology focus fields from the Derwent Innovations Index: biology, ceramics and glass, chemical engineering, computation and control, electronics, image and communications, industrial standards, inorganic chemistry, metallurgy, testing and diagnostics, (bio)mechanics, organic chemistry, pharmaceutics, and polymers. The patents for which no technology focus was available were classified into one of the above groups based on the content of their abstracts.

The technologies identified by means of the qualitative analysis of the technology groups encountered in the abstracts and the technology focus fields from the Derwent Innovations Index are presented below.

1) Cell and tissue technologies – relate to cell and tissue biology with the purpose of improving bone cell functions or structures in order to improve fracture repair.

2) Gene technologies – biotechnologies designed to genetically modify properties and structures of the bone tissue or substances from the organic component of the bone matrix with the purpose of identifying, modifying or suppressing a given cellular biotechnical or physiological mechanism or property.

3) Pharmaceutical technologies – relate to the pharmacology of drugs for prophylactic, treatment, or palliative purposes, like (nano)films or (nano)coatings that can be released or impregnated with (nano)particles of different pharmaceutical forms in different biomaterials.

4) Technologies for ceramic materials – ceramic biomaterials made of different bone-like composites in different forms, sizes, and rearrangements, and associated with the most varied of agents capable of improving their functions and their applications as biomaterials, including interaction with components of the bone matrix and bone tissue.

5) Technologies for inorganic materials – inorganic materials constituted of different bone-like composites in different forms, sizes, and rearrangements, and associated with the most varied of agents capable of improving their functions and their applications as biomaterials, including interaction with components of the bone matrix and bone tissue.

6) Technologies for testing and diagnostics – implants and devices of different sizes with different characteristics and functions, which may be impregnated with bioactive agents or other substances, mostly used for biomaterial testing, diagnostics, and support for cell growth (scaffolding).

7) Technologies responsible for chemical modifications – used for the chemical modification of substances, bioactive agents, and (bio)chemical reactions to improve biological properties and tissue-material interactions.

8) Technologies for metal materials – different metal alloys constituted of different bone-like composites in different forms, sizes, and rearrangements, and associated with the most varied of agents capable of improving their functions and their applications as biomaterials, including interaction with components of the bone matrix and bone tissue.

9) Technologies for (bio)polymeric materials – for bone-like (bio) polymeric composites in different forms, sizes, and rearrangements, and associated with the most varied of agents capable of improving their functions and their applications as biomaterials, including interaction with the components of the bone matrix and bone tissue.

10) Technologies for chemically engineered processes – related to chemical processes and treatment of biomaterials based on engineering of different components.

11) (Bio-)mechanical technologies – related directly to the (bio)mechanics of implants and their properties, like fixation, connection, reconstruction, flexibility, elasticity, surface coatings, and implant systems.

12) Computer technologies – computer systems used for the functioning of automatic implants.

13) Electrical and electronic technologies – for implants that depend on electrical or electronic components to function.

14) Technologies for industrial standardization – for the industrial standardization of implants or their components.

15) Other technologies – all the technologies that do not fit into the other categories and are not very prevalent, i.e. they do not correspond to a trend in types of implants.

Selection and treatment of the technological information extracted from the scientific articles:

The review of the literature specialized in orthopedic prosthetics and regenerative medicine yielded a thesaurus of all the terms used in the criteria of this methodology. The choice of keywords to search for scientific articles followed the following criteria:

• Terms that follow a logical pattern based on the main specialized areas and their synonyms in orthopedics;

• Terms nano, bone, osteo, osseo, and engineer and derivations thereof using the asterisk (*) wildcard;

• Terms identified in association with the other areas researched, namely nanotechnology, biotechnology, and tissue engineering.

The search strategy was developed using the following criteria:

• Search for general prostheses: TS=((bone* OR knee OR hip OR spine OR joint OR hand OR foot OR feet OR acetabulum OR femoral OR spinal OR shoulder* OR elbow* OR osteo* OR osseo* OR prostheses OR prosthesis OR implant* OR graft* OR substitute* OR alloy*) AND (orthopedic* OR orthopaedic*)).

• Search for orthopedic prostheses developed using biotechnology: TS=((bone* OR knee OR hip OR spine OR joint OR hand OR foot OR feet OR acetabulum OR femoral OR spinal OR shoulder* OR elbow* OR osteo* OR osseo* OR prostheses OR prosthesis OR implant* OR graft* OR substitute* OR alloy*) AND (orthopedic* OR orthopaedic*) AND ((tissue AND engineer*) OR biotech*))).

