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Importance of interaction between areas of knowledge and institutions in the development of a health innovation: a study of thematic area networks and institutional co-authorship networks in development of computed tomography (CT)

Importancia de la interacción entre áreas del conocimiento e instituciones en el desarrollo de una innovación en salud: estudio de las redes de área temática y de coautoría institucional en la aparición y el desarrollo de la tomografía computarizada (TC)

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Abstract

OBJECTIVE: To identify thematic area networks and institutional co-authorship networks in the initial development of the CT, to recognize their characteristics in order to demonstrate the importance of interaction in a health innovation. METHODS: The method proposed by the researchers at the University of Manchester and thematic area studies was used. The databases used were ISI-Web of Science (ISI-WoS) and SCOPUS. The pioneer article was located and the literature limited to subsequent years was systematically reviewed. Excel Node XL, Pajek wiki and Ucinet software were used for data processing. RESULTS: Thematic areas and institutional co-authorship networks were obtained in the early years of CT development. Multiple types of interactions are evident. CONCLUSION: The success of the process of invention, innovation and diffusion in the development of CT required the interaction of many disciplines (medicine, physics and engineering) and institutions (University hospitals, Universities, companies, Research centers and scientific communication media). The study of the thematic areas and SNA (Social Networks Analysis) allow to know the processes of invention and innovation and identify new fields of research.

CT Computed Tomography, Knowledge Network in medicine, Health Innovation

Resumen

OBJETIVO: Identificar las redes de áreas temáticas y de coautoría institucional en el desarrollo inicial de la TC y reconocer sus características para demostrar la importancia de la interacción en el desarrollo de una innovación en salud. MATERIALES Y METODOS: Se utilizó el método propuesto por los investigadores de la Universidad de Manchester y los estudios de áreas temáticas. Las bases de datos utilizadas fueron ISI-Web of Science (ISI-WoS) y SCOPUS. Se localizó el artículo pionero y se revisó sistemáticamente la literatura limitada a los años posteriores. Se utilizaron los programas, Excel Node XL, Pajek wiki y Ucinet para el procesamiento de la información. RESULTADOS: Se obtuvieron redes de áreas temáticas y de coautoría institucional de los primeros años del desarrollo de la TC Se evidencian los múltiples tipos de interacción. CONCLUSIÓN: El éxito del proceso de invención, innovación y difusión en el desarrollo de la TC, requirió la interacción de muchas disciplinas (medicina, física e ingenierías) e instituciones (Hospitales universitarios, Universidades, Empresas, centros de investigación y Medios de comunicación científicos). El estudio de las áreas temáticas y el uso del ARS (Análisis de Redes Sociales) permiten conocer los procesos de invención e innovación e identificar nuevos campos de investigación.

TC Tomografía computarizada, Redes de conocimiento en Medicina, Innovación en salud

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Introduction

Innovations in health care, and especially in medicine, have produced a remarkable advance in the last century, reflected in indicators such as life expectancy, which in Latin America and the Caribbean increased from 29 years in 1900 to 74 years in 2010. Pan American Health Organization (PAHO) – World Health Organization (WHO) (2012). In recent years, there has been an accelerated process of innovation in medicine aimed at improving diagnosis, treatment and prevention, which, although they have improved the quality of life, have also generated significant increases in the growth of spending, causing tension among health professionals, institutions, patients and public policy makers. (Fuchs & Sox, 2001). In 2010, total health expenditure per capita ranged from US$90 in Bolivia to US$8.463 in USA. PAHO-WHO (2012)

Historically, the concept of innovation has been studied from different areas of knowledge, as can be seen in the Oslo Manual (Organization for Economic Co-operation and Development/The Statistical Office of the European Union (OCED/Eurostat) (2005) or in the work of Rodriguez Devis (2006). In the study of economic growth, Schumpeter proposed it as a radical technical change and as an endogenous incremental process. (Schumpeter, 1912). Nelson proposed an evolutionary development of innovation, using the mechanisms of variation and selection (1987) (1995). Mokyr equated technological innovation with the appearance of a new species (1998) (2002) (2010). With the work in economic history Rosenberg (1974) (1976) (1983) (1994) continued with the development of the Innovation Systems paradigm (Nelson & Rosenberg, 1993), the importance of universities in the Innovation Systems, (Rosenberg & Nelson, 1994), the concept of National Innovation systems by Lundvall (1992) and Sectoral systems of innovation by Malerba (2004).

