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Reverse Aging Technology Patents for 20 Years (2003–2023): Trends and Insights

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ABSTRACT

Rapid advancements in reverse aging technology, including telomere rejuvenation, gene therapy, stem cell therapies, and regenerative medicine, have great potential to halt the aging process. However, the implementation of these advancements in clinical practice has been hampered by issues with long-term safety, efficacy, regulatory barriers, societal concerns, and ethical dilemmas. This paper responds to this gap by analyzing the patent landscape of reverse-aging technologies between the years 2003 and 2023, focused on trends, key players, and innovation ecosystems. Patent data from Lens.org, which includes all the application submissions between 2003 and 2023 for gene therapy, stem cell therapies, telomere extension, and regenerative medicine, was used to conduct a patent landscape analysis. After applying the inclusion and exclusion criteria, a final set of nine patents was obtained from the 18 manually screened patents from an original dataset of over 160 million records using structured keyword searches, Boolean operators, and Cooperative Patent Classification (CPC) codes. Analytical tools, such as VOSviewer, mapped regional patterns and thematic trends by visualizing term and keyword co-occurrence. Results show different trends in patents, with biotechnology and regenerative medicine advancements driving increase. Patent activity is dominated by the US and WIPO, reflecting their leadership in innovation. Fragmented innovation landscape highlights interdisciplinary research clusters and further calls for more sophisticated analytical techniques and standardized terminology. While reverse aging technologies hold enormous, even revolutionary, potential, ethical behavior, legal frameworks, and equal access are still problematic. Strategic international collaboration and strong intellectual property frameworks, further reinforced by standardized methodologies, are what it means to accelerate innovation by addressing these issues.

Keywords: ethical considerations, gene therapy, patent landscape analysis, regenerative medicine, reverse aging technologies.

INTRODUCTION

Gene therapy, stem cell treatments, senolytic medications, and regenerative medicine are some of the gene and cellular therapies that can provide better health outcomes and delay the onset of age-related diseases. Through specific delivery using adeno-associated vectors, gene therapy works on increasing the expression of aging suppressor genes (Kitaeva et al., 2024). By biological reprogramming, stem cell therapies, particularly induced pluripotent stem cells or iPSCs, hold promise for regenerative medicines and allow modeling of aging diseases (Gupta et al., 2023). Senolytic drugs, such as quercetin and dasatinib, have been successful in curing health conditions since they target the senescent cells responsible for age-related decline and chronic inflammation (Masternak, 2023). In the context of regenerative medicine, transdifferentiation allows for cells to shift from one type into another and could provide therapeutic possibilities for diseases related to aging organs (Gupta et al., 2023). They target various aging mechanisms through innovative approaches in reverse aging technologies such as gene therapy, stem cell therapy, rejuvenation of telomeres, and regenerative medicine that may work together to potentially revert the damage brought by aging. Gene therapy, for example, focuses on repairing genetic flaws brought on by aging—e.g., via CRISPR-Cas9 techniques on genes KLOTHO and FOXO, which were demonstrated to enhance cellular longevity and lessen the signs of aging (Barragán et al., 2024).

Likewise, partial reprogramming by Yamanaka factors has been successfully carried out in prolonging the life and improving health span in old mice (Macip et al., 2023). Stem cell therapies use the regenerative powers of stem cells to repair damaged tissues and organs, which may reverse functional decline associated with aging, including structural degeneration and reduced resistance to diseases (Chang et al., 2022). Telomere rejuvenation is a way of extending telomeres, which shorten with age and contribute to cellular senescence, in order to maintain the health and longevity of cells (Barragán et al., 2024). Regenerative medicine uses cellular and molecular methods to restore the function of tissues, offering a holistic approach to the battle against age-related decline (Guo et al., 2022). While these technologies hold great promise, challenges still exist in their practical application and long-term efficacy, requiring further research and clinical trials to establish their effectiveness in humans. Innovative approaches in reverse aging technologies include a variety of strategies that target biological aging at different levels.

Recent advances in epigenetics, cellular reprogramming, and nanotechnology have given way to effective interventions focused on reversing not only the outward signs of aging but also the underlying cellular mechanisms. In epigenetic interventions, Epicelline, a key ingredient in the Eucerin Hyaluron-Filler Epigenetic Serum, has shown to be effective in reversing ten clinical signs of skin aging by modulating epigenetics (Boreham, 2024). Furthermore, AI-driven age clocks are now used to determine biological skin age and predict the potential anti-aging ingredients for better personalization of treatment approaches (Boreham, 2024). Cellular reprogramming, including the generation of induced pluripotent stem cells (iPSCs), seeks to revert aged cells back to a state similar to stem cells, perhaps restoring youthful activities (Zhang & Gladyshev, 2020). The most recent approaches center around senescent cell clearance by the targeted removal of these cells, improving tissue health and function ("Canonical and novel strategies to delay or reverse aging", 2023). Nanotechnology applications in the delivery of anti-aging compounds include nano-delivery systems that offer increased stability and improved efficacy for compounds delivered through liposomal encapsulation and intelligent nanoparticles, which provide better absorption and longer-lasting in-vivo retention (Hirlekar & Patil, 2013; Giannouli, 2022). While these new approaches hold tremendous promise, significant challenges persist in translating some of the technologies into general clinical practice, since complexity in aging and individual variability require much more research before these interventions will be optimized for broad application.

Increased patenting activity in aging reversal technologies indicates great scientific progress and commercialization of related innovations. Patents are important for safeguarding new discoveries, promoting investment in aging-related technologies (Lucheng & Yan, 2011), and pointing toward research trends, such as the rising attention being paid to cellular reprogramming and genome editing (Zhang, 2012). The rise of patent marketplaces will also promote collaboration and innovation in aging research (Yanagisawa & Guellec, 2009). Major pharmaceutical and biotech firms have already begun focusing on aging research, incorporating it into their business models, and areas such as Basel in Switzerland have emerged as hubs for aging research (Bakula et al., 2019). Societal factors may still oppose the full implementation of aging interventions, even with all the progress shown in the patent landscape, which indicates that scientific progress alone may not suffice for full implementation (Vijg & Grey, 2014).

Technologies of rapid development in reversal of aging, such as telomere rejuvenation, gene therapy, stem cell therapies, and regenerative medicine, may be able to halt age-related degeneration. There are also challenges in turning such developments into practical therapeutic uses. While cellular reprogramming by iPSCs, gene editing by CRISPR-Cas9, and telomere rejuvenation look promising, more extensive clinical trials are necessary to ascertain their safety and efficacy over the long term. Although nanotechnology, senescent cell depletion, and epigenetic therapy represent novel approaches toward the mechanisms of aging, their widespread adoption is being hampered by safety and regulatory issues and patient response to therapy. Further, the patent landscape indicates increased attention is being placed upon these technologies, further highlighting their potential for commercialization. Yet there remains a host of unanswered societal and ethical questions, such as the effects of interventions that alter biological aging. In fact, much remains to be discovered about the social integration and practical applications of reverse aging technologies, further requiring extensive study to determine their scientific feasibility as well as looking more broadly at sociological, ethical, and legal concerns. Thus, this analysis of patent data on reverse aging technologies from 2003 to 2023 will fill the knowledge gap by putting innovation trends, important players, and new technological developments surrounding these approaches into perspective.

The present study seeks to analyze the patent trends of the reverse aging technologies from 2003 to 2023 by identifying top patent applicants according to the count of documents, finding patent jurisdictions based on the count of documents, and identifying the kind of patent documents. Top CPC classification codes, patent owners, inventors, and referenced patents—each categorized based on their legal status—would also be discussed in this regard. The presented study summarizes relevant patents on the topic of reverse aging technologies, generates term co-occurrence, and builds keyword co-occurrence maps with the patent abstracts and titles through the VOSViewer tool. This study uses the Lens.org database to identify the leading innovators, technological trends, and jurisdictional patterns. It further explores how various regulatory frameworks and innovation ecosystems impact the geographic differences in patent activity (Ali & Sinha, 2023; "Patent analysis: an approach using bibliometrix," 2023).

METHODS

Research Design

This study adopted patent landscape analysis as a core research design to explore systematically the trends, key innovators, and jurisdictional hotspots of reverse aging technologies. Based on the Lens.org database, which includes more than 127 million records from 105 jurisdictions, this study focuses on patent activity in reverse aging technologies from 2003 to 2023. Patent landscape analysis provides a structured approach to understanding technological innovation in areas such as gene therapy, stem cell treatments, telomere extension, and regenerative medicine, uncovering patterns of innovation and market dynamics (Cambia, 2023; Worsley & Twist, 2005). This method transforms raw patent data into actionable insights through methods such as patent mapping and citation analysis (TT Consultants, 2024). Through this methodology, the report finds technology gaps and emerging trends (Gevers, 2024) while accessing insights on the competitive landscape from an analysis of the activities of leading players (InventionIP, 2024). In view of increasing global health and longevity focus, this report systematically analyzes the two decades of patent filing activity, providing knowledge critical to informing policy-making and investment strategies in the regenerative medicine industry (Cambia, 2023; Sinclair, 2023). The approach of patent landscape analysis began with broad to detail by incorporating the data filters. For instance, in this report, the initial search relevant to reverse aging technologies has 160,762,691 patent records, and then it was narrowed to 18 and then nine (9).

Keyword Search

A structured keyword search in the Lens.org database was carried out to fetch relevant patents from the main search terms "reverse aging," "age reversal," "genetic therapies," "stem cell treatments," "telomere extension," and "cell rejuvenation." This design ensured that there would be an as-complete-as-possible collection of patents relevant to reverse aging technologies.