• Search for orthopedic prostheses developed using nanotechnology: TS=((bone* OR knee OR hip OR spine OR joint OR hand OR foot OR feet OR acetabulum OR femoral OR spinal OR shoulder* OR elbow* OR osteo* OR osseo* OR prostheses OR prosthesis OR implant* OR graft* OR substitute* OR alloy*) AND (orthopedic* OR orthopaedic*) AND (nano*)).

• Search for orthopedic prostheses developed using nanobiotechnology: TS=((bone* OR knee OR hip OR spine OR joint OR hand OR foot OR feet OR acetabulum OR femoral OR spinal OR shoulder* OR elbow* OR osteo* OR osseo* OR prostheses OR prosthesis OR implant* OR graft* OR substitute* OR alloy*) AND (orthopedic* OR orthopaedic*) AND ((tissue AND engineer*) OR biotech*)) AND (nano*)).

The articles were categorized according to the area and sub-area of knowledge they are classified under in the Web of Science database. In dubious cases, the article's abstract was consulted to classify the scientific knowledge encountered in the technologies covered.

The areas of relevance were used to build up the groups of technologies extracted from the scientific articles: cell biology and genetics, chemistry, computer science, engineering, nanomaterials science, and orthopedics.

The technologies present in the scientific research encountered in the articles are similar to those encountered in the patent documents. The areas that the articles relate to are described below; this description may or may not correlate to the earlier list.

1) Orthopedics-related technologies – related to orthopedic medicine and research from this area into the treatment of bone diseases and bone repair. New methods and surgical procedures that yield new knowledge in the use and improved application of implants were included. Equivalent to the (bio)mechanical technologies described in subsection 3.1.

2) Engineering-related technologies – equivalent to the (bio) mechanical technologies described in subsection 3.1.

3) Nanomaterial technologies – covers all metal, ceramic, (bio) polymeric, and other nanomaterials made of different bone-like composites in different forms, sizes, and rearrangements, and associated with the most varied of agents capable of improving their functions and their applications as biomaterials, including interaction with components of the bone matrix and bone tissue.

4) Cell and gene technologies – these technologies were combined, since several similar articles were classified as biotechnology and cell biology. They have to do with genetic modification, tissue engineering, and stem cell research. They correspond to cell and tissue technologies and gene technologies described in subsection 3.1.

5) Chemical technologies – equivalent to technologies responsible for chemical modifications described in subsection 3.1.

6) Computer and other IT-related technologies – have to do with the calculations and mathematical and computer models involved in biocomputation or (bio)mechanics. Equivalent to the computer technologies described in subsection 3.1.

7) Other technologies – as in subsection 3.1, these are technologies whose areas do not represent a trend.

Results and Discussion:

Results and discussion of the data retrieved from the patent documents

Using the methodology described above, a total of 22,615 patents were retrieved from the Derwent Innovations Index. The breakdown of the technologies they describe is as follows:

• biotechnology-based implants – 861 patents;

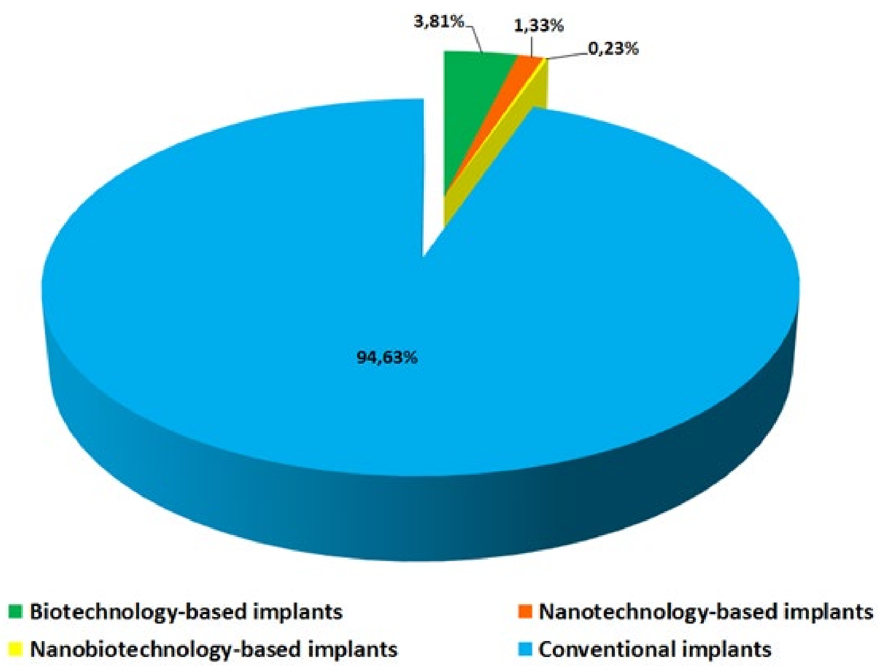

Figure 1. Breakdown of patents for orthopedic implants according to the technological field involved, based on patents indexed in the Derwent Innovations Index from 2000 to 2014 (own research)

