

The use of exosomes in dermatology – current knowledge and future perspective – a review

**Karolina A. Górską^{1,2*}, Bartłomiej Kwiek^{1,3}, Aleksandra Rosiak-Buller^{1,2},
Michał Ławiński², Marcin Ambroziak^{1,2}**

¹ Ambroziak Clinic, Warsaw, Poland

² Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences,
Jastrzębiec, Poland

³ Faculty of Medicine, Lazarski University, Warsaw, Poland

(Accepted July 14, 2026)

The field of dermatological research has witnessed a rapid surge in interest surrounding exosomes – nanoscale extracellular vesicles with multifaceted biological functions. This bibliometric analysis, based on 171 publications extracted from the Web of Science Core Collection, explores the evolving landscape of exosome research in dermatology. Using VOSviewer software, we visualized term co-occurrence networks, identified key contributors, and mapped thematic clusters, revealing that exosome-related research has expanded significantly since 2018, with exponential growth in both publication output and citation frequency. China and the United States emerged as dominant contributors, while Europe and Oceania showed growing engagement. The *Journal of Investigative Dermatology* led in publication volume and citation impact, reflecting its central role in disseminating high-quality research in this domain. Keyword mapping highlighted critical research themes such as skin regeneration, wound healing, immune modulation, and therapeutic applications in chronic and inflammatory skin conditions. High-impact terms – including melanocyte, angiogenesis, mesenchymal stem cells, and microRNAs – reflect both foundational molecular mechanisms and translational relevance. Furthermore, emerging trends suggest increasing interest in plant-derived exosomes and their potential integration with technologies like laser therapy for enhanced transdermal delivery. Despite their promise in diagnostics, therapeutics, and cosmetic applications, challenges remain in standardisation, scalability, and regulatory validation. This study provides a comprehensive overview of the current state and future directions of exosome research in dermatology, offering valuable insights to guide future interdisciplinary innovations and clinical translation.

*Corresponding author: k.gorska@klinikaambroziak.pl

KEY WORDS: aesthetic medicine / anti-aging / anti-inflammatory / bibliometrics / dermatology / exosomes / skin regeneration / stem cells / Vos viewer / Web of Science

Introduction

The structure and origin of endosomes

Endosomes are dynamic intracellular organelles that play a pivotal role in trafficking and signaling within eukaryotic cells. Their structure and function arise from the endocytic pathway, forming a complex network essential for maintaining cellular homeostasis and facilitating intercellular communication [Lu and Hong 2008]. As vesicular structures of endocytic origin, endosomes are responsible for the internalisation, sorting, and recycling of proteins, lipids, and nucleic acids. Additionally, they contribute to the degradation of unnecessary molecules through lysosomal pathways or their repurposing for various cellular functions. Endosomes are formed by the invagination of the plasma membrane, leading to the generation of early endosomes [Scott *et al.* 2014]. These structures mature through progressive acidification and structural remodeling, transforming into late endosomes or multivesicular bodies (MVBs) [Boriachek *et al.* 2017]. MVBs then direct their contents toward lysosomal degradation or release them into the extracellular space in the form of exosomes. Exosomes, nanometric extracellular vesicles (30-150 nm), originate from the intraluminal vesicles of MVBs following their fusion with the plasma membrane, representing a critical mechanism of intercellular communication [Al-Shubaily and Al-Zahrani 2021]. This specialised transport system highlights the versatility of endosomes in both intracellular dynamics and intercellular signaling. The key components of exosomes are proteins, lipids, nucleic acids and DNA. Exosomes contain a variety of proteins, including membrane-associated proteins and cytosolic proteins. These proteins can include cytokines, growth factors, and enzymes, which are essential for the biological functions of exosomes [Isaac *et al.* 2021]. The lipid bilayer membrane of exosomes is crucial for their structure and function. Lipids not only form the membrane but also participate in signaling processes [Lo Cicero and Raposo 2013]. Moreover exosomes carry various types of RNA, including messenger RNA (mRNA), microRNA (miRNA), and other non-coding RNAs. These nucleic acids can regulate gene expression in recipient cells and are involved in various physiological and pathological processes [Taylor and Gercel-Taylor 2013]. Some exosomes also contain DNA, which can be transferred to other cells, potentially influencing their genetic and functional characteristics [Al-Shubaily and Al-Zahrani 2021].