Boolean operators were used in order to efficiently combine search terms within the Lens.org database. The "AND" operator ensured the inclusion of more than one term (for example, "reverse aging" AND "genetic therapies"), and the "OR" operator included synonyms or variations (for example, "gene therapy" OR "stem cell treatments"). The wildcard (*) was added in order to catch multiple word variations (for example, "aging" in order to include both "aging" and "age"). Therefore, the search string in the query bar of Lens.org was: ("reverse aging*" OR "age reversal") AND ("genetic therapies*" OR "stem cell treatments" OR "telomere extension" OR "cell rejuvenation"). First, this search retrieved 160,762,691 patent records without filters to nine patents applying the inclusion and exclusion criteria with manual screening. The final search code applied was: ("reverse aging*" OR "age reversal") AND (("genetic therapies*" OR ("stem cell treatments" OR ("telomere extension" OR "cell rejuvenation"))) AND classification_cpc: (C12N15 AND ("00*" OR A61K45" AND ("00*" OR (C12N2510 AND ("00*" OR A61P39" AND ("00*" OR (A61K31 AND ("00*" OR A61K35" AND "00"))))))). This code generated 18 patent records and was manually screened, then the patent was further filtered by document type, group by simple family resulting to the final patent of nine for analysis.

Inclusion and Exclusion criteria

Specific filtering criteria were applied to the search results: patents published between January 1, 2003, and December 31, 2023, having titles, abstracts, and claims. The Cooperative Patent Classification system was used to narrow down the focus of categories related to reverse aging. Gene therapy, stem cell research, telomere regeneration, and other interventions related to aging were identified through relevant CPC codes. Inclusion codes were C12N15/00*—mutation or genetic engineering; A61K45/00*—medicinal preparations with active ingredients not otherwise provided for; C12N2510/00*—genetically modified cells; A61P39/00*—specific therapeutic agents not otherwise provided for antinoxious or protective agents; A61K31/00*—medicinal preparations containing organic active ingredients; and A61K35/00*—medicinal preparations containing material or reaction products not otherwise specified. Exclusion codes included A61P35/00 (antineoplastic agents), A61P19/00 (drugs for skeletal disorders), and A61Q19/00 (preparations for skin care). The inclusion codes were searched from Espacenet Patent search (https://worldwide.espacenet.com/patent/cpc-browser#!/CPC=A61H) using the same search query used in Lens.org to look for relevant CPC codes: ("reverse aging*" OR "age reversal") AND ("genetic therapies*" OR "stem cell treatments" OR "telomere extension" OR "cell rejuvenation"). The patents invented mainly for cosmetics purpose are not included in the study.

Data Extraction

Data for this study is primarily sourced from Lens.org. Lens.org is an open-access platform offering users a search, analysis, and visualization of more than 127 million global patent records and scholarly data (Cambia, 2023). It is a very important source for researchers, academicians, and industry people to understand the convoluted landscape of patents and scholarly works. The datasets extracted from Lens.org included: Patent Trends (2003-2023), Top Patent Applicants by document count, Patent Jurisdictions by document count, Patent Document Types based on document count, Top CPC Classification Codes, Top Patent Owners based on document count, Top Inventors, Top Cited Patents classified based on legal status, Summary of Patents relevant to Reverse Aging Technologies (2003-2023). A CSV file containing the table summary output data regarding patent records for reverse aging technology was exported from Lens.org. Before presenting the data results, the researcher cleaned the data by removing any information not necessary to perform VOSviewer text mapping and proper formatting of words and columns. Then, the researcher imports the file into VOSViewer and analyzes the abstracts and patent titles for term co-occurrence mapping. VOSViewer's Term Co-occurrence Map was exported as an output and utilized in utilizing the findings of this study. More analysis was executed to look for keyword co-occurences.

Data Filters

In order to retain the usage of complete and trustworthy data, filters were implemented to assure the dataset's relevance. These filters focused on patents granted between January 1, 2003, and December 31, 2023, while excluding 2024 to prevent any delays in database updates that could distort results. Since only 18 patent records were there in total which was manually screened, the study covered both granted and pending patents. It was further filtered by Document Family and then by group of simple families to avoid duplication and redundancy – resulting in a patent record of 9. Key jurisdictions such as the US and WO-WIPO were included in the jurisdictional focus; however, since only nine patent records were left after the final query, further jurisdictional filtering was not needed.

Data Cleaning and Refinement

In order to ensure data integrity for the graphical data analysis in Lens.org, the researcher first refined the data to eliminate duplicates, consolidated variations in applicant names, checked for identical patents across jurisdictions, and performed consistency checks to confirm the accuracy of CPC codes, publication dates, jurisdictions, and other important data points. Before being imported into VOSviewer, the Lens.org-generated data was cleaned to only include relevant information while ensuring correct column organization, spacing, and capitalization. The output CSV file was then used for VOSviewer term co-occurrence text mapping. The keyword occurrence analysis was done by the researcher manually inserting a keyword column next to the abstract. The researcher manually constructed ten keywords per patent abstract because the lens.org output csv file did not contain keywords. AI was used to double-check me as well.

Data Analysis

Patent Trends (2003–2023), Top Patent Applicants by Document Count, and Patent Jurisdictions by Document Count were the key aspects covered in the data analysis. It not only pinpointed the top CPC classification codes and patent owners by document count but also analyzed the types of patent documents. Identifying the Top Inventors and Top Cited Patents by legal status was part of the further investigation. The research concluded with a VOSviewer Term Co-occurrence Map created from patent titles and abstracts exported from Lens.org. The Summary of Patents Relevant to Reverse Aging Technologies (2003–2023) detailed conceptual and thematic patterns. Using any word or term that appears in the full text of the document (titles, abstracts, or other content), term co-occurrence mapping examines how frequently terms (including keywords, phrases, or significant terms) occur within documents in order to identify broader thematic areas and relationships. The network visualization displays nodes as terms and edges that represent their co-occurrence, with node size reflecting term frequency or significance. Of the 142 terms, 16 have at least two occurrences, which is the minimal requirement. A relevancy score was determined for every one of the sixteen terms. The most relevant terms were selected based on these scores. The researcher followed VOSViewer's default coverage of 60% of the most relevant terms. The researcher further analyzes the patent abstract through keyword co-occurrence analysis. Keyword Co-occurrence Mapping analyzes the co-occurrence of formal keywords within documents by using keywords selected by authors from the abstracts to identify connections and clusters. This provides insight into areas of research and trending topics. Network visualization of keywords as nodes and edges shows how often the keywords co-occur, with node size indicating frequency or importance. However, the researcher manually extracted ten keywords for analysis from every patent abstracts since the lens.org csv file did not contain data on keywords. AI was also used to double-check the keywords.

RESULTS

Figure 1 depicts patent publishing patterns in reverse aging technologies from 2003 to 2023, showing different invention activities over the 20-year period. From 2003 to 2010, modest patent activity may indicate that this research was in its early stage. The data from 2010 to 2023 indicates a progressive increase in patent filings, especially from 2010 to 2015, which could be indicative of increasing focus on innovative solutions for fields such as antibiotic research and biotechnology. This trend suggests a strong rise in scientific interest and technological development in this period.

Figure 1 Patent Publication Trends (2003-2023) by Document Count

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Figure 2 on Top applicants of reverse aging technology patents by document count from 2003 to 2023. Dischler Louis leads, representing the most significant contribution as an individual in the field. Following close is Cedars-Sinai Medical Center and Lyell Immunopharma INC., institutional entities actively engaged in promoting research in reverse aging.Turn Biotechnologies INC., Bioviva USA INC., and Klotho Therapeutics INC. also make it onto the list, further exemplifying commercial interest in anti-aging therapeutic approaches. This list shows that universities have a substantial and significant role in both basic and applied research in the area of reverse aging technologies.

Figure 2 Top Patent Applicants by document count

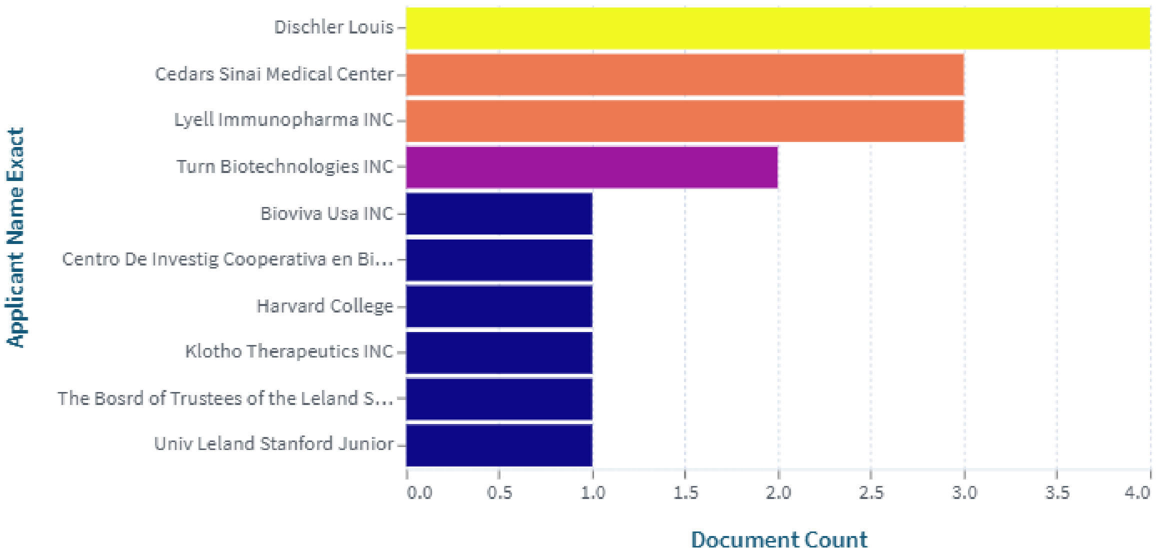

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Figure 3 shows the distribution of patent filings related to reverse aging technologies by jurisdiction from 2003 to 2023. The United States has the most documents, followed closely by WIPO, which indicates that the country has considerable funding, advanced research facilities, and a culture of technological innovation. The U.S. shows a strong commitment to research and development, with patent applications accelerating faster than in other nations—a kind of innovative renaissance. Activity at WIPO reflects global interest in reverse aging technologies, where international applicants seek broader market protection and strategic patenting. Though the U.S. and WIPO dominate filings, increasing investment by other nations signals a shift in the global dynamics of innovation, fostering both competition and cooperation in the industry.