• nanotechnology-based implants – 301 patents;

• nanobiotechnology-based implants – 53 patents;

• conventional implants – 21,400 patents.

The data are displayed graphically in Figure 1, which shows the overwhelming prevalence of patents for conventional implants (94.63%).

Although only 5.37% of the patents constitute new prosthetic technologies, this is still a significant number from the perspective of understanding the development of emerging biomaterials. This fact could well indicate that the more knowledge-intensive a technology is, the less representative it is in the graphic, since nanotechnology and nanobiotechnology are still emerging fields.

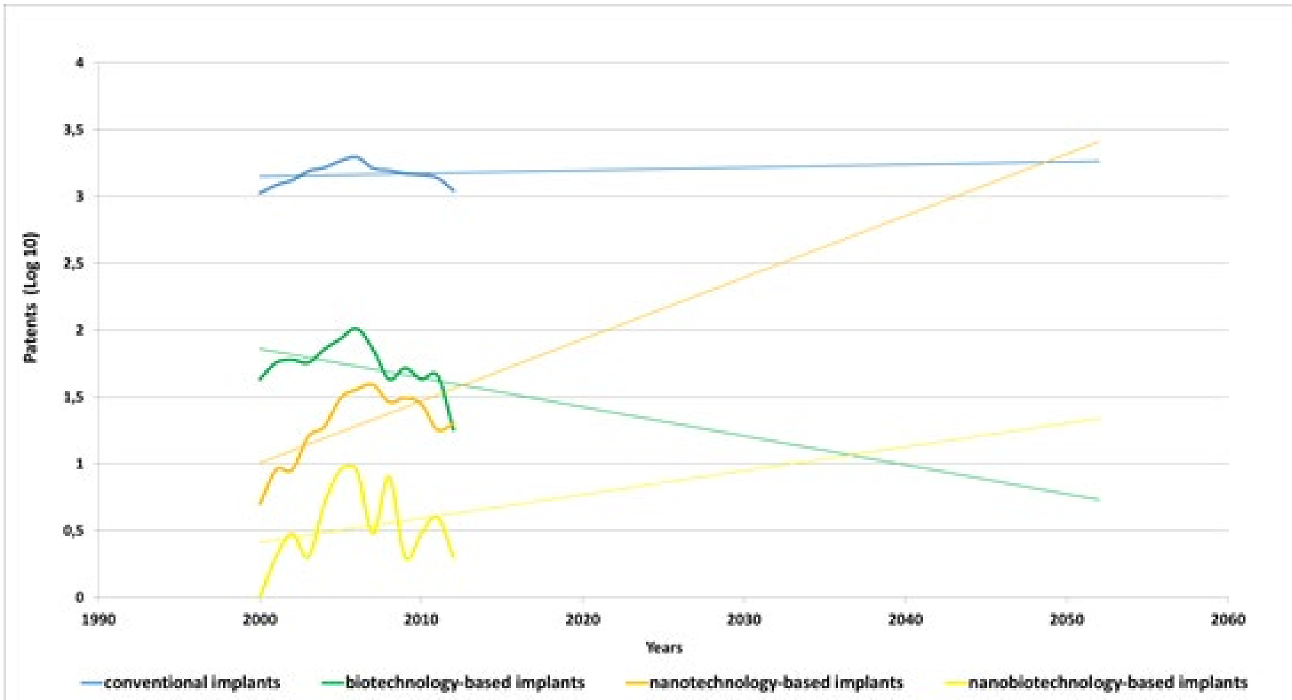

Figure 2. Different types of patents for orthopedic implants per year of priority application (2000-2012) (own research) N.B. The number of patents is expressed as log10 to facilitate comparison between the widely varying patenting figures for the different types of implants

The chronological breakdown (per priority year) of patent applications for different types of orthopedic implants can be seen in Figure 2.

N.B. The number of patents is expressed as log10 to facilitate comparison between the widely varying patenting figures for the different types of implants.