The endosomes' therapeutic function in medicine

Endosomes, as dynamic membrane systems, play crucial roles in various cellular processes, including the sorting and recycling of membrane proteins, intracellular delivery of proteins, and signal transduction [Geldner 2004, Gould and Lippincott-

Schwartz 2009]. Their therapeutic potential in medicine is primarily explored through their derivative, exosomes, which are small extracellular vesicles of endocytic origin. The key therapeutic roles of exosomes in medicine fall into the following areas: drug delivery, regenerative medicine, immune modulation, neurotherapeutics, and diagnostic. Exosomes are being explored as vehicles for drug delivery due to their ability to transfer proteins, RNA and other molecules between cells. This ability is particularly promising for targeted therapies in cancer [Morishita *et al.* 2017, Lou *et al.* 2021]. Moreover, they can be engineered to carry specific therapeutic agents, improving the precision and efficacy of treatments [Lou *et al.* 2021, Hosseini *et al.* 2021]. They originate from mesenchymal stem cells (MSCs) and other sources have shown significant potential in tissue repair and regeneration. They are involved in processes such as cartilage reconstruction, tendon regeneration and nerve tissue repair [Namini *et al.* 2023, Jordan and Haroon 2024, Miron *et al.* 2024]. Furthermore, their paracrine effects, mediated by the release of bioactive molecules, contribute to their therapeutic benefits in regenerative indications [Keshtkar *et al.* 2018, Taheri *et al.* 2019]. Exosomes are able to modulate immune responses, which are beneficial in the treatment of autoimmune diseases and cancer therapy. They can suppress T and NK cell functions and increase the activity of immune suppressor cells, promoting immune regulation [Zhang and Grizzle 2011, Matsuzaka and Yashiro 2022]. The promising aspect is that exosomes have been researched for their role in neurodegenerative diseases. They are capable of delivering therapeutic molecules across the blood-brain barrier, making them suitable for treating diseases such as Alzheimer's and Parkinson's [Wu *et al.* 2023]. Exosomes contain disease-specific biomarkers, therefore they are useful in the diagnosis and early screening of diseases such as cancer and diabetes [Borges *et al.* 2013].

The role of exosomes in dermatology

Exosomes, small extracellular vesicles released by various cell types, play a crucial role in intercellular communication and have gained significant attention in dermatology for their potential therapeutic applications. Current research highlights their involvement in wound healing and tissue regeneration, skin rejuvenation and anti-aging treatments, treatment of dermatological diseases, aesthetic medicine and cosmetic applications, hair regeneration, as well as diagnostic and therapeutic advancements. Given their versatility, exosomes hold great promise in dermatology, with potential applications spanning from therapeutic interventions to diagnostic tools. However, further research and development are essential to fully unlock their capabilities. This study aims to: (i) explore the extensive body of literature on exosomes in medicine, and (ii) examine their diverse applications and emerging therapeutic potential in dermatology. Through this analysis, we seek to identify new directions for research and innovation in this rapidly evolving field.

Material and methods

The online academic literature database, Web of Science (WoS) Core Collection, was queried on January 3, 2025, using the following search string: ‘TS = *exosomes**’. This query identified publications containing “*exosomes*” and its derivatives in their titles, abstracts, and/or keywords, yielding 42,209 results. An additional filter was then applied by adding the term ‘TS = *dermatology**’ to narrow the search. This refined query returned 171 papers, including 45 review papers. The primary publication and citation data were directly retrieved from the WoS platform, and the full records of the 171 papers were exported as a tab-delimited file for processing in VOSviewer - a software tool designed for creating, visualising, and analyzing bibliometric networks [van Eck and Waltman 2009]. VOSviewer is one of the most useful tools to gain insights into the structure and development of a research field [review in: Yeung *et al.* 2024; Sun *et al.* 2023]. Using this software, a network visualisation was performed, including creating networks of researchers, journals, institutions, countries, and keywords, while applying clustering algorithms to identify groups or themes for further bibliometric analysis. Specifically, VOSviewer was utilized to generate a term map of exosomes in dermatology. Additionally, analyses derived from the WoS data were used to create tables and figures, such as WoS categories, times cited, and publications over time. The botanical nomenclature follows World Flora Online [2025].