Figure 3 Patent Jurisdictions by document count

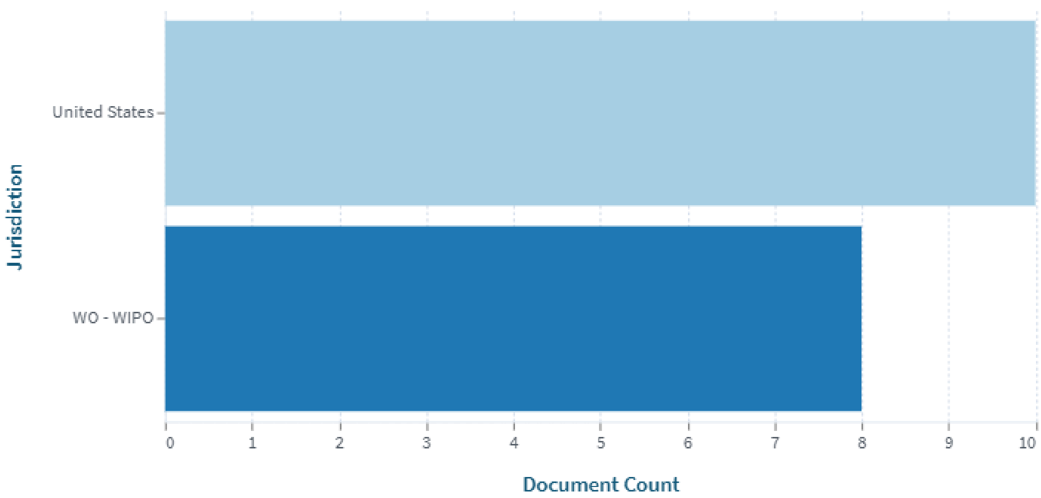

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Figure 4 provides important insights into the development and dynamics of the intellectual property landscape in reverse aging technologies. The upward trend in patent applications from 2003 to 2023 indicates a strong economic and social interest in anti-aging inventions, showing that researchers and organizations are proactively seeking rights to intellectual property. This growth evidences strategic change in the way businesses engage with the patent system and is in line with global trends of historically high patent filings.

Figure 4 Patent Document Types based on document count

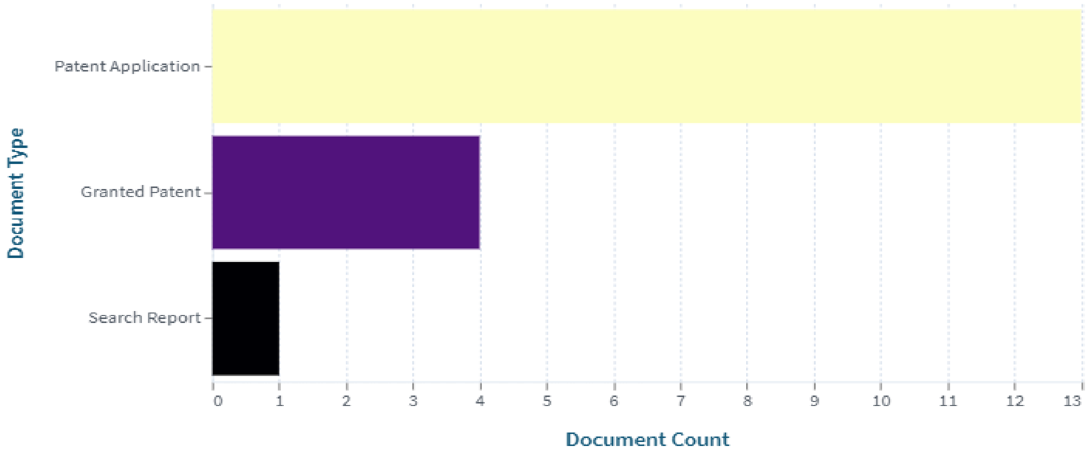

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Table 1 shows the various CPC categories, which illustrate the diversity of reverse aging technologies over the past 20 years. In this data, progress can be seen in genetic engineering and pharmacology, focused on molecular techniques and chemical compositions. The "Human Necessities" (A61K) classification shows the attempt to treat aging-related conditions, such as alopecia and arthritis, by substances like curcumin and coenzyme Q10, with advanced delivery systems like liposomes to improve stability and absorption. In parallel, "Chemistry Metallurgy" codes (C12N) show the advance of genetic engineering, including microRNA, RNA-directed polymerases, and genetically modified cells acting against aging at the molecular level. Another approach, senotherapeutics, is developing: the proposal to prolong health by removing senescent cells from the body. Genetic engineering and pharmaceuticals lead the field, but other approaches, such as lifestyle modifications and natural products, give a wider view of strategies against aging.

Table 1 Top CPC Classification Codes

4 A61K31/194 **Human Necessities** having two or more carboxyl groups, e.g. succinic, maleic or phthalic acid	**4** A61K31/20 **Human Necessities** having a carboxyl group bound to a chain of seven or more carbon atoms,	**4** A61K31/26 **Human Necessities** Cyanate or isocyanate esters Thiocyanate or isothiocyanate esters	**4** A61K31/353 **Human Necessities** 3,4-Dihydrobenzopyrans, e.g. chroman, catechin	**4** A61K31/455 **Human Necessities** Nicotinic acids, e.g. niacin Derivatives thereof, e.g. esters, amides
4 A61K31/4745 **Human Necessities** condensed with ring systems having nitrogen as a ring hetero atom, e.g.	**4** A61K31/5415 **Human Necessities** ortho- or peri-condensed with carbocyclic ring systems, e.g.	**4** A61K31/7004 **Human Necessities** Monosaccharides having only carbon, hydrogen and oxygen atoms	**4** A61K31/706 **Human Necessities** containing six-membered rings with nitrogen as a ring hetero atom	**4** A61K45/06 **Human Necessities** Mixtures of active ingredients without chemical characterisation, e.g.
4 A61K9/0019 **Human Necessities** Injectable compositions; Intramuscular, intravenous, arterial,	**4** A61K9/127 **Human Necessities** Liposomes	**5** A61P17/14 **Human Necessities** for baldness or alopecia	**5** A61P19/02 **Human Necessities** for joint disorders, e.g. arthritis, arthrosis	**5** A61P19/08 **Human Necessities** for bone diseases, e.g. rachitism, Paget's disease
10 A61P39/00 **Human Necessities** General protective or antinoxious agents	**5** C12N2501/65 **Chemistry metallurgy** MicroRNA	**8** C12N2510/00 **Chemistry metallurgy** Genetically modified cells	**4** C12N9/1276 **Chemistry metallurgy** RNA-directed DNA polymerase (2.7.7.49), i.e. reverse transcriptase or	**5** C12Y207/07049 **Chemistry metallurgy** RNA-directed DNA polymerase (2.7.7.49), i.e. telomerase or reverse-transcriptase

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Figure 5 presents the top patent owners in the field of reverse aging technologies, ranked by document count over the 20-year period from 2003 to 2023. Cedars-Sinai Medical Center is ranked first and is indicative of

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considerable translational research in anti-aging technologies. Stanford University is noted for pioneering work on cellular senescence and its effects on aging. Bioviva USA Inc. is a biotech firm that has been recognized for innovative cellular-level treatments targeting aging. Turn Biotechnologies Inc. is also noted for its epigenetic advancements in rejuvenation techniques, further illustrating the importance of biotechnology in this area.

Figure 5 Top Patent Owners based on document count

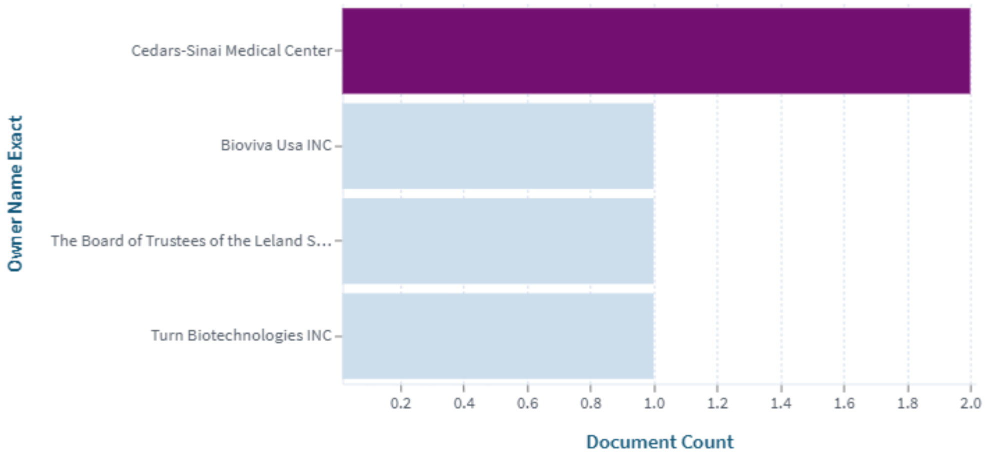

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Figure 6 shows the top inventors in reversing aging technologies, with Dischler Louis at the forefront, holding almost four patents. This may indicate his central position, possibly being affiliated with a leading organization or institution. Only a few other inventors, like Grigorian Lilian, Huang Yin, and Klausner Richard D., have about 2.5 each, thus contributing to the secondary role. Further, the chart depicts a large variety of inventors, from Yamasaki Yasuhiro to Bojireddy Naveen, who have one or two patents, a very scattered piece of evidence for the high interest in the field. Most of the inventors have less than two patents, which might be evidence that this is still an early stage of innovation and there is no consolidation in the intellectual property, which is typical for patent fragmentation and overlapping rights.