Innovation in the framework of the neo-institutional evolutionary economy corresponds to a process of technical and technological change, which transforms the environment, creating and destroying institutions and organizations, which feed back into the process, modifying the social structure, with the ultimate goal of adaptation to a constantly changing environment (Hernandez Umaña, 2004).

Among the institutions associated with innovation and closely linked to property rights are patents and copyrights, as examples of adaptation.

In Latin American countries, such as Argentina, Brazil, Colombia, and Mexico, there are significant lags in health innovation indicators. There are cultural, regulatory, and financial barriers that hinder innovation (Pérez-Orive & Ibarra Ponce de Leon, 2019) (Vargas Yara, Dubay Rodríguez, & Silva Ortiz, 2021) (Ruiz-Ibañez, 2012) (Naranjo Valencia & Calderón Hernández, 2010).

Different groups have worked on the analysis of the innovation process in health: Gelijns y Rosenberg (1995), Gelijns, Zivin y Nelson (2001), Stuart, Ozdemir y Ding (2007), Costa-Font, Courbage, McGuire (2009), Wilson y Ramamurthy y Nystrom (1999). The main gap in the literature related to health innovation is between the understanding of the emergence of the invention and its subsequent diffusion (Costa-Font, Courbage, & Mina, 2009).

Additionally, to increase complexity, it has been documented that innovations are reinvented and diffused between and across different types of organizations (Greehalgh, Robert, Bate, Macfarlane, & Kriakidou, 2005). The research group at the University of Manchester (Consoli & Mina, 2009) (Consoli & Ramlogan, 2008) (Ramlogan & Consoli, 2008) (Mina & Ramlogan, 2007) (Anderson, 2007) (Anderson, Neary, & Pickstone, 2007) (Ramlogan, Mina, Tampubolon, & Metcalfe, 2007) (Metcalfe, James, & Mina, 2005) with the model “Gateways and pathways in a health system”, located within the institutional evolutionary economics, studies the evolutionary process of particular cases such as: glaucoma, intraocular lenses, total hip replacements and myocardial reperfusion devices. This model documents 5 intercommunicating spheres (Graphic 1), using bibliometric studies and social networks analysis over time as tools, illustrating the gateways and pathways of connection between the health system and the innovation system. Scientific collaboration can be analyzed using bibliometric techniques aimed at representing through maps or co-authorship networks the working groups and networks that constitute the research front of a scientific area (Osca-Lluch, 2005) (Osca-Lluch, Velasco, Lopez, & Haba, 2009).

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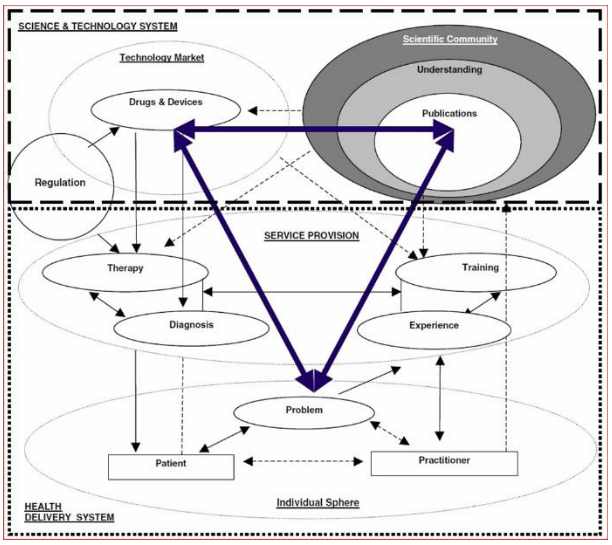
Within the studies on the diffusion of innovations, the use of Social Network Analysis (SNA) is evident (Valente T. W., 2010) (Valente & Davis, 1999) (Valente T. W., 1996) (Valente & Rogers, 1995), (Wasserman & Faust, 1994) as a tool for study and understanding.