Results

The analysed literature set contains 171 scientific articles (Suppl. 1). We provide the dataset on the cumulative annual values of publications and their citations containing the keywords “exosomes in dermatology” (n=171), based on bibliographic data from the Web of Science (WoS) (Fig. 1). The x-axis represents the years from 2000 to 2024, while the left y-axis corresponds to the number of publications, and the right y-axis indicates the number of citations. The bars represent the yearly cumulative number of publications. Here, a noticeable increase in the number of publications begins around 2015, with a rapid rise observed from 2018 onwards, peaking in 2023 and 2024. The line chart shows the cumulative number of citations received by these publications. Citations exhibit a lag behind publications initially but show exponential growth starting from 2018, surpassing 700 citations by 2024.

The global distribution of scientific publications (Fig. 2) related to exosomes in dermatology highlights the contributions of various countries. The data is visualised using a heat map, where the intensity of the orange color represents the number of publications from each country, as indicated by the gradient scale in the top-right corner. Dominant contributors include China, which leads with the highest number of publications (n=63), signifying its prominent role in research on exosomes in dermatology, followed by the United States with 36 publications, reflecting its significant contributions to the field. Moderate contributors such as South Korea

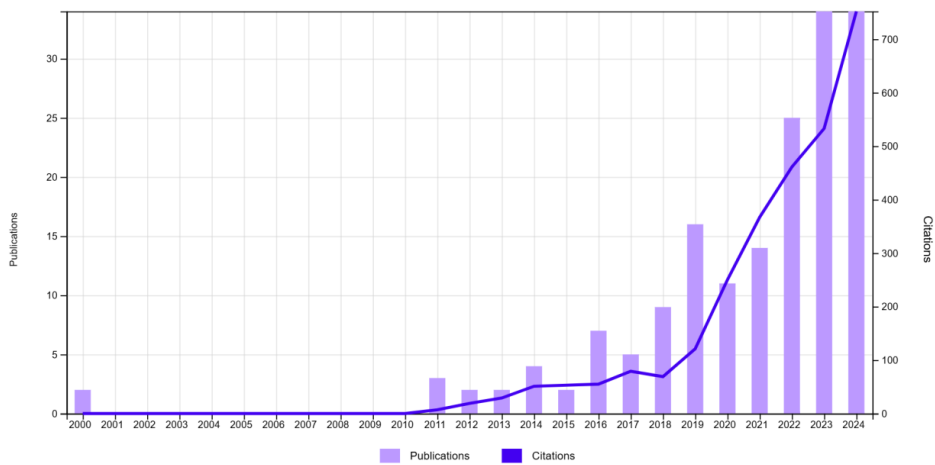


Fig. 1. Cumulative values of publications and their citations containing the keywords exosomes in dermatology (n=171) for each year performed from WoS analysis tool.

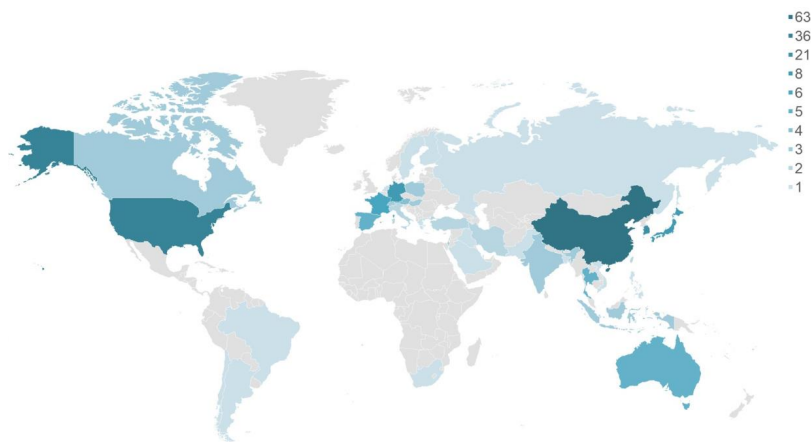


Fig. 2. The map of publication number per country. Source WoS, The graphical chart performed by: Australian Bureau of Statistics, GeoNames, Microsoft, Navinfo, Open Places, OpenStreetMap, Overture Maps Foundation, TomTom, Wikipedia, Zenrin. Legend: People's Republic of China - 63, USA - 36, South Korea - 21, Germany and Japan - 8, France - 6, Australia, Spain and Thailand - 5, Austria - 4, Canada, Hungary, India, Indonesia, Israel, Poland, Switzerland and UK - 3, Iran, Italy, Singapore, Taiwan and Tukey - 2, Argentina, Bangladesh, Brazil, Chile, Finland, Greece, Iraq, Lebanon, Monaco, Netherlands, Pakistan, Philippines, Russia, Saudi Arabia, South Africa, Sweden and Vietnam - 1.