Figure 6 Top Inventors of Reverse Aging Technologies

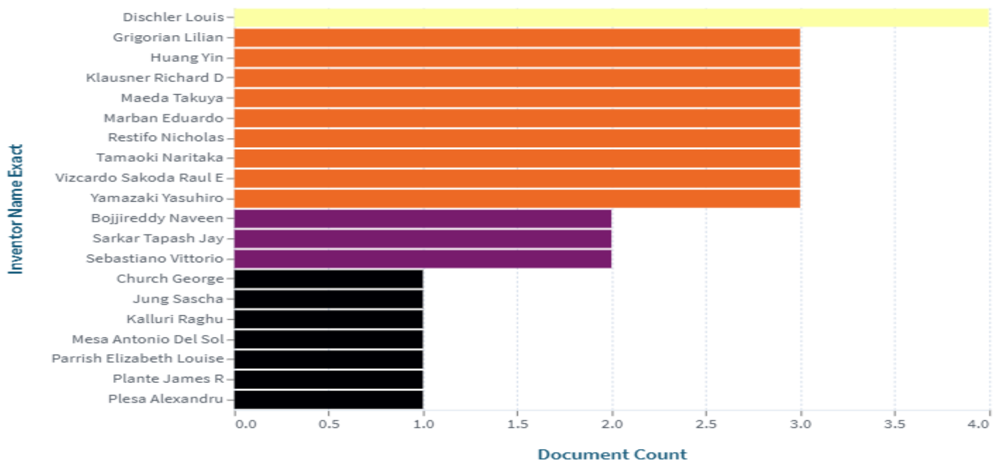

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Figure 7 analyzes the publication dates of the most frequently cited patents in reverse aging technologies, which are concentrated in April and October between 2003 and 2023. In addition, patents published in April 2010, October 2015, and October 2020 are highlighted with a high citation count, which indicates critical years of key technological advancement. Moreover, the bubble size represents the simple family size, showing that patents with larger family sizes are more likely to receive more citations, especially those from critical years. It implies

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that patents with more international filings or multiple claims would have a higher impact by meeting a broader technological need.

Figure 7 Top Cited Patents classified based on legal status

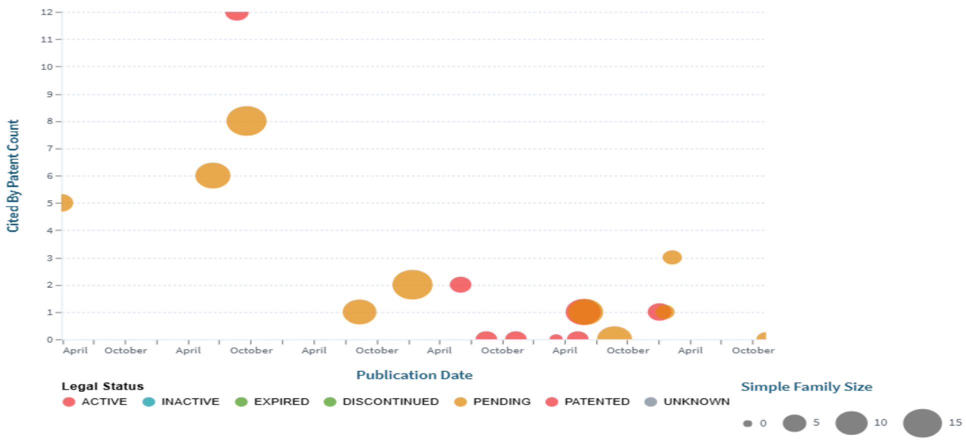

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Table 2 shows the important patents of reverse-aging technology from 2003 to 2023, including cellular reprogramming techniques for rejuvenating aged cells, gene therapies targeting aging-related expressions, and innovations such as Cardiosphere-Derived Cells (CDCs) and extracellular vesicles (EVs) for cardiovascular aging. Other important patents include transient cellular reprogramming using non-integrated mRNAs, therapeutic applications of the Klotho protein, and methods addressing mitochondrial dysfunction through stem cell therapies, antioxidants, and nanozymes. These highlight some of the important areas of focus in regenerative medicine and aging interventions.

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ımmary of Patents relevant to Reverse Aging Technologies (2003-2023)

Nos	Title	Publication Year	Application Number	Application Date	Applicants	Inventors	Owners	Document Type	Cites Patent Count	Cited by Patent Count	NPL Citation Count	CPC Classifications
1	Products And Methods For Assessing And Increasing Klotho Protein Levels	2019	US 2018/0064333 W	06/12/2018	Klotho Therapeutics Inc	Tarsio Joseph F;;Raturi Dinesh;;Ramage William		Patent Application	0	6	0	A61K38/00;;A61K45/06;;C12N9/2402;;C12Y302/01031;;G01N33/689 G01N2333/924;;G01N33/573;;C12N9/96;;C12N9/24;;G01N33/6893;; 1N33/573;;A61K38/47;;A61P39/00;;C12Y301/01031;;G01N2333/924;; 1N2560/00
2	Methods And Compositions For Reducing Epigenetic Age And Mitochondrial Dysfunction	2021	US 202117176276 A	16/02/2021	Dischler Louis	Dischler Louis		Patent Application	0	2	0	A61K31/353;;A61K31/194;;A61K31/20;;A61K31/26;;A61K31/455;;A61 1/4745;;A61K31/5415;;A61K31/7004;;A61K31/706;;A61P39/00;;A61K /7004;;A61K31/194;;A61K31/20;;A61K31/26;;A61K31/353;;A61K31/4 ;A61K31/4745;;A61K31/5415;;A61K31/706;;A61P39/00
3	Transient Cellular Reprogramming For Reversal Of Cell Aging	2021	US 201916979842 A	13/03/2019	The Bosrd Of Trustees Of The Leland Stanford Junior Univ	Sebastiano Vittorio;;Sarkar Tapash J	The Board Of Trustees Of The Leland Stanford Junior University (2019-03-13)	Patent Application	18	2	14	A61K35/12;;A01N1/0226;;A61K35/28;;A61K45/06;;G01N33/6872;;A6 31/7105;;C12Q1/6876;;C12Q2600/158;;C12N2501/65;;C12N5/069;;C N5/0656;;C12N2510/00;;A61P11/00;;A61P19/00;;A61P19/02;;A61P1 8;;A61P27/02;;A61P21/00;;A61P17/14;;A61P17/00;;A61P17/08;;A01N 0226;;A61K31/7105;;A61K35/12;;A61K35/28;;A61K45/06;;C12N2501/ ;;C12N2510/00;;C12N5/0656;;C12N5/069;;C12Q1/6876;;C12Q2600/1 ;G01N33/6872;;C12N5/0656;;C12N5/0621;;A61K31/7105;;A61P29/00 61P21/00;;A61P19/02;;A61K35/30;;A61K48/00;;G01N33/6872;;C12N 1/65;;A61K48/0083;;C12N5/0668;;C12N15/89
4	Cardiosphere-Derived Cells And Their Extracellular Vesicles To Retard Or Reverse Aging And Age-Related Disorders	2023	US 201716333581 A	19/09/2017	Cedars Sinai Medical Center	Marban Eduardo;;Grigorian Lilian	Cedars-Sinai Medical Center (2017-09-27)	Granted Patent	478	1	396	A61K35/34;;A61P9/00;;A61P9/04;;A61P17/14;;A61P19/08;;A61P39/0 C12N5/0657;;A61K35/34;;A61K9/0019;;A61K9/127;;A61K2039/55555 61P9/00;;A61P9/04;;A61P17/14;;A61P19/02;;A61P25/28;;A61P39/00 61Q19/08;;C12N5/0657;;C12N9/1276;;C12N9/2471;;C12Y207/07049 12Y302/01023

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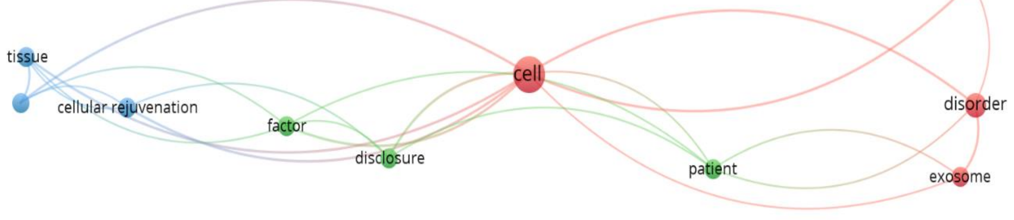
t to Reverse Aging Technologies (2003-2023) (Continued)