For comparative purposes, the priority years researched were 2000 to 2012, since no patents for nanobiotechnology-based implants were found from before 2000. The apparent drop-off in 2012 can be explained by the mandatory period of confidentiality after filing and time taken to index the patent applications filed in 2013 and 2014.

According to Figure 2, there is a slight, almost constant rise in the number of patents for conventional implants throughout the period in question. The number of patents for biotechnology-based implants is falling, but there is a significant increase in the number of patents for nanotechnology- and nanobiotechnology-based implants.

These trends could be explained by the more widespread development of technologies for biomaterials than for tissues. As a science, biotechnology is at a more advanced stage of technological maturity than nanotechnology. The second generation of bioactive biomaterials first came out in the 1970s: almost 20 years before the third generation of biomaterials and 50 years ago. This could indicate the need for a new technological leap, which is justified by the almost flat trend in conventional implants, the decline in biotechnology-based implants, and the rise in nanotechnology- and nanobiotechnology-based implants. This does not, however, mean that biotechnology is becoming obsolete, but that from the perspective of tissue-material interactions, tissue-related technologies have reached maturity, and now the principal focus is on the technologies inherent to materials.

Comparatively speaking, the trend for nanotechnology-based implants is more marked than the trend for nanobiotechnology-based implants because the latter are the result of technological convergence, and this requires a greater effort from the perspective of knowledge.

The extrapolation of the trendlines indicates that the patenting of nanobiotechnology-based implants will outgrow patenting of biotechnology-based implants by around 2037. Meanwhile, patenting of nanotechnology-based implants should surpass patenting of conventional implants by the middle of the century.

Analyses of technological trends for orthopedic implants observed in the patent documents

The technologies identified in the patents, as described earlier, are shown in Figure 3.

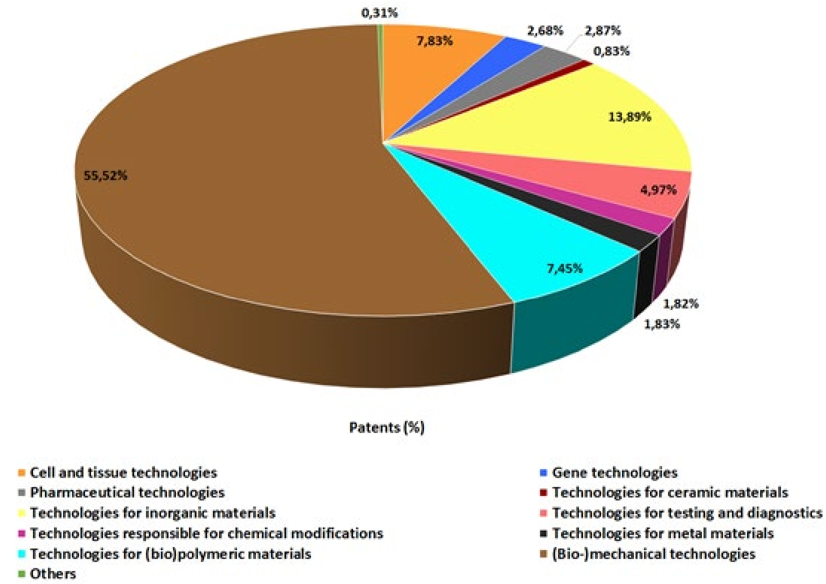

Figure 3. Patent applications per type of technology identified in orthopedic implants (own research)

The main technologies encountered in the patents for orthopedic implants were: (bio)mechanical technologies (55.52%), inorganic materials (13.89%), cell and tissue technologies (7.83%), and biopolymeric materials (7.45%).

Results and discussion of the data retrieved from the scientific articles:

Using the search, refinement, and adjustment criteria, we retrieved a total of 8,688 articles indexed on the Web of Science database between 2000 and 2014. They are represented in Figure 4 and classified below according to the technologies they address:

- biotechnology-based implants – 2,835 articles;
- nanotechnology-based implants – 588 articles;
- nanobiotechnology-based implants – 407 articles;
- conventional implants – 4,857 articles.

It is clear from Figure 4 that conventional implants are the main target of interest in the scientific articles on the Web of Science published on the subject, which represent the state of research and development in orthopedic implants. Interestingly, the proportion of articles about biotechnology-, nanotechnology- and nanobiotechnology-based implants is higher than is the proportion of the same technologies in the patents identified. This indicates the growth of these areas, as addressed throughout this study. Biotechnology is an established area around the world, which is why it is more prominent than the other areas. The three areas represent the scientific progress of implants in the future, and taken together account for 44% of all the articles retrieved, or almost half of all the scientific publications about orthopedic implants.