(n=21) and Germany (n=8) demonstrate active involvement in this area of research. Emerging contributors, including Australia (n=5), Spain (n=6), and France (n=5), show smaller but notable contributions, indicating growing interest and potential for further development. A wide range of countries, such as Austria (4), Canada,

Table 1. The most productive authors, affiliations, countries, journals, and journal categories containing the keywords exosomes in dermatology (n=171) for each year

Item	Number of papers (% of 171)	Total citation	Citation per paper (CPP)
(A) Author			
Park, Kui Young	4 (2,3%)	38	9,5
Cho, Byong Seung	4 (2,3%)	4	1
Kwon, Hyuck Hoon	3 (1,7%)	38	12,6
Seok, Joon	3 (1,7%)	27	9
Arias-Santiago, Salvador	3 (1,7%)	60	20
Gao, T.	3 (1,7%)	6	2
Li, C.	3 (1,7%)	6	2
Montero-Vilchez, Trinidad	3 (1,7%)	60	20
Sanchez-Diaz, Manuel	3 (1,7%)	60	20
Sierra-Sanchez, Alvaro	3 (1,7%)	60	20
Liu, L.	3 (1,7%)	6	2
Wang, G.	3 (1,7%)	13	4,3
Luengaran, Suparuj	3 (1,7%)	4	1,3
Tempark, Therdpong	3 (1,7%)	4	1,3
Cho, B. S.	3 (1,7%)	6	2
(B) Organizations			
ExoCoBio Inc.	9 (5,2%)	5	0,5
Fourth Military Medical University (FMMU)	7 (4,1%)	329	47
Huazhong University of Science and Technology (HUST)	5 (2,9%)	134	26,8
Thomas Jefferson University (TJU)	5 (2,9%)	51	10,2
Chung-Ang University (CAU)	5 (2,9%)	42	8,4
Sun Yat-sen University (SYSU)	4 (2,3%)	53	13,25
Chulalongkorn University (CU)	4 (2,3%)	5	1,25
(C) Country			
People's Republic of China	63 (36,8%)	1155	18,3
USA	36 (21,1%)	880	24,4
South Korea	21 (12,3%)	294	14,0
Japan	8 (4,7%)	318	39,8
Germany	8 (4,7%)	38	4,8
France	6 (3,5%)	162	27,0
Thailand	5 (2,9%)	5	1,0
Australia	5 (2,9%)	65	13,0
Spain	5 (2,9%)	62	12,4

Hungary, India, Indonesia, Israel, Poland, Switzerland, and the UK (3 each), as well as Iran, Italy, Singapore, Taiwan, and Turkey (2 each), exhibit lower but distributed research output. A number of countries, including Argentina, Bangladesh, Brazil, Chile, Finland, Greece, Iraq, Lebanon, Monaco, Netherlands, Pakistan, Philippines, Russia, Saudi Arabia, South Africa, Sweden, and Vietnam, contribute minimally with 1 publication each, reflecting initial engagement in this research area. The nine most productive countries are demonstrated in Table 1C.