	Publication Year	Application Number	Application Date	Applicants	Inventors	Owners	Document Type	Cites Patent Count	Cited by Patent Count	NPL Citation Count	CPC
ructs And enation And	2023	US 2022/0073751 W	14/07/2022	Turn Biotechnologies Inc	Bojjireddy Naveen;;Sarkar Tapash		Patent Application	20	1	17	C12N15/85;;C12N9/127;;C12N N2506/1307;;C12N2510/00;;C 11;;C12N15/86;;C1
tions ising	2022	US 202117534341 A	23/11/2021	Lyell Immunopharm a Inc	Vizcardo Sakoda Raul E;;Restifo Nicholas;;Klaus ner Richard D;;Huang Yin;;Maeda Takuya;;Tamao ki Naritaka;;Yama zaki Yasuhiro		Patent Application	2	1	4	C12N5/0636;;C12N2510/00;;C /604;;C12N2501/606;;C12N25 N2760/18842;;A61K39/4611;;A 631;;A61K39/464412;;C07K16/ 1;;C07K14/7051;;C12N5/0636; 501/51;;C12N2501/515;;C12N2 N2501/604;;C12N2501/606;;A6 4488;;A61K39/4632;;A61K39/4 /00;;C12N2501/602;;C12N2501 2N2501/2302;;C12N2501/515; 31;;A61K35/17;;C12N5/0636;; 01/606;;C12N2501/604;;C12N2 A61K39/4631;;A61K39/4611;;A 644
nes For ted With Dysfunction	2020	US 2020/0017194 W	07/02/2020	Univ Texas	Kalluri Raghu		Patent Application	47	1	33	A61K47/62;;A61K47/6911;;C12 2501/65;;C12N5/0663;;C12N25 61K9/127;;A61K35/28;;A61K48 38/45;;C12N9/96;;C07K14/705 06;;A61P43/00;;A61P39/00;;A6 P43/00;;A61K9/0019;;A61K9/0 ;A61K48/0033;;C12N5/0663;;C C12N2501
nting Age	2022	US 201615369783	05/12/2016	Bioviva Usa Inc	Parrish Elizabeth	Bioviva Usa Inc (2018-12-01)	Granted Patent	0	0	6	A61K38/45;;A61K38/1709;;A61 1K38/1709;;A6
ondrial	2022	US 202117380333 A	20/07/2021	Dischler Louis	Dischler Louis		Granted Patent	7	0	35	A61K31/353;;A61K31/194;;A61 1/4745;;A61K31/5415;;A61K31 /7004;;A61K31/194;;A61K31/2 ;A61K31/4745;;A61K3
tochondrial	2021	US 202117176276 A	16/02/2021	Dischler Louis	Dischler Louis		Granted Patent	7	0	34	A61K31/353;;A61K31/194;;A61 1/4745;;A61K31/5415;;A61K31 /7004;;A61K31/194;;A61K31/2 ;A61K31/4745;;A61K3
llular	2023	US 2023/0066647 W	05/05/2023	Harvard College;;Centro De Investig Cooperativa En Biociencias Cic Biogune;;Univ Of Luxembourg	Plesa Alexandru;;Jun g Sascha;;Church George;;Mesa Antonio Del Sol;;Wang Helen;;Shadpo ur Michael		Patent Application	0	0	0	C12N5/0602;;C12N25

Taken together with the clusters identified in Table 3, Figure 8 of the VOSViewer Term Co-occurrence Map offers a comprehensive view of the major themes driving reverse aging patent research. Three large clusters of research appear to focus on cellular and systemic rejuvenation, carrying substantial implications for regenerative medicine. The "Blue Cluster" highlights tissue repair and cellular rejuvenation as the primary themes, underlining the aspect of cellular integrity during anti-aging interventions. The "Green Cluster" focuses on translation to clinical practice by highlighting therapeutic targets and patient outcomes. The "Red Cluster" speaks to extracellular vesicles, specifically exosomes, as potential therapeutic interventions in aging diseases through a system-wide approach.

Figure 8 VOSViewer Term Co-occurrence Map Extracted from Title and Abstract of Patents Relevant to Reverse Aging Technologies Exported from Lens.org



Note: Reproduced from VOSviewer Version 1.6.20 (https://www.vosviewer.com). Free to use.

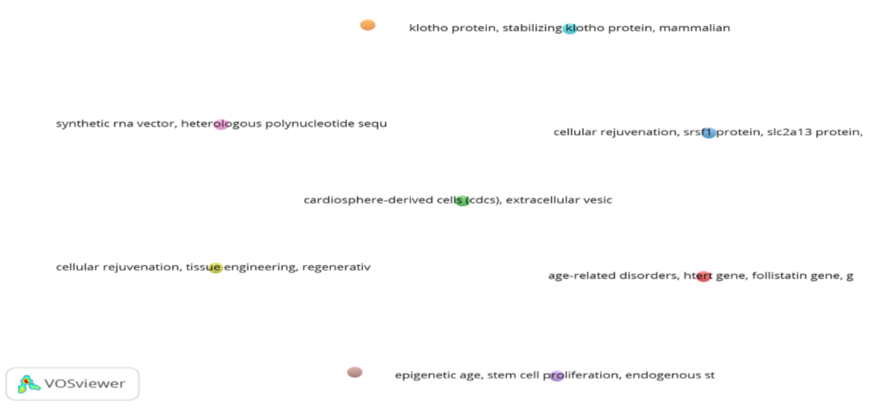
Table 3 Term Co-occurrence Clusters and Relevance

Clusters	Occurences	Relevance
Cluster 1 (4 Items)		
cell	7	0.38
disorder	3	1.72
exosome	2	2.22
organism	2	1.4
Cluster 2 (3 Items)		
disclosure	2	0.54
factor	2	0.41
patient	2	0.64
Cluster 3 (3 Items)		
cellular rejuvenation	2	0.79
reprogramming factor	2	0.94
tissue	2	0.94

Note: The table data was retrieved from VOSviewer Version 1.6.20 (https://www.vosviewer.com). Free to use.

Figure 9 on Co-occurrence network of reverse aging technology at the keyword level based on bibliographic patent data. The network describes the interrelations of the keywords according to their concurrent occurrence within patents and presents important research subjects and their linkages in a graphical form. Yet, the diagram shows an unexpected feature: the total link strength is 0, which may mean either that the data is fragmented or that there are methodological limitations because no obvious co-occurrences or thematic overlaps were found among the studied terms. Enhanced by this visual analysis, Table 4 lists the clusters of keywords and the instances of each. It identifies well-known organizations such as those working on "Klotho protein," "cellular rejuvenation," "synthetic RNA vector," and "age-related illnesses," but it does not allow any quantification of the links, which gives further support to the disjointedness of the dataset.

Figure 9 Keyword Co-occurrence based on bibliographic data



Note: Reproduced from VOSviewer Version 1.6.20 (https://www.vosviewer.com). Free to use.

Table 4 Keyword Cluster and Occurrences

Clusters	Occurences	Total link Strength
Cluster 1 (1 Item)		
age-related disorder, htert…	1	0
Cluster 2 (1 Item)		
cardiosphere-derived cells	1	0
Cluster 3 (1 Item)		
Cellular rejuvenation, tissue..	1	0
Cluster 4 (1 Item)		
epigenetic age, stem cell…	1	0
Cluster 5 (1 Item)		
klotho protein, stabilizing…	1	0
Cluster 7 (1 Item)		
lipid-based nanoparticles…	1	0
Cluster 8 (1 Item)		
rejuvenated t-cells…	1	0
Cluster 9 (1 Item)		
synthetic rna vector…	1	0

Note: The table data was retrieved from VOSviewer Version 1.6.20 (https://www.vosviewer.com). Free to use.

DISCUSSIONS

The patent publishing patterns in reverse aging technologies from 2003 to 2023 show variations in invention activity throughout the 20-year period. The data show a progressive increase from 2010 to 2015, which indicates increased attention to innovative solutions in such fields as antibiotic research and biotechnology. Issues including financial limitations and legal limits most likely contributed to the decline observed between 2015 and 2020 (Charlton & Andras, 2005; Mandel & Vesell, 2004). The resurgence from 2020 to 2022 showcases biotechnology and nanotechnology discoveries, with advancements in antimicrobial medications such as CRISPR technology and customized antibodies, as well as the incorporation of nanotechnology driving improvements (Mantravadi et al., 2019). However, the slight decline in 2023 may be an indication of shifting research objectives, market saturation, or a move toward sustainable scientific activities. Pressures from commercialization have further changed this environment, and debates around gene patenting and conflicts of interest have brought attention to the tension between innovation and regulatory frameworks (Toews, 2015). These trends show how important strategic priority is in ensuring substantial and sustainable scientific progress despite the continuing challenges.

A growing number of patents are being filed for reverse aging technologies, which have the potential to transform a variety of sectors, including healthcare, education, research, policy, industry, and investing. Companies might exploit this growth to develop innovative anti-aging medicines while monitoring moral dilemmas and business competition, particularly in the biotechnology industry (Read et al., 2008). Strategic commercialization approaches are necessary to ensure flexibility and competitiveness (Babikova & Korsakov, 2023). Researchers are urged to enhance technological advancements and eliminate barriers to adoption; collaborative efforts are fostering advances in areas including regenerative medicine and stem cell applications (Vijg & Grey, 2014; Zocchi et al., 2019). To facilitate ethical behavior and responsible innovation, lawmakers need to change current legislative frameworks, while stakeholders have to collaborate in solving moral dilemmas (Sixsmith, 2022; Read et al., 2008). In an attempt to cultivate transdisciplinary competencies and moral sensitivity, educational institutions can incorporate longevity concerns into their programs (Read et al., 2008). Investors can find attractive opportunities while controlling risks associated with market saturation (Babikova & Korsakov, 2023). While technologies of reverse aging are full of promise, responsible and equitable developments will require balancing innovation with ethical and societal implications.

The top applicants of reverse aging technologies patents by document count from 2003 to 2023 reveals Dischler Louis as at the top in this regard, representing individual contributions with the highest number of patents filed in this area. Following closely are Cedars-Sinai Medical Center and Lyell Immunopharma INC., which are institutional entities actively pushing the frontier of research in reverse aging. Turn Biotechnologies INC., Bioviva USA INC., and Klotho Therapeutics INC. also make an appearance on this list; these private-sector-based companies signal a clear commercial interest in anti-aging therapeutic approaches. More than anything, though, this list points to the substantial and indispensable role universities play in contributing to both the foundational and applied research of reverse aging technologies.