Graphic 1 "Gateways and pathways in a health system"
Source: (Consoli & Mina, 2009) (Consoli & Ramlogan, 2008)

1. Individual sphere: The patient presents a health problem that is transmitted to the health professional, to be solved. Doctor - patient relationship (medicine) and principal - agent (economy).

2. Health service provision sphere. This corresponds to the health system where the practitioner (MD, nurse or similar) with the information transmitted from the patient makes a diagnosis and proposes a treatment, according to the training, the knowledge acquired and the availability in the system.

3. Sphere of scientific knowledge materialized in publications, from which both the training of health personnel and the development of drugs and devices for health care are nourished.

4. The sphere of the drugs and devices. Technological market.

5. The sphere of regulation given by the territorial, national and international entities involved in the health systems, and in the markets for devices and drugs.

Methods

For this research, it was chosen to study the emergence (invention - radical innovation) and development (incremental innovations and diffusion) of CT because it revolutionized the practice of medicine (Rubin, 2014) and had not been studied with this methodology. No other technology changed so much the practice of Neuroradiology, Neurology and Neurosurgery, which has not been the same since the brain became visible (Leeds & Kieffer, 2000). The development of CT allowed its use to spread rapidly to other areas of the human body.

It was decided to apply the method proposed by the group of researchers from the University of Manchester.

On this general basis, a series of observations were made in order to fulfill the proposed objective.

Methodological process:

- Review of the historical development of CT.

- Definition of the initial search: First systematic review of the literature. Terms: "CT", "Tomography", "Computed Tomography", "EMI Tomography" and "ACTA Tomography". Bases: Pub Med (National Library of Medicine. National Institute of Health., 1996) and Science Direct (Elsevier, 1995).

- Definition of the databases to be used: PubMed, Science Direct, Scopus, ISI-WoS, and ResearchGate.

- Initial exploration and descriptive statistics of the search.

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- Determination of the years of study. The documents of Ambrose and Hounsfield in 1973 were established as pioneering articles of CT innovation (Ambrose & Housnfield, 1973) (Hounsfield, 1973) which are among the classics of diagnostic radiology (Thomas, Banerjee, & Bush, 2005) The 1- year lag of 1 year between application, technology development and scientific publication is corroborated). It was decided to explore the evolution of scientific production from the emergence of the innovation to the development of the first 2 incremental innovations, years 1972 to 1975.

- Redefinition of the search: "comput * and tomograp *" and the use of databases: ISI-WoS and Scopus.

- Collection of information in tables for normalization. It was carried out in Excel and used the NodeXL (CodePlex.Open Source Community, 2010) and Pajek (Batagelj, Mrvar, & Zaveršnik, 1997) and Ucinet (Borgatti, Everett, & Freeman, 2002) software were used for data processing, graph creation, centrality calculations and other associated measures. The algebraic representation of the graph is given by the Adjacent Matrix A in which:

$$x_{ij} = 1\ if(i,j) \in\ E \qquad (1)$$

Creation of the database and statistical description of the information.

Development of the network graph for each year and a global one. For the graphs, the Netdraw program was used with the default algorithm and the following settings: Graph distribution criteria: Distances + Repulsion + equality in edge length and proximity given by geodetic distance. The algorithm behind is the Gower – Multi Dimension Scale (Borgatti, Everett, & Freeman, 2002). Once the graph was obtained, the presentation and reading of the labels was improved. Sub graphs isolated or not attached to the main network were ordered in the graph for convenience. The node size varies according to the centrality criterion used.