The most productive authors based on the number of papers they have published, total citations, and citations per paper (CPP) are compiled in Table 1 (A). Among the 171 papers analyzed the top contributors are Park, Kui Young and Cho, Byong Seung. Each of these authors contributed 4 papers (2.3% of the total). However, their impact differs significantly in terms of citations per paper: Park achieves a high CPP of 9.5

with 38 total citations, while Cho has a much lower CPP of 1 with 4 citations. The high-impact authors are Kwon, Hyuck Hoon (CPP: 12.6-38 citations) and Seok, Joon (CPP: 9, 27 citations). They are notable for their significant citation counts despite publishing fewer papers (3 papers each, 1.7% of the total). The exceptional citations per paper have Arias-Santiago, Salvador, Montero-Vilchez, Trinidad, Sanchez-Diaz, Manuel, and Sierra-Sanchez, Alvaro stand out with an impressive CPP of 20, each accumulating 60 citations from 3 papers. The moderate contributors are Gao, T., Li, C., Liu, L., and Cho, B. S.. They share similar metrics, each contributing 3 papers with a low CPP of 2, reflecting a total of 6 citations. Furthermore, Wang, G. demonstrates moderate influence with 3 papers and a CPP of 4.3 (13 total citations). Following authors like Luengaran, Suparuj and Tempark, Therdpong each contributed 3 papers but had minimal impact with a CPP of 1.3 (4 total citations).

A clear distinction between organizations excelling in both productivity and citation impact is presented in Table 1 (B). These insights highlight the varying contributions of institutions to the academic landscape. The leading organization by volume is ExoCoBio Inc., which contributed 9 papers (5.2% of the total). However, its citation impact is minimal, with a total of 5 citations and a low CPP of 0.5 indicating limited academic influence. In contrast, the high-impact organization Fourth Military Medical University (FMMU) demonstrates exceptional citation metrics, with 7 papers (4.1% of the total), an outstanding total of 329 citations, and a remarkable CPP of 47. This reflects both high productivity and significant academic influence. Another notable institution is Huazhong University of Science and Technology (HUST), which also stands out with a CPP of 26.8 – derived from 5 papers (2.9%) and 134 citations. Similarly, Thomas Jefferson University (TJU) maintains a strong position, with a CPP of 10.2 from 5 papers, totaling 51 citations. Slightly fewer scientific papers were published by Chung-Ang University (CAU), which produced 5 papers (2.9%), accumulating 42 citations and achieving a CPP of 8.4 reflecting a solid academic contribution. Sun Yat-sen University (SYSU) contributed 4 papers (2.3%), with 53 citations and a CPP of 13.25 – indicating a higher-than-average impact per paper. Alternatively, Chulalongkorn University (CU) shares similar productivity metrics with SYSU, contributing 4 papers (2.3%). However, its academic influence is limited, with only 5 citations and a CPP of 1.25.

A summary of the scientific journals (Tab. 2) shows the most works on the topic of exosomes in dermatology, classified according to the Web of Science (WoS) categories. The data reflects the number of papers, total citations, and citation per paper (CPP) for each journal, based on a total of 171 publications. The leading journals like The Journal of Investigative Dermatology ranks highest, with 51 papers (29.8% of all publications) and a total of 902 citations, resulting in an impressive citation per paper (CPP) of 17.7. This highlights its prominent role as a primary outlet for impactful research in this domain. The Journal of Cosmetic Dermatology follows with 26 papers (15.2%) and 227 total citations, yielding a CPP of 8.7. This suggests a significant focus on exosomes in dermatological aesthetics. The journal with high CPP is Experimental

Table 2. Scientific journals in which the most frequently published works on TS=*exosomes** in TS=*dermatology** classified according to Web of Science Categories (n=171)

Name of the scientific journal	Number of papers (% of 171)	Total citation	Citation per paper (CPP)
Journal of Investigative Dermatology	51 (29,8%)	902	17,7
Journal of Cosmetic Dermatology	26 (15,2%)	227	8,7
Experimental Dermatology	18 (10,5%)	380	21,1
Clinical Cosmetic and Investigational Dermatology	10 (5,8%)	94	9,4
Journal of Dermatological Science	9 (5,3%)	328	36,4
British Journal of Dermatology	5 (2,9%)	59	11,8

Dermatology stands out with a CPP of 21.1; the second-highest among the listed journals, derived from 18 papers (10.5%) and 380 citations. This reflects its substantial influence despite publishing fewer papers compared to the leading journals. The Journal of Dermatological Science has the highest CPP at 36.4; derived from 9 papers (5.3%) and 328 citations, highlighting the high impact and relevance of its publications. Other Notable Journals are Clinical Cosmetic and Investigational Dermatology contributed 10 papers (5.8%) with 94 citations, resulting in a moderate CPP of 9.4; and The British Journal of Dermatology published 5 papers (2.9%), garnering 59 citations and a CPP of 11.8; reflecting its selective yet impactful contributions.