A collaborative ecosystem among individuals, research institutions, and private companies in driving advancements that address both the scientific challenges and societal needs can be the only way to see the reverse aging technologies innovation landscape thrive. Industries may tap into expertise from the best applicants and nurture innovations in this field (Siu, 2024), while academic institutions hold great importance in closing knowledge gaps through interdisciplinary research (Schulz et al., 2015). Policymakers can increase opportunities for funding and create an enabling regulatory environment to support innovation ecosystems (Vijg & Grey, 2014), and investors are encouraged to provide support to high-performing entities with promising breakthroughs (Zhang, 2012). However, as technological advancement picks up speed, addressing public concerns and ethical considerations becomes very important for the successful implementation and acceptance of reverse aging technologies in society (Vijg & Grey, 2014).

The distribution of patent filings related to reverse aging technologies by jurisdiction from 2003 to 2023, shows United States at the top of the document count, followed closely by WIPO, as a result of significant funding, leading-edge research facilities, and a culture that encourages technological advances (Trappey, 2013). The U.S. evinces a strong commitment to research and development, with an acceleration in patent applications that exceeds that of other nations, representing an innovative renaissance (Powers & Leal, 1994). At the same time, the World Intellectual Property Organization (WIPO) flags the fact that there is worldwide interest in reverse aging technologies as international applicants are seeking a way to get wider market protection and strategic patenting (Trappey, 2013). WIPO patent activity manifests global efforts to take a competitive advantage in this quickly changing field (Powers & Leal, 1994). While the U.S. and WIPO dominate the filings, increasing investment from other nations shows a new turn in global dynamics of innovation and opens even more competition and cooperation in the industry.

The findings on the competitive landscape of innovation and patenting present critical implications for stakeholders to strategically focus on key areas. The sheer number of U.S. patents filed demonstrates that this is a strong environment in which companies have to be leaders in technology and strong IP strategies in order to be competitive, specifically in industries such as artificial intelligence (Yang & Yu, 2019). IP rights will only be truly effective if utilized and enforced (Veer & Blind, 2012). The prevalence of WIPO filings further demonstrates the requirement for global strategies to enter international markets, with jurisdictions like the U.S. and WIPO offering excellent locations for high-value investments (Yang & Yu, 2019). Policymakers can facilitate regional attractiveness by improving the IP framework and providing R&D incentives, as stronger intellectual property rights attract offshoring of innovation (Valacchi, 2018). Academic and research institutions provide the critical global partnerships that create diverse networks that can be leveraged to increase the speed of innovation (Dovgal & Dovgal, 2020). In healthcare, the ethical implementation of reverse aging technologies is paramount to ensure equitable access and responsible practices. However, while a focus on patenting and innovation is crucial, overemphasis on IP protection could hinder collaboration and open innovation, potentially slowing broader technological progress.

Strong economic and societal interest in reverse aging technology inventions reflects in the increasing trend of patent applications in the anti-aging technology industry between 2003 and 2023, hence indicating that researchers and organizations are working to obtain the rights to intellectual property (Fink et al., 2016). This growth reflects a strategic shift in the way businesses engage with the patent system and falls in line with global trends of historically high patent filings (Fink et al., 2016). The gap between applications and granted patents indicates, however, that the patent examination process is tough, particularly concerning proving originality and novelty, two important prerequisites for approval (Rout, 2018). According to Nekrasov and Mironov (2019), more thorough review typically yields fewer approved patents than applications. A tendency for quick filings over in-depth research is also suggested by the small amount of search reports, which suggests insufficient prior art searches (Holgersson, 2012). Exam rejections could result from this prior art gap (Ding, 2011). Although the increase in applications shows that the innovation landscape is thriving, sustainability issues could occur if a large number of applications do not result in issued patents, which could overestimate the true technological advancements in the industry.

The reverse aging field is a crowded space with much interest and investment in state-of-the-art technologies, such as p16 inhibitors and stem cell therapies, evident through an immense number of patent applications (Bishop & Beach, 2013; Zhang, 2012). Yet, such a gulf between applications and granted patents brings to light inefficiencies in the innovation funnel and reinforces the need for enhanced pre-filing strategies and competitive intelligence. In many cases, applications fail because of poor prior art searches and badly drafted claims; it implies that organizations should emphasize comprehensive searches and drafting to improve the quality of patents and reduce the hassle of rejections during the approval process (Vijg & Grey, 2014). Another indicator of search reports suggests there is room to discourage duplication and incentivize originality in new innovation (Singh & Srivastava, 2022). Policymakers play their role at the top of this ecosystem, providing more clarity on laws and guidelines, support, and encouragement for high-quality patenting while ensuring the protection of novel breakthroughs through innovation (Singh & Srivastava, 2022). It is only by the collaboration of researchers, patent professionals, and policymakers that the complexities in the reverse aging field can be negotiated, such challenges overcome, and innovation sustained. These barriers notwithstanding, the competitive nature of the sector provides impetus to its progress and collaboration in opening up new fronts in age-related therapies (Vijg & Grey, 2014).

A number of CPC categories shows the diversity in the field of reverse aging technologies within the last 20 years. Generally, the information indicates progress in genetic engineering and pharmacology with a focused approach on molecular techniques and chemical compositions. The "Human Necessities" (A61K) classification has focused on efforts to treat aging-related conditions like alopecia and arthritis with substances like curcumin and coenzyme Q10, as well as sophisticated delivery systems like liposomes, in order to improve stability and absorption (Giannouli, 2022; Kyoo et al., 2016). Parallel to this, "Chemistry Metallurgy" codes (C12N) show genetic engineering advances such as microRNA, RNA-directed polymerases, and genetically modified cells for molecularly addressing aging (Benhamú et al., 2022; Ding et al., 2017). Among the advances is senotherapeutics, which aims at prolonging health by eliminating senescent cells (Benhamú et al., 2022). While genetic engineering and medicines take up most of the industry, other strategies that include lifestyle modifications and natural products give a much broader approach to the fight against aging (Ding et al., 2017).

With increasing emphasis on genetic engineering for tailor-made treatment, recent progress in the area of reverse aging points out the significant role of the pharmaceutical sector in developing gerotherapeutics and advanced drug delivery systems. FDA-approved drug repurposing is becoming one of the major geroscience interventions, while pharmaceutical breakthroughs target the molecular causes of aging to ameliorate chronic diseases (Forman & Pignolo, 2024; Léone & Barzilai, 2024). Together with the steps in genetic engineering, targeting cellular degeneration opens new possibilities for the development of tailor-made treatment based on the unique genetic make-up of an individual to enhance treatment outcomes and boost patient satisfaction (Kitaeva et al., 2024; Zhang et al., 2024). At the same time, these advancements raise very important regulatory and moral issues, putting into the limelight the cooperation between lawmakers and researchers, assurance of safety, accessibility, and health policy equity. Combining innovation with inclusion will be indispensable for reverse aging technologies to achieve their full potential.

There are many contributors in the reverse aging technology landscape across different organizations. In this regard, Cedars-Sinai Medical Center is ranked first with respect to patent ownership, which means a lot of translational research on anti-aging technologies has been pursued (Liu et al., 2024). Stanford University conducts pioneering research on cellular senescence and its effects on aging (Mansfield et al., 2024), while Bioviva USA Inc., a biotech firm, offers innovative treatments with its sights set on aging at the cellular level (Nunkoo et al., 2024). Turn Biotechnologies Inc. epigenetically advances rejuvenation techniques (Boreham, 2024) as an interesting example of how crucial biotechnology can impact this area. This multidisciplinary ecosystem promotes the creation of novel treatments through the confluence of knowledge of biomaterials and epigenetics, with medical facilities, biotech firms, and research universities contributing to its richness (Liu et al., 2024; Boreham, 2024). Ethical issues and concern about fair access to those developments accompany progress and ensure that benefits brought by reverse aging technologies will be available for everyone.

The findings of aging interventions all point toward an ecosystem, involving established medical institutions, biotech companies, and academic research. Cedars-Sinai Medical Center has proven that such institutions are very crucial in bringing discoveries from science to practical applications, acting as a hub for clinical research and development of technologies in aging (Boccardi et al., 2024; Tohit & Haque, 2024). Biotech companies, for example, Bioviva USA Inc. and Turn Biotechnologies Inc., are developing genetic and cellular therapies, reflecting the increased attention of the biotech industry toward personalized medicine for better health outcomes of the elderly population (Kitaeva et al., 2024; Unfried, 2024). Meanwhile, universities such as Stanford University give the basic information necessary for early-stage innovations, guiding best practices and regulations in the treatment of the senior citizenry (Tohit & Haque, 2024; Kraft & Bermejo, 2024). While these cutting-edge developments underline the promise of aging technology, the question of just access comes into play as exclusive intellectual property rights might keep the benefits of the technologies from most people. In order for these innovations to be available for diverse populations around the world, policy makers would have to rise to the challenge.