Betweenness as centrality measure was selected, which is defined as: C_B (n_i) which is the sum of the estimated probabilities on all pairs of actors not including the i-th actor:

$C_B(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}$ for a node i different from j and k. (Wasserman & Faust, 1994)

Analysis and interpretation of the results. They are grouped into three categories: definition and historical review of CT, analysis of thematic areas including patents and analysis of institutional co-authorship.

Results

Computed tomography (CT)

CT is a type of diagnostic imaging study, widely used in the clinic, it is a technique in which an X-ray shot passes through a thin axial section of a patient in various directions. Parallel collimation is used to capture X-rays to a thin fan, which defines the thinness of the tomographic plane. The detectors measure the attenuation intensity of radiation once it passes through the body. A mathematical reconstruction of the images calculates the local attenuation of each point in the CT slice. These local attenuation coefficients are converted into "CT numbers" and are finally converted into degrees of gray in an image (Prokop & Galanski, Principles of CT, Spiral CT, and multislice CT, 2003).

The invention of CT was produced with the work developed by the British engineer Hounsfield and the South African-British MD Neuroradiologist Ambrose, (he studied some semesters of engineering) who applied concepts from the work of physicists Radon (German) and Cormack (South African-USA) (initially studied electrical engineering) (Mendoza Vega, 1992). Hounsfield and Ambrose developed the first prototype in 1970, the first model in 1971, the first commercial product: HEAD SCANNER (EMI MARK 1), and its first use on a patient in 1972. All pioneering work was carried out at Atkinson Morley's Hospital in London and in Electrical and Musical Industries (EMI) Central Research Laboratories in Middlesex (UK).

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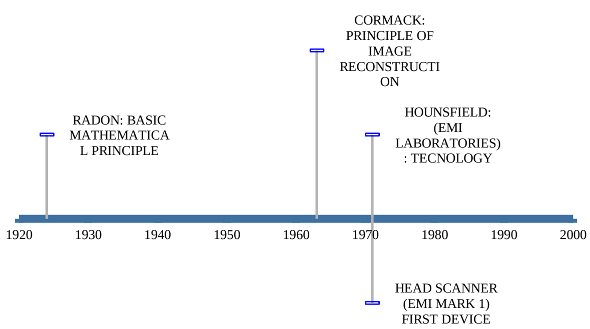
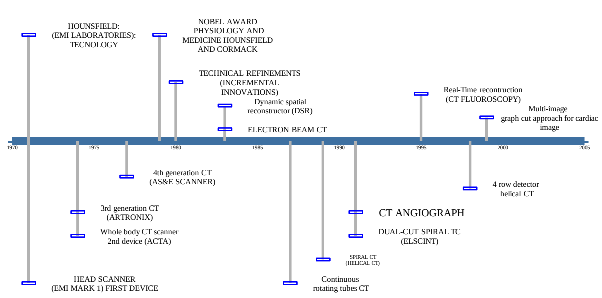
They presented their first paper in April 1972 at the Annual Congress of the British Institute of Radiology and in November 1972 at the Annual Meeting of Radiological Society of North America's in Chicago.

Subsequently, there was a notable diffusion-dissemination of technological innovation, progressive incremental innovations are documented, until the next great milestone, which corresponds to the development of the model and the commercial product: 0100 ACTA Scanner which was the first automated and computerized transverse axial whole body scanner, invented by Dentist and Biophysicist Ledley in 1973, developed at The Georgetown University Medical Center in Washington, DC (Smithsonian. National Museum of American History, 2010), commercialized since 1974. In that same year at the Washington University School of Medicine in St Louis, they developed another Model called: Artronix scanner 1100 © with an analogous but different technology to that of the EMI Mark 1. The next major milestone was the development of the AS&E SCANNER in 1977, by AS&E © American Science and Engineering, Inc., domiciled in Cambridge, Massachusetts. The timeline of the development of innovation is presented in graphics 2 and 3 and in table 1.