The temporal evolution of articles published between 2000 and 2014 can be seen in Figure 5.

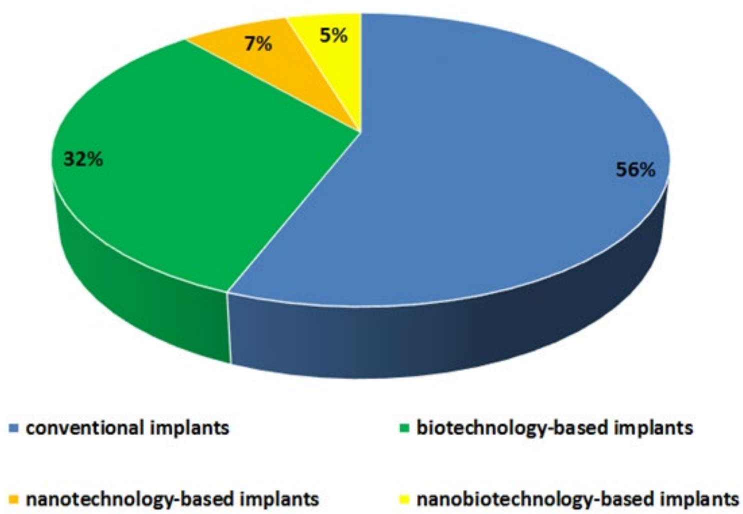

Figure 4. Scientifi c articles about diff erent types of orthopedic implants indexed on the Web of Science database between 2000 and 2014 (own research)

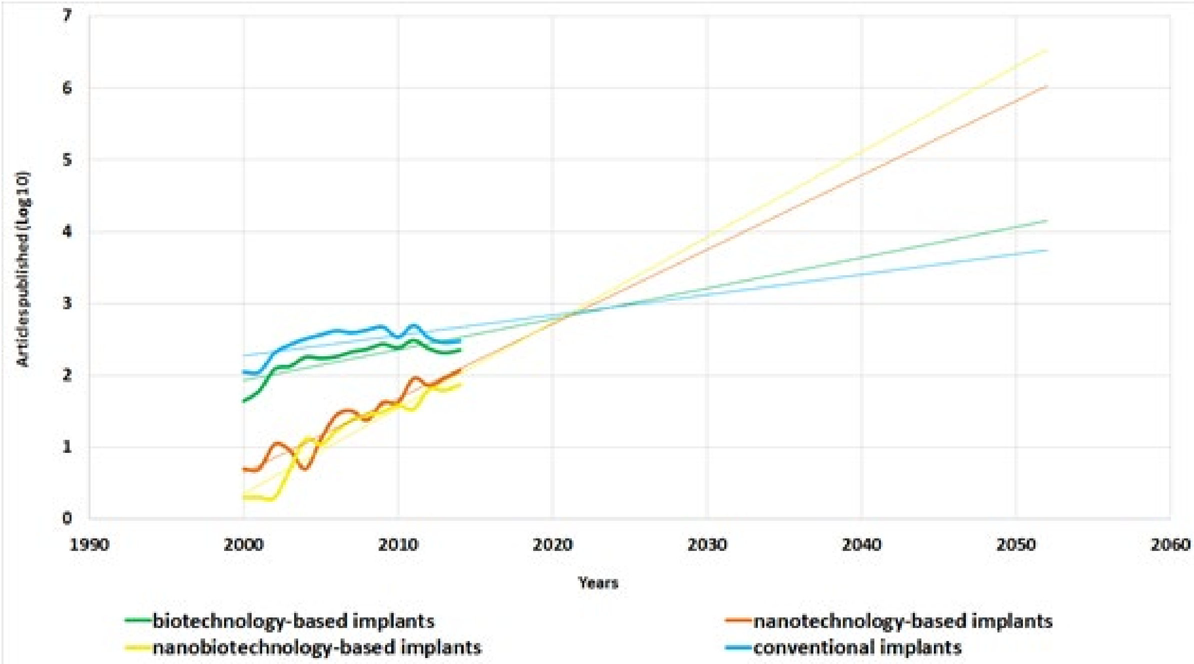

Figure 5. Quantity of articles published about different types of orthopedic implants between 2000 and 2014 (own research)

N.B. The number of patents is expressed as log10 to facilitate comparison between the widely varying patenting figures for the different types of implants.