An overview of the publications is presented in Table 3, summarising studies that match the query TS=*exosomes** and TS=*dermatology**, classified according to their Web of Science Categories. The dataset comprises 171 publications, with each category listed alongside the corresponding number of publications and their

Table 3. Selected publication from TS=*exosomes** in TS=*dermatology** classified according to Web of Science Categories (n=171)

Field: Web of Science Categories	Record count	% of total (n=171)
Dermatology	142	83,04
Biochemistry Molecular Biology	6	3,51
Cell Biology	6	3,51
Surgery	5	2,92
Chemistry Multidisciplinary	4	2,34
Developmental Biology	3	1,75
Engineering Biomedical	3	1,75
Pharmacology Pharmacy	3	1,75
Biology	2	1,17
Biotechnology Applied Microbiology	2	1,17
Materials Science Biomaterials	2	1,17
Medicine General Internal	2	1,17
Anatomy Morphology	1	0,59
Biochemical Research Methods	1	0,59
Cell Tissue Engineering	1	0,59
Dentistry Oral Surgery Medicine	1	0,59
Food Science Technology	1	0,59
Medicine Research Experimental	1	0,59
Microbiology	1	0,59
Multidisciplinary Sciences	1	0,59
Public Environmental Occupational Health	1	0,59
Veterinary Sciences	1	0,59

exploring the biological roles and pathways mediated by exosomes. Next is applications and therapeutic use with following keywords like application, therapy, regeneration, and wound repair form a cluster focused on the translational and therapeutic potential of exosomes in dermatology. And the last is cellular components with stem cells, melanocyte, and vitro reflect research on specific cell types and their interactions with exosomes. The node color stands for citations per paper (CPP). The color gradient of the nodes indicates the average citations per paper (CPP) associated with each term, with a color legend in the bottom-right corner of the map. Yellow nodes (e.g., melanocyte and melanogenesis) signify high-impact terms, while blue nodes represent less-cited terms. The node size represents the frequency. Larger nodes, such as exosome, skin, and patient, signify higher frequencies of occurrence in the dataset, indicating their central role in the field. Smaller nodes like flow cytometry and inhibitor represent more specialized or niche areas. Interconnections describe the co-occurrence strength. The proximity between nodes and the density of connecting lines reflect the strength of co-occurrence between terms. For instance, the mechanism is closely connected to effect and proliferation, suggesting frequent co-mention in studies. This survey as well as abstract and titles shows emerging topics concerning exosomes in dermatology (Fig. 4, Tab. 4). Terms like melanocyte, melanogenesis, vitro, and RNA highlight rising topics in dermatology research involving exosomes. Their connections to both molecular mechanisms and therapeutic applications suggest growing interest. According to the analysed title and abstract we can indicate an application in dermatology by recurring terms like therapy, regeneration, and wound repair emphasize the focus on regenerative medicine and dermatological conditions, demonstrating the translational relevance of exosome research in improving skin health. Moreover, the term map (Fig. 3) reveals the interdisciplinary nature of exosome research, bridging fields such as cell biology, molecular biology, dermatology, and regenerative medicine.

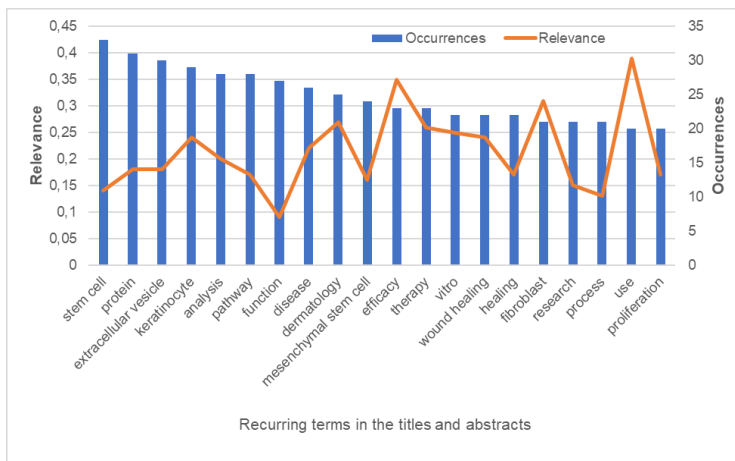


Fig. 4. Frequency and relevance of recurring 20 top terms in titles and abstracts of exosomes in dermatology publications.