Graphic 2 Pre TC timeline
Source: Author's development

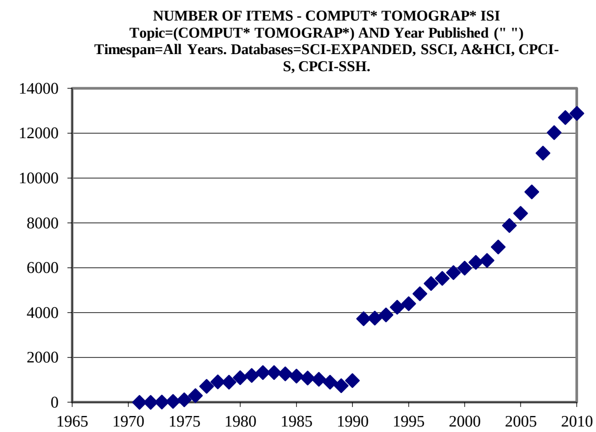


Graphic 3 TC timeline
Source: Author's development

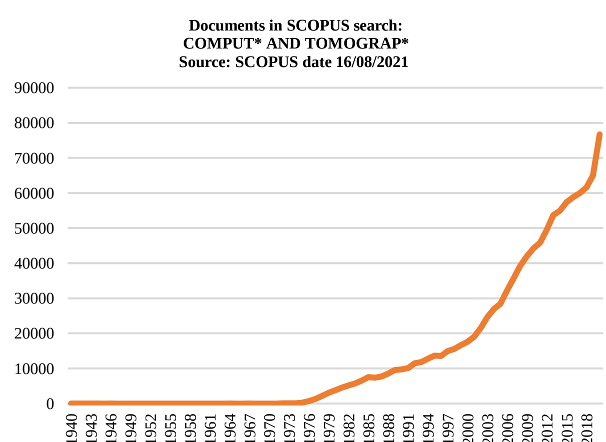
Type	1º Generation	2º Generation	3º Generation	4º Generation	Electron beam scanning
Principle	Translation y rotation		Rotation		Electron beam deflection
Detectors	Simple	Series	Arc (30º-60º)	Ring (360º)	Semicircular (210º)
Active detector roots	2	1-2	1-16	1	4
Sensing elements/roots	1	3-52	256-1000	600-4000	432/864
Take time	135-300 s	5-150 s	0,4-10s	1-5s	>=50ms

Table 1 Comparison of CT generations and type
Source: (Prokop & Galanski, Principles of CT, Spiral CT, and multislice CT, 2003)

Once the historical review is done, it is evident that radical innovation occurred in 1972 and then continued with a process of incremental innovations in different areas. As a result of the exploration of the literature and the descriptive statistical analysis based on the pioneer paper, the relationship between historical facts and the curve of scientific publications over the years becomes evident. The S trend proposed by Rogers is illustrated (2003) (2002), graphic 4 from ISI-WoS and graphic 5 from SCOPUS.

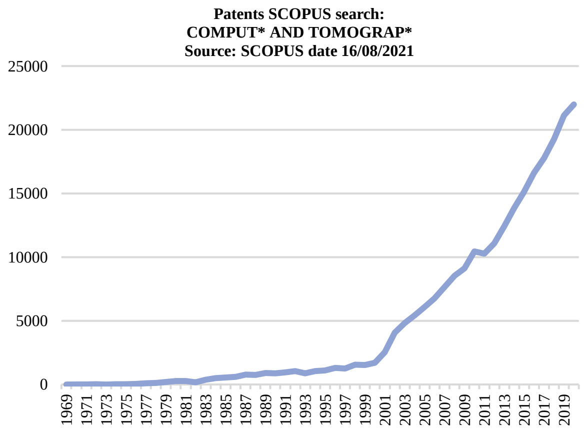


Graphic 4 Scientific publications in the exploration of the search: COMPUT* TOMOGRAP* in ISI WoS
Source: ISI-WoS Search date 03/10/2011



Graphic 5 Scientific publications in SCOPUS with search COMPUT* AND TOMOGRAP*
Source: SCOPUS Search date 08/16/2021

Another relevant finding for the research is the number of patents associated with the search graphic 6.