There is an upward trend in the number of articles published for all types of orthopedic implants. Unlike the analysis of patents, the analysis of articles considers scientific rather than technological developments. As such, this growth profile makes sense, since conventional implants are still worthy of study, including in countries that do not have the technological infrastructure to produce such technologies, which are already mature in other parts of the world. The scientific development of conventional implants could indicate the emergence of new technologies that do not use nanotechnology or biotechnology as the basis for new materials. It could also mean a better clinical understanding of the use of current biomaterials in orthopedic medicine.
As for the biotechnology-based implants, scientific discoveries about the use of mesenchymal stem cells (32%) and the use of scaffolds in regenerative medicine (25%) is certainly the main factor behind the growth in this area of research. Taken together, these two areas account for over 50% of all the scientific research involving this area of prosthetics.
Finally, there is the already identified upward trend in interest in nanotechnology- and nanobiotechnology-based implants. In line with the technological trend seen in patenting, scientific research is also focusing on new nanomaterials, their mechanical and bone-like properties, and their interactions with bone tissue and capacity to mimic the bone matrix.
If we extrapolate the trendline, it indicates that after 2022, the scientific articles on nanotechnology and nanobiotechnology for orthopedic implants will outstrip the number of publications on implants developed using biotechnology and conventional means.

Analyses of the technological trends in orthopedic implants observed in the scientific articles indexed in the Web of Science:

The trends observed in the articles are presented in Figure 6.
The main trends identified in the published articles were technologies for orthopedics (43%), technologies deriving from engineering (24%), nanomaterial technologies (11%), and cell and gene technologies (10%).
Orthopedics is the medical area that comes closest to engineering. Fields like biomedical, clinical, biomechanical, and metallurgical engineering are the main areas engaged in the scientific development of new implants. Allied to orthopedics and engineering, nanomaterial research (11%) and cell and gene technologies (10%) are the two areas that are growing fastest in terms of scientific research in this area (21% in total). The new biomaterials and technologies that can improve tissue-material interactions are the object of research around the world. The use of stem cells to differentiate bone tissue and the use of scaffolds are both important trends.

Creation of a taxonomy and the technological trends in orthopedic prosthetics:

The classification of the groups of technologies described in the patents and articles yielded a taxonomy of trends that covers all the technologies identified. These represent the profile of the scientific and technological developments in orthopedic prosthetics at the current time and in the foreseeable future. They are grouped together according to the development, production, testing, applications, uses, targets of action and/or interaction of the implants (Figure 7)

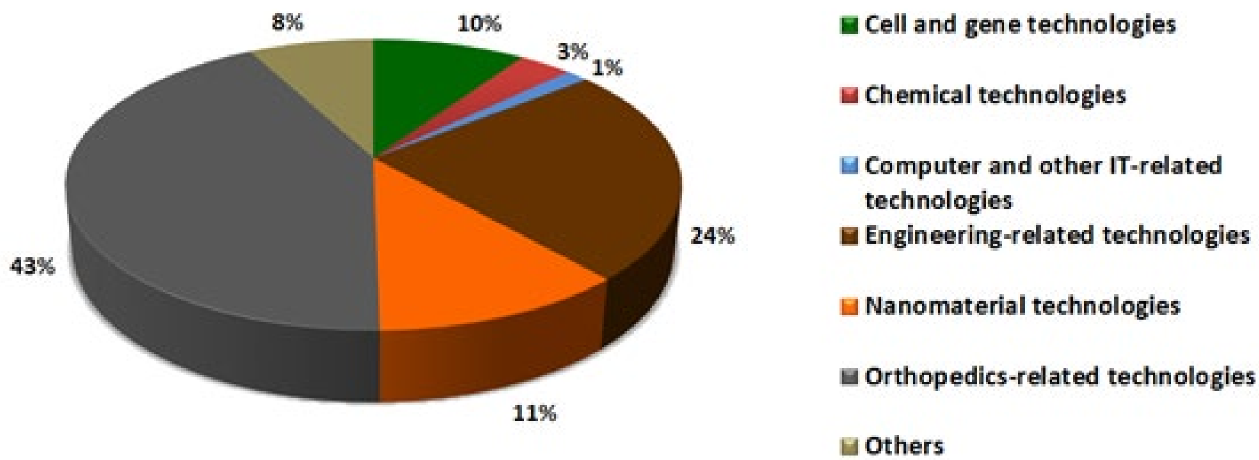

Figure 6. Technological trends based on the areas of knowledge of the scientific articles about orthopedic prosthetics retrieved from the Web of Science database, indexed between 2000 and 2014 (own research)