On the top inventors of the reverse aging technologies, Dischler Louis is the most prominent inventor with nearly four patents, which suggests that he can be a core inventor possibly affiliated with a top organization or institution in the technology. At around 2.5 patents each, a handful of minor innovators such as Grigorian Lilian, Huang Yin and Klausner Richard D. can also contribute a substantial but secondary role in the progress of the field. Reverse aging is a broad discipline attracting a broad spectrum of researchers and inventors as the chart's numerous inventors, including Yamasaki Yasuhiro and Bojireddy Naveen, who have one to two patents, demonstrate. Most inventors have less than two patents, which suggests that this technology is still in its early stage of innovation, and there is not much consolidation of the intellectual property. Fragmentation leads to overlapping rights, so-called patent thickets, in fields of technology, complicating making use of innovations, damaging an innovation ecosystem's efficiency (Entezarkheir, 2019). Pro-patent changes in U.S. legal systems have exacerbated the issue by encouraging patent proliferation without much consolidation (Entezarkheir, 2019). In addition, by creating ambiguity and increasing costs for subsequent inventors, poor patents -about 13% of U.S. patents- add complexity (Kwon, 2021). Individual inventors only hold a few patents, which suggests that the discipline is young and has yet to produce any significant disruptive improvements (Macher et al., 2023). While fragmentation creates challenges, it also supports a diverse creative landscape in which multiple innovators can explore various paths, which may ultimately lead to unexpected discoveries.

Key innovators, collaborative efforts, and emerging players show that reverse aging technology trends are highly dynamic and changeable. Pioneers like Dietrich Louis are central to the trajectory of research, while a large number of secondary contributors continue to progress in the field through multi-disciplinary collaboration (Kim et al., 2016; Ivanitskaya et al., 2024). Another feature to recognize is that the big number of inventors holding between 1 and 1.5 patents signals maturity in the field and opens up more chances for disruptive innovations by newcomers (Bastian et al., 2021). Moreover, it has been pointed out that the high representation of inventors with major organizations reveals a competitive space, reflecting the research and market interests' interplay in this domain (Deng et al., 2023). In addition, tracking the contribution over time may show tendencies of further integration and consolidation, which are important steps in scaling technologies for maximal impact in the field's further development (Morley & Puhvel, 1984). Broader analyses including institutional and geographical factors would give further insight into innovation hotspots and collaboration possibilities. Individual contributions are important, but more cohesive work on the collaborative framework would achieve full potential of reverse aging technologies and fair access to benefits derived from them.

The most frequently cited patents of reverse aging technologies have their publication dates clustered around a few months: April and October from 2003 to 2023. Indeed, in the case of patents published in April 2010, October 2015, and October 2020, there are a lot of citations, indicating that these years correspond to critical advancements in the field (Aristodemou & Tietze, 2020; Maxwell, 2020). Looking at the bubble size, which is the simple family size, one will notice that the patents with a larger family size attract more citations, particularly those on key years (Aristodemou & Tietze, 2020; Marx & Fuegi, 2021). That means the patents with a larger international filing or multiple claims may have more significant impacts, as they may solve more extensive technological needs (Maxwell, 2020; Marx & Fuegi, 2021). However, although the citation metrics provide important information, they cannot completely represent the true impact of the patents, since some of them might not gain many citations because of their niche applications or poor dissemination (Aristodemou & Tietze, 2020).

The clustering of highly cited patents around specific years identifies critical innovation periods influenced by increased funding and technological development, with the most notable peak activity occurring in 2015 and 2020. Those years represent the most successful global patenting strategies, which also bring to light international collaboration and detailed claim drafting (Geissler et al., 2024; Danish & Sharma, 2023). What is more, the distribution of citations by legal status demonstrates that active patents from the peak years keep on driving new innovation, whereas expired patents stemming from earlier periods, such as 2010, are referenced more as foundational (Agnihotri, 2023; Mafu, 2023). Valuable technical knowledge is given out by expired patents, which in turn triggers further innovation, therefore creating knowledge spillovers and opening new opportunities for research and development in the reverse aging field (Mafu, 2023). Focus on recent innovation is important, but stakeholders must not forget that the untapped potential of expired patents can help guide investments and ensure research efforts are aligned with technologies having the most impact.

The patents relevant to reverse aging technologies from 2003 to 2023 depict a few important trends, innovation focus areas, and technological developments during this 20-year period. During the period spanning 2003 to 2023, there was a noticeable trend of significant improvement in patent trends related to reverse aging technologies. In this regard, the filings began rising with innovations in biochemistry and regenerative medicine starting from the mid-2010s. This evidenced strong research and development activities in anti-aging solutions. Increasing patent applications through 2015 and 2018 may indicate increased interest in the areas of cellular rejuvenation, genetic engineering, and advanced drug delivery systems, as components of multi-pronged therapeutic strategies for anti-aging therapies (Alves et al., 2024; Liu et al., 2024). Progress in biomaterials has also had an impact on drug delivery and targeted therapy in relation to influencing cellular aging, while nanotechnology has helped in improving the cosmetic market with anti-aging formulation activities more effective due to the promotion of better antioxidant action (Alves et al., 2024; Liu et al., 2024). Larger patent family size would indicate more broad international applicability, hence better market relevance and adoption potential over the next couple of decades (Liu et al., 2024). Challenges such as ethical considerations and regulatory hurdles will, however, continue to weigh upon the dynamics of innovation and commercialization of such technologies (Pasupuleti, 2024).

The strategic importance of patent filings in cutting-edge areas such as genetic reprogramming and stem cell therapies is underscored by concentrated patent activity during periods of significant scientific breakthroughs, signaling both investment opportunities and a competitive landscape. Significant filings in stem cell and nanotechnology domains reflect rapid advancements in healthcare applications, with pivotal patent activity suggesting opportune moments for commercialization and investment (Iyer & Jain, 2024). Patent activity in the rest of the world is mainly concentrated in the USA, the EU, and Australia, which raises concerns about equitable access to innovations and governance in an apparently competitive environment with dominant players (Hernández-Melchor et al., 2022). These trends can be used by researchers and policymakers to identify funding opportunities, while companies may align strategies with active research areas to enhance their market presence ("The patent landscape in the field of stem cell therapy: closing the gap between research and clinic," 2023). On the other hand, the focus on patenting may create an enabling environment for monopolistic practices, which stifle innovation and access, especially in crucial health technologies; therefore, balanced intellectual property policies are important for fairness and sustainability of innovation (Ernst, 2015).

Advances in reverse-aging technology have taken regenerative medicine by storm, focusing on cellular and molecular pathways in the treatment of age-related disorders. Much promising are cellular reprogramming techniques towards the rejuvenation of old cells and the reversal of senescence, while gene therapy provides a way to alter genetic expressions related to aging (Pasupuleti, 2024; Syed, 2023). Interventions under development seek to increase healthspan and longevity through actions targeting one of the main causes of aging: mitochondrial dysfunction through actions such as reduced oxidative stress and better generation of cellular energy (Pasupuleti, 2024; Tabassum, 2023). The development of precision diagnostics now allows for earlier diagnostics of age-related diseases to provide tailored treatment, further improved by new developments related to 3D bioprinting and advanced biomaterials to improve diagnostic efficacy (Bhutambare et al., 2024; Farshan, 2024). All revolutionizing developments do still come with quite a few problems—for example, moral dilemmas and inequalities in access (Pasupuleti, 2024; Bhutambare et al., 2024).

A patent on Cardiosphere-Derived Cells (CDCs) and their extracellular vesicles (EVs), which target cardiovascular aging, marks a breakthrough in regenerative medicine. This is an innovation utilizing the regenerative properties of CDCs and EVs to target key aging mechanisms, including elongation of telomeres and restoration of gene expression (Das et al., 2024; Shiraishi et al., 2024). While EVs mediate important paracrine effects necessary for cardiac repair, including promoting angiogenesis and modulating inflammation, CDCs have shown preclinical efficacy in improving cardiac function and reducing fibrosis in models of ischemic heart disease (Diomede et al., 2023; Mayo et al., 2023). CDCs form an important part of regenerative therapy because they can treat a variety of aging-related diseases other than cardiovascular diseases (Shiraishi et al., 2024; Zubkova et al., 2023). Standardization of applications and ensuring that therapeutic outcomes are consistent remains challenging, and further study is needed to maximize their clinical potential.

To mitigate the risks of permanent genetic alterations and enhance safety for therapeutic use, the Transient Cellular Reprogramming patent (US 2021/0010034 A1) discloses a new strategy for cellular rejuvenation based on the use of non-integrated mRNAs to reverse aging without compromising differentiation states (Avelar et al., 2024; Ivanova et al., 2024; Oshimura et al., 2024; Sahu et al., 2024). The approach reduces oncogenesis risk through the use of transitory mRNAs to avoid long-term genetic alterations (Oshimura et al., 2024). Partial reprogramming induces cellular rejuvenation without total dedifferentiation by increasing mitochondrial activity and chromatin accessibility (Avelar et al., 2024). Compared with more traditional approaches, for example, those involving viral vectors, the technique has demonstrated an improved safety profile. Therapeutic uses are in the treatment of age-related degenerative diseases and in enhancing tissue repair (Ivanova et al., 2024; Oshimura et al., 2024). Additional research is required to optimize these strategies for clinical use since there remain challenges in ensuring the complete removal of reprogramming components to avoid adverse outcomes such as cancer (Sahu et al., 2024).

Klotho protein, having critical roles in aging and lifespan, draws increasing attention as it holds promise in diagnosis and treatment. The pending patent WO 2019/113373 A2 has the theme of increasing Klotho levels to battle aging-related diseases by combining molecular diagnostics with strategies for treatment, thus further cementing personalized medicine strategies. Klotho is thus directly associated with the regulation of life span; mice overexpressing the gene for klotho through genetic manipulation live longer than usual, and ones with a deficiency die early (Fanaei-Kahrani & Kaether, 2024). Having established itself as an anti-aging protein, its influence extends over critical biological pathways such as inflammation and calcium homeostasis (Kumar, 2024; Prudhomme & Wang, 2024). There exist therapeutic agents—Gene Therapy and hormone products—that can enhance Klotho levels and subsequently prevent problems in aging (Poursistany et al., 2023). Especially beneficial for older populations, the soluble type of Klotho has, for example, potential regarding the reduction of inflammation and in muscle repair after injury (Prudhomme & Wang, 2024). Just like the rest of what's trending, which is precision medicine, diagnostic advancements allow for the introduction of kits used in measuring levels of Klotho, opening a way toward diagnosing aging and targeted therapy interventions (Genovese & Leonhardt, 2024). Further research into Kloth in regenerative and aging therapies must be done for the full application of its properties since there is still much not understood about how Kloth works, and the general safety of applications in clinical scenarios.