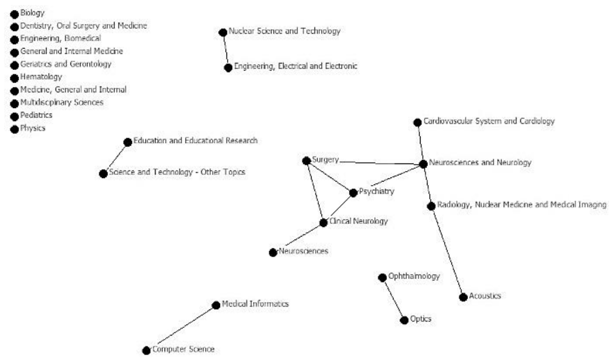


Graphic 6 Patents in SCOPUS with search COMPUT* AND TOMOGRAP*
Source: SCOPUS Search date 08/16/2021

Graphic 6 also reveals an incremental production of patents associated with the improvement of technology, strongly associated with the historical event. Reading the abstracts of the papers, it is evident that after the milestone of EMI Mark 1, the development was continued on 3 fronts: one related to the improvement of the image quality produced from radiation, a second front in the improvement of data processing for image reconstruction and a third front in the use of the images obtained in clinical practice, not only in the Central Nervous System where it originated, but in different body areas.

Study of thematic area networks on computed tomography (CT) between 1973 and 1975.

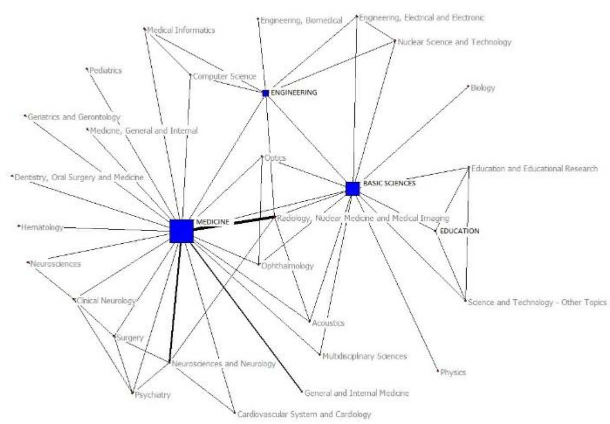
With the database obtained in the search in ISI-WoS, using the search formula "Comput* Tomograp*", restricted to the years 1973 to 1975, the graph presented in graphic 7 was found, illustrating the appearance of a main network of Medical thematic areas and subnetworks of Engineering and Computer Science.



Graphic 7 Network of thematic areas: COMPUT* TOMOGRAP* 1973-5. ISI WoS
Source: Author's development

By applying the concept of weak ties and adding another classification of the papers associating them to general thematic areas, like this: MEDICINE, ENGINEERING, BASIC SCIENCES and EDUCATION, the graph is represented in graphic 8.

With the proposed transformation, a single network is obtained. It can be seen that, by betweenness centrality, the field of MEDICINE is the most central, followed by BASIC SCIENCES and then ENGINEERING.



DATABASE: ISI-WoS (03/2011).
NODES: thematic areas. Node colors and shapes: Types of thematic areas
Blue square: general area. Added by the author based on the general area to which the specific area belongs.
Red circle: specific area. Taken from the ISI WoS base of SC item
Node size: Centrality by betweeness. Size of the tie line - contact strength

Graphic 8 Network of specific and general thematic areas: COMPUT * TOMOGRAP * 1973-5. ISI WoS
Source: Author's development

The strongest link is between two clinical areas: "Radiology, Nuclear Medicine and Diagnostic Imaging" and "Neurology - Neurosciences".