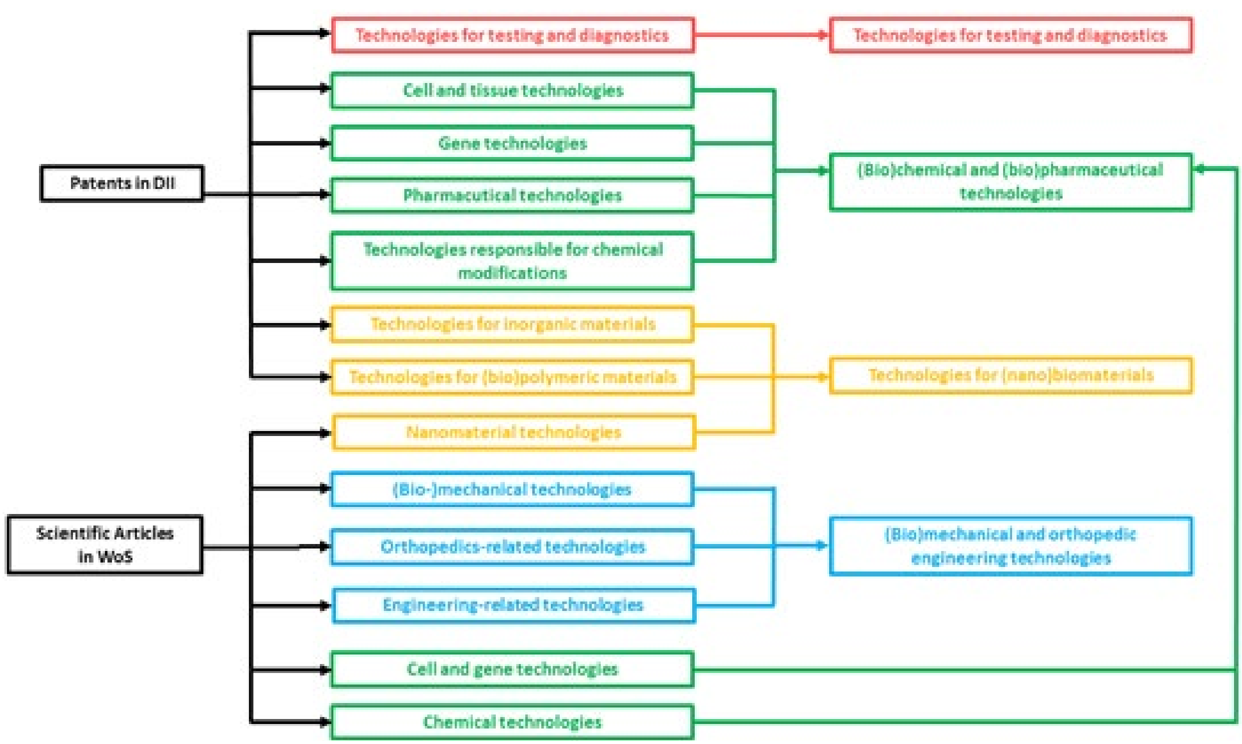

Figure 7. Development of a taxonomy grouping the technological trends identified (own research)

The (bio)chemical and (bio)pharmaceutical technologies are grouped according to their action and/or interaction with the tissue. The technologies for (nano)biomaterials are grouped according to their action and/or interaction with the materials. The (bio)mechanical and orthopedic engineering technologies are related to the development, production, application or use of the implants. Finally, the technologies for testing and diagnostics are for testing the mechanical properties and components of the implants so that they function adequately according to the standards of effectiveness, quality, and safety stipulated in national or international technical regulations.

The trends in the research and development of orthopedic prostheses are described below.

1) (Bio)chemical and (bio)pharmaceutical technologies – These include genetic modification, chemical, and biological technologies designed to improve functions, structures, (bio) chemical reactions, and the genetic material of the bone cells in order to improve fracture repair and tissue-material interactions. They include the actions of drugs, immunomodulators, and the manipulation and engineering of tissues, cells, and their components.

2) Technologies for (nano)biomaterials – These are all the technologies belonging to any (nano)biomaterial (metal alloys, inorganic metals, bioceramics, biopolymers, etc.) made of different bone-like composites in different forms, sizes, and rearrangements, and associated with the most varied of agents capable of improving their functions and their applications as biomaterials, including interaction with components of the bone matrix and bone tissue. Nano-implants or nanoscaffolds fit into this group.