Visualisation of keyword co-occurrence relationships within the domain of exosomes in dermatology (Fig. 5) is based on 171 papers. The size of each node corresponds to the frequency of keyword occurrences, with larger nodes indicating more frequently mentioned terms in the analyzed dataset. The term exosomes is central, reflecting its dominant role in the context of dermatological research. Keywords such as: mesenchymal stem cells, skin, proliferation, and angiogenesis appear prominently due to their relevance and strong connections to exosomes. The proximity between nodes reflects the strength of association or co-occurrence between keywords, as measured by the total link strength. For instance, mesenchymal stem cells are closely connected to wound healing, highlighting the interplay between these terms in regenerative dermatology. The relevance of nodes reflects their role in connecting different clusters and themes. Nodes like exosomes, mesenchymal stem cells, and wound healing are central due to their high connectivity and frequency, signifying their importance across multiple areas of dermatological research. Smaller nodes such as microRNAs and oxidative stress provide molecular-level insights, while clinical terms like therapy and efficacy bridge research to real-world applications. Together, they demonstrate the multifaceted impact of exosomes in dermatology. The color of each node represents the density of connections and reflects variations in the total link strength across the dataset. Warmer colors (yellow) signify terms with higher connectivity, while cooler colors (e.g., blue) indicate less connected terms. Keywords like expression, therapy, and apoptosis exhibit intermediate relevance, connecting various clusters of terms. Clusters of keywords demonstrate thematic groupings, such as those related to cellular biology (e.g., stem-cells, fibroblasts) or disease mechanisms (e.g., oxidative stress, vitiligo). Terms like microRNAs and extracellular vesicles underscore the molecular focus in exosome-related dermatological research. This figure provides an overview of the networked relationships between key terms, enabling researchers to identify critical concepts, thematic areas, and emerging trends in the field of exosome research in dermatology.

The top 20 most recurring keywords derived from bibliographic data related to exosomes in dermatology extracted from the Web of Science (WoS) databases are compiled in Table 5. The keywords are ranked based on their occurrence frequency and total link strength, reflecting their relevance and interconnectedness within the research field. The occurrences indicate how frequently each keyword appears in the dataset. The keyword exosomes has the highest frequency (63 occurrences), signifying its central role in the field. Total link strength measures the strength of co-occurrence relationships between each keyword and others (Fig. 6). Here exosomes have the highest total link strength (359), showing its strong association with other terms in the dataset. Furthermore, central keywords which are exosomes, extracellular vesicles, and proliferation have both high occurrences and total link strengths, emphasizing their pivotal role in dermatological research involving exosomes. The terms like: angiogenesis, wound healing, and therapy highlight the applications of exosomes in regenerative and therapeutic contexts. Molecular processes such as expression,

Table 5. Based on bibliographic data obtained from WoS for exosomes in dermatology the following top 20 most recurring keywords were presented and their occurrence along with total link strength between keywords

No.	Keyword	Occurrences	Total link strength
1	exosomes	63	359
2	extracellular vesicles	27	180
3	exosome	25	114
4	expression	19	96
5	proliferation	18	134
6	angiogenesis	18	120
7	skin	17	114
8	therapy	14	91
9	mesenchymal stem-cells	12	74
10	wound healing	12	65
11	cells	12	56
12	microvesicles	11	84
13	fibroblasts	10	78
14	stem-cells	10	73
15	inflammation	9	74
16	dermatology	9	67
17	micromas	8	57
18	growth	8	52
19	activation	8	51
20	apoptosis	8	49