According to Madreiter-Sokolowski et al. (2024), Moawad et al. (2024), Ore et al. (2024), Somasundaram et al. (2024), and Zhang et al. (2024), "The Methods for Reducing Mitochondrial Dysfunction" (US 202117380333 A), a pending patent by Harvard College that addresses mitochondrial dysfunction, offers a promising strategy for mitigating aging-related decline across various organ systems. According to Madreiter-Sokolowski et al. (2024) and Somasundaram et al. (2024), mitochondria play a critical role in ATP synthesis and maintenance of cellular homeostasis, and their dysfunction is implicated in oxidative stress, mitochondrial DNA damage, cellular senescence, and organ failure. Cell therapies using stem cells for mitochondrial transfer, antioxidants, mitochondrial biogenesis stimulators, and nanozymes targeting mitochondrial repair may be used in the treatment of neurodegenerative diseases such as Alzheimer's and Parkinson's (Madreiter-Sokolowski et al., 2024; Moawad et al., 2024; Ore et al., 2024; Zhang et al., 2024). Resolving mitochondrial dysfunction may improve outcomes in metabolic syndromes and neurodegenerative illnesses by reducing the impact of aging on different organ systems (Madreiter-Sokolowski et al., 2024; Moawad et al., 2024). Nevertheless, there are still significant obstacles in the way of turning these strategies into successful medicines, such as the complexity of mitochondrial biology and the need for organ-specific interventions.

Innovative patents focusing on the cellular and molecular features of aging provide diagnostic, therapeutic, and regenerative solutions with revolutionary implications for healthcare and define the emerging field of reverse aging technology. The CDC patent shows the clinical feasibility of cell-based therapies, particularly for cardiovascular health, advancing the rejuvenation of aging hearts and promoting the development of medication for cardiovascular diseases (Liu et al., 2024). Indeed, transient reprogramming strategies, like targeted partial reprogramming using Yamanaka factors OSKM show promise in increasing longevity and improving health markers in elderly mice (Kalies et al., 2024; Sahu et al., 2024). Mitochondria-targeting strategies augment cellular rejuvenation and the regenerative capacity of old cells (Oshimura et al., 2024). These advances enable precision diagnostics for the early detection of aging-related diseases, allowing for timely therapies and potentially reducing healthcare expenses (Jaalouk et al., 2024). Non-genetic approaches to reversing cellular senescence are provided by safer rejuvenation therapies, such as pharmacological reprogramming, without increasing the risk of tumor formation and extending life span (Kalies et al., 2024). But long-term safety issues, ethical considerations, and the need for stringent regulatory oversight remain paramount to ensuring effectiveness and equity in clinical translation.

Taken together with the clusters identified in Table 3, Figure 8 of the VOSViewer Term Co-occurrence Map, there is a more holistic view of the major themes driving reverse aging patent research. Three large research clusters focusing on different aspects of cellular and systemic rejuvenation with significant implications for regenerative medicine define the study of reverse aging technologies. With considerable university contributions in China and the United States, the "Blue Cluster" centers on tissue repair and cellular rejuvenation, showing the importance of cellular integrity in anti-aging interventions (Song et al., 2024; Tang et al., 2024). Including words such as "factor," "disclosure," and "patient" to emphasize its attention toward therapeutic targets and patient outcomes, the "Green Cluster" puts an emphasis on the translation of scientific findings into clinical use. It reflects a tendency that basic research is conjugated with practical solutions for therapies against aging diseases (Kahaer et al., 2024). In line with some recent publications focusing on extracellular vesicles, particularly exosomes, in vascular aging and other biological processes, the "Red Cluster" tackles these vesicles through a system-wide approach as a possible therapeutic intervention in aging diseases (Ji et al., 2024; Tang et al., 2024). While these are advances, ethical considerations and long-term effects of these interventions in humans remain very important matters for future studies and regulatory scrutiny.

Emphasis on the interdisciplinary nature of cluster analysis is given by its application in research on reverse aging in view of its strong implications for business, technology, and scientific education. Due to increasing demand for health care solutions with age, there was a sudden rise in patent filings; an outline of competitive environment is indicated by the focus on "disclosure" in the green cluster that drives technological development and strategic cooperation towards intellectual property protection (Zeng et al., 2024). Target applications that improve outcomes in therapy enable further innovations in biotechnology and personalized medicine with the advance under the CDC patent, as the red cluster focusing on "exosome" reflects the exciting prospect of making use of extracellular vesicles in cellular rejuvenation and regeneration therapy (Liu et al., 2024). Such advances show why science teachers should bring interdisciplinary concepts to the forefront of their curriculum design, emphasizing intellectual property, ethical issues, and the nature of cooperation in reverse aging research. Among examples of applied courses encouraging students toward careers at the intersection of biology, technology, and medicine are exosomes and regenerative drugs. The competing forces of a patent and proprietary discoveries may realize development; hence, counterbalancing strategies are required to ensure that advances in reverse aging research benefit society at large, not hindering discovery (Vasil'chenko et al., 2024).

The keyword co-occurrence network of reverse aging technology based on bibliographic patent data shows the interconnections of the keywords, according to their concurrent occurrence within patents, and brings forward important research subjects and their linkages in a graphical manner. However, the network diagram shows an unexpected result: the total link strength is 0, which may indicate that either the data is fragmented or there are methodological limitations because no significant co-occurrences or thematic overlaps were found among the studied terms. Enhanced by this visual analysis, Table 4 lists the clusters of keywords and the instances of each. It flags well-known organizations working on "Klotho protein," "cellular rejuvenation," "synthetic RNA vector," and "age-related illnesses," but it does not allow any quantification of the connections, which reinforces the disjointedness of the dataset even more.

The outcome of a total link strength of 0 in Figure 9 emphasizes how specialized and new reverse aging research is, illustrating a field where research streams are still developing in parallel with little to no integration. The sparseness of identified relationships suggests that no established networks or defined terminology exist in the subject, even when the minimum keyword co-occurrence criterion is set to 1. To enable a more focused and accurate study, this collection was curated; patent documents were filtered by the basic family categories. To work around the exclusion of the designated phrases in the Lens.org export, there has been a need to retrieve them manually from the patent abstracts with the aid of AI techniques. Since the human interpretation is limited, so are AI capabilities; the described hybrid manual-AI technique facilitated bespoke keyword choice but introduced certain unpredictability regarding minor linkages or synonyms that might have been excluded.

A fragmented nature of datasets presents both opportunities and problems when improving analytic techniques and fostering integration across disciplines in reverse aging research. Building a unified knowledge network through standardization of terminology, improvement in analytical techniques, and development of automated tools is an approach that closes gaps and encourages innovation in reverse aging technology. By reducing data fragmentation and promoting cross-disciplinary integration of sectors such as gene therapy and regenerative medicine, the standardization of keywords and terminologies enables a better understanding of aging mechanisms in general (Yu & Romero, 2024).

While new cutting-edge techniques, such as Integrative Data Analysis (IDA), have substantial findings by consolidating datasets with compatible measures, revisiting analytical methodologies like reducing the co-occurrence threshold may retrieve weaker associations but give insights with meaning (Canada et al., 2024). While the addition of graph neural networks and big language models increases knowledge extraction for deeper insight into biological systems, improving the AI-assisted keyword extraction methods should improve biomedical literature mining further (Ivanisenko et al., 2024). In particular, the lack of identified connections in recent studies highlights the needs for consistent efforts to bridge disciplinary boundaries. Exploration of specialized areas like epigenetics may bring in more reversal aging technology opportunities and innovation.

CONCLUSION

This study of reverse aging technologies from 2003–2023 shows that despite transdisciplinary progress in biotechnology, genetic engineering, and mitochondrial health, breakthroughs remain limited due to fragmented datasets, inconsistent terminology, and inefficiencies in the patent system. Addressing these systemic barriers requires the integration of ethical frameworks, equitable access mechanisms, and regulatory coherence across jurisdictions to ensure that innovation does not exacerbate existing inequalities. Reverse aging holds transformative potential for combating age-related diseases, improving quality of life, and reducing healthcare costs, yet realizing these benefits demands balancing intellectual property rights with fair and transparent access to innovations across both developed and developing economies. Progress will rely on strengthening collaboration among academic institutions, biotech firms, policymakers, and regulatory agencies, while investing in standardized terminology, multidisciplinary data integration, and AI-driven analytical tools to reveal emerging linkages and accelerate responsible innovation. Beyond scientific implications, the findings emphasize the moral responsibility to design sustainable innovation ecosystems, foster global partnerships, and establish enforceable frameworks for sharing inventions, so that the benefits of reverse aging technologies are distributed inclusively across societies. However, this paper has its limitations: it lacks qualitative insights from inventors or stakeholders that could deepen understanding of innovation barriers, remains narrowly focused on patents without integrating complementary scientific or commercial data sources, and does not yet incorporate emerging non-patented technologies such as open-source gene editing or AI-driven longevity tools that could provide a fuller picture of the innovation ecosystem. In this way, the research underscores both the promise of reverse aging and the need for more holistic, ethically grounded, and globally inclusive approaches to make it a cornerstone of accessible and sustainable healthcare solutions for generations to come.

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