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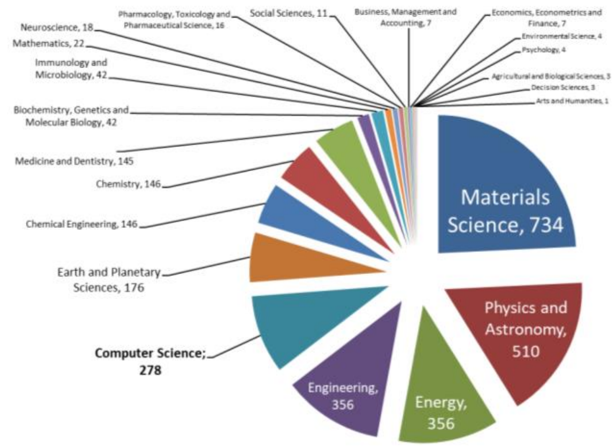
It is documented that the process of invention and innovation of CT required the participation and interaction of many disciplines. Evaluating the network, the great influence of medical clinical areas such as: Radiology, Neurology and neurosciences, Ophthalmology, Surgery, Cardiology, interacting with basic sciences such as Acoustics, Optics, General Physics and Biology and with Engineering, especially Electrical, Electronics and Biomedical, together with Computer Science, can be appreciated.

Reviewing the historical fact, CT arose from the interaction of a neuroradiologist who had studied a few semesters of engineering, with an engineer specialized in sonars and radars, who had participated in the Second World War. During the first years of development, the quality of the image was improved, due to work in Physics, especially by improvements brought from Astrophysics, which was the area with the best knowledge of X-rays. Simultaneously, the capacity to interpret the signals obtained was improved, with the advances made in the areas of Computer Science and Informatics.

All these developments generate inventions, which are reflected in patents as shown in graphic 6, which are subsequently converted into new CT equipment, with more detectors, better detection quality, faster acquisition and increasingly specific software. There has been a progressive and significant growth in the number of patents has been observed since 1999.

The distribution of patents by thematic area is presented in Graphic 9. It shows the great multi-disciplinarity involved in the development of CT. The area of knowledge where there are more patents related to CT is "Materials Science" with 734, followed by "Physics and Astronomy" with 510, "Energy" with 356, "Engineering" with 356, "Computer Science "With 278," Earth and Planetary Sciences "with 176 patents.

It is documented that, in the technological development of CT, there is multidisciplinary and interdisciplinary work involving different areas of knowledge.



Graphic 9 Thematic areas of patents in SCOPUS with search COMPUT * TOMOGRAP *
Source: SCOPUS Search date 04/30/2012

Institutional co-authorship network study on CT between 1973 and 1975

They are determined as institutions:

Centers: institutions that correspond to the different work sites of the authors of the documents. They are represented by different types of organizations such as Universities, General Hospitals, University Hospitals, Research Centers and Companies. In the work they are defined as the organizations with affiliation of the authors of the documents (Blue square).

Journals: Institutions that coordinate the dissemination of knowledge acquired through communications available to researchers: scientific journals, books and other documents present in the databases analyzed. In the work they are defined as the medium where the bibliographic production was published (Red circle).

Meetings: Institutions that coordinate meetings between researchers from different centers to share information in the study area. The types of organizations that are included within this institution are congresses, symposia, seminars, "meetings" and others that are documented in the databases analyzed. In the work they are defined as formal meetings where effective interaction of different authors was presented and which was documented in a publication (Green rhombus).

Graphic 10 and Table 2 show the data for organizations with a level of betweenness greater than 2000 between 1973 and 1975.