3) Technologies for testing and diagnostics – These are associated with implants and devices of different sizes with different characteristics and functions, which may be impregnated with bioactive agents or other substances, mostly used for biomaterial testing, diagnostics, and support for cell growth (scaffolding).

4) (Bio)mechanical and orthopedic engineering technologies – These are directly related to the (bio)mechanics of implants, orthopedic medicine, and their properties, like fixation, connection, reconstruction, flexibility, elasticity, surface coatings, and implant systems. The use of implants for the treatment or replacement of bones with benign or malignant tumors or other bone diseases are included in this group. New surgical methods and procedures that provide new knowledge related to the applicability of implants are also included. Smart implants produced using biomechatronics fit into this group.

Figure 8 shows the trends in each of the taxonomic groups formed based on the scientific research identified in scientific articles and the technological developments observed in patents.

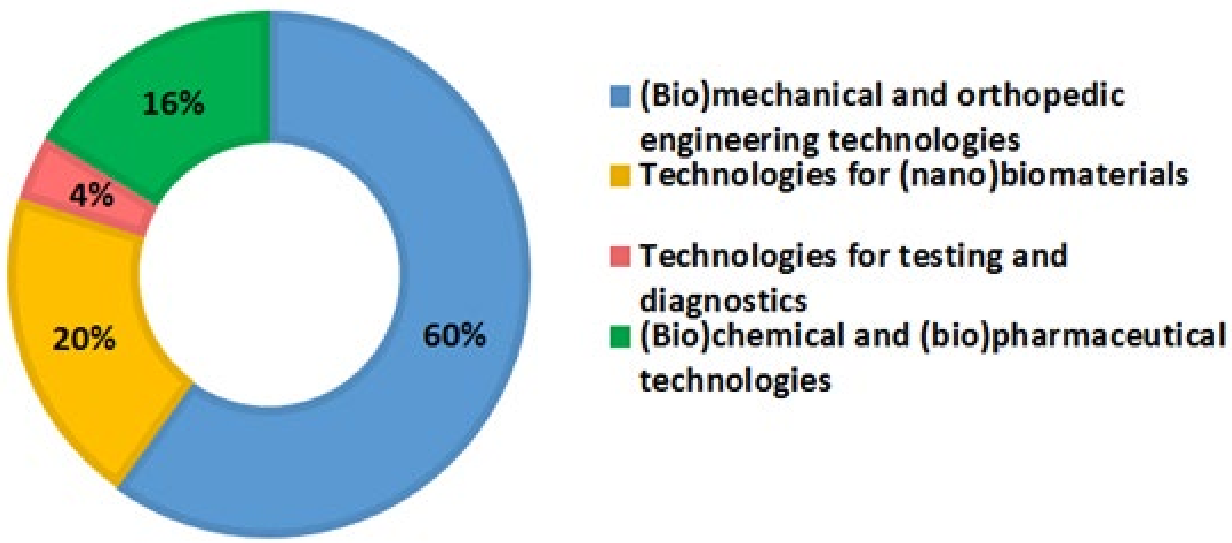

Figure 8. Current trends in the research and development of technologies for orthopedic implants, according to articles on the Web of Science database and patents on the Derwent Innovations Index database (2000-2014) (own research)

(Bio)mechanical and orthopedic engineering technologies (60%), (nano)biomaterials technologies (20%), and (bio)chemical and (bio)pharmaceutical technologies (16%) represent the current trends in orthopedic prosthetics. The last two categories together correspond to the application of nanobiotechnology to new biomaterials for implants (32%) and indicate the future trends in orthopedic prosthetics. Just 4% relate to technologies for testing and diagnosis.

Conclusion:

This analysis of technology trends had the power to demonstrate that the potential for innovations in orthopedic prosthetics is at a transitional moment, as displayed by the technological information retrieved and analyzed.

The implants developed using nanotechnology and nanobiotechnology represent the cutting edge of devices available at the present time, and are the main trends encountered in this study. Tissue-material interactions are the main target of all the research efforts and new technologies produced, but the focus is now more on the research and development of materials than tissues.

The use of scaffolds for the growth and differentiation of stem cells in bone tissue and genetic modification of tissue are the key technologies being developed in the field of biotechnology. The growth of biopolymeric (nano)biomaterials that are osteoconducting, biocompatible, biodegradable, and have excellent elastic properties are at the cutting edge of biomaterials research.

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