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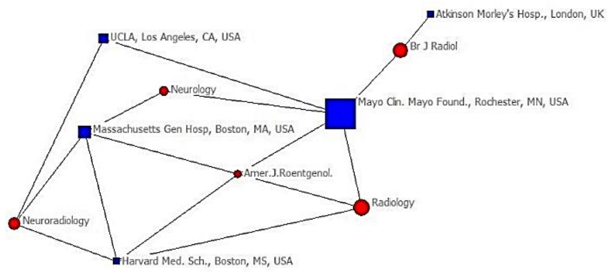

DATA BASES: Pub Med + Science Direct (08/2010) ISI WoS (03/2011) SCOPUS (09/2012)	NODES: Organizations. Colors and shapes of nodes: Types of organizations (Institutions) - Blue square: Center - Red circle: Journal - Green rhombus: Meeting Node size: Centrality by Betweenness

Graphic 10 Main institutional co-authorship network in CT years 1973-5. Betweenness greater than 2000
Source: Author's development

ID	Betweennes
Mayo Clin. Mayo Found., Rochester, MN, USA	13.644,697
Br J Radiol	8.017,953
Radiology	6.757,192
Massachusetts Gen Hosp, Boston, MA, USA	5.076,172
Neuroradiology	4.769,314
UCLA, Los Ángeles, CA, USA	3.819,570
Neurology	3.633,620
Amer.J.Roentgenol.	2.859,655
Harvard Med. Sch., Boston, MS, USA	2.372,417

Table 2 Co-authorship network organizations in CT years 1973 -1975. Betweenness greater than 2000
Source: Author's development

The importance of the interaction between health research centers, university hospitals such as: Mayo Clinic, Massachusetts General Hospital, universities: UCLA, Harvard and the scientific journals Br J Radiology and Radiology in the development of CT is appreciated.

Conclusions

In health innovation, the interaction between different areas of knowledge plays a fundamental role. The appearance of CT arises from the clinical need of a Neuroradiologist with Engineering concepts, interested in non-invasive means to improve diagnosis and reduce complications, the knowledge of an Engineer, applying concepts of a physicist with studies in Electrical Engineering (Nobel Prizes in Medicine and Physiology 1979) (Mendoza Vega, 1992), financed by a record company.

The development of incremental innovations in CT required the interaction between different clinical areas of Medicine, Engineering and Basic Sciences, reflected in a progressive growth of patents in different areas, deepening its applications, disseminating knowledge and developing new CT equipment.

Confirming the model “Gateways and pathways in a health system” in the study of CT, the patient, service, knowledge and market spheres interact. Innovation in health is a complex, co-evolutionary, changing system, without pre-established schemes, with multiple types of association, evidenced ex-post, co-ordered between many disciplinary areas, inside and outside medicine, mediated by institutions and organizations in various branches of science and industry.

The transaction costs associated with the interaction in a multi and interdisciplinary work are quite high, so they must be leveraged in institutions that allow them to be reduced, in this case the presence of universities, university hospitals and scientific publications was evidenced.

This work shows that the use of bibliometrics and SNA on a health technology allows us to reach conclusions similar to those proposed by Rosenberg (1972), Nelson (1994) and Hall (2010), on interdisciplinarity and coordinated development between different institutions and organizations.

Other methodological approaches that reach similar conclusions are the MassMEDIC (2010) (Emmons & Porter, 2006), the works on spin-offs between research universities, research and development laboratories and the government (Carayannis, Rogers, Kurihara, & Allbritton, 1998) (Steffensen, Rogers, & Speakman, 1999) and the works on the participation of university research centers in the development and diffusion of innovations (Stuart, Ozdemir, & Ding, 2007) (Sabharwal & Hu, 2013) (Wu, 2012) (Peterson, Rogers, Cunningham-Sabo, & Davis, 2007).

While the invention and continuous development of CT revolutionized the practice of medicine the study of thematic area networks and the use of SNA provide insight into the processes of invention and innovation (Rubin, 2014), and identify potential radical and incremental innovations and with them new fields of study and research.

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