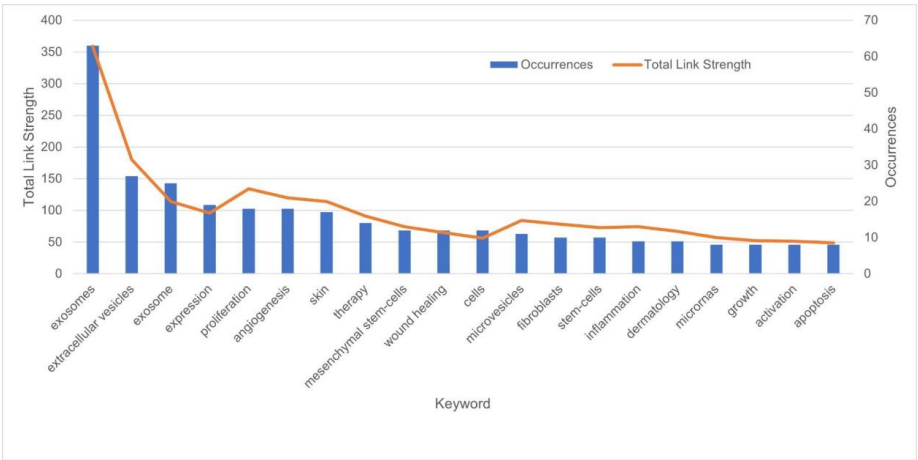


Fig. 6. Visualisation of top 20 keywords occurrence extracted from term rom TS=exosomes* in TS=dermatology* according to the total link strength between them.

inflammation, and apoptosis underscore the mechanistic aspects studied in exosome-related dermatology. The structural and functional terms like skin and dermatology reflect the broader biological and clinical context of the research. Microvesicles and

fibroblasts highlight cellular components closely associated with exosome studies. Keywords such as micornas=microRNAs and growth indicate growing interest in the molecular and cellular pathways influenced by exosomes.

This analysis provides a detailed overview of the recurring themes and focus areas within the domain of exosomes in dermatology. The strong linkages between keywords (Fig. 6) emphasize the interdisciplinary nature of this research field, connecting molecular mechanisms, therapeutic applications, and clinical relevance.

Discussion

Analysed literature

Our study reveals the extensive body of literature on exosomes in dermatology. Over the past decade, there has been a noted rapid expansion and significant impact of research on exosomes in dermatology [Kose *et al.* 2022, Szwedowicz *et al.* 2022]. This trend reflects the field's evolution, with a growing body of literature driving further advancements and generating widespread interest within the scientific and medical communities [Hartman *et al.* 2022, McGraw *et al.* 2024].

This indicates increasing recognition and impact of the research in the scientific community over time. The simultaneous rise in publications and citations suggests that exosomes in dermatology have become a focal point in recent biomedical research, reflecting both the field's maturity and relevance. The sharp increase in citations post-2018 highlights not only the volume of research but also the quality and influence of the work being produced [Wang *et al.* 2019, Olumesi and Goldberg 2023].

The comprehensive overview of exosomes research, highlighting the most prominent authors, their affiliations, countries of origin, as well as the journals and categories relevant to this research. These findings facilitate a discussion on the principal contributors, geographical patterns, and the influence of academic output within this domain.

Leading contributors like China and the United States demonstrate their strong positions in exosome research, likely driven by advancements in technology, funding availability, and collaboration networks. It highlights regional strengths, underscores disparities in research activity, and identifies opportunities for increased collaboration and engagement in underrepresented regions [Jiang *et al.* 2019, Wang *et al.* 2022]. The data reinforces the international nature of the field while pointing to significant imbalances in publication output [Guo *et al.* 2019, Rudnicka and Olszewska 2022]. Research activity is concentrated in Asia (e.g., China, South Korea, Japan) and North America (United States), with substantial contributions from Europe (e.g., Germany, France, the UK) and select countries in Oceania (e.g., Australia). Limited research activity is observed in South America, Africa, and parts of the Middle East, suggesting untapped opportunities for research expansion [Ellistasari *et al.* 2022].

Taking into account the prevalence of the exosome subject in the reviewed scientific journals, *The Journal of Investigative Dermatology* dominates in terms of the

number of publications and total citations, suggesting its central role in disseminating dermatological research involving exosomes [Fang *et al.* 2022, Larregina *et al.* 2024]. Journals with higher CPP, such as *The Journal of Dermatological Science and Experimental Dermatology*, indicate a focus on publishing highly impactful studies, despite fewer total publications [Yang *et al.* 2024, Liu *et al.* 2024]. The diversity of journals contributes to the field of exosomes in dermatology, with a few key journals dominating in terms of publication volume and citation impact. The data underscores the interdisciplinary nature of this research area, spanning topics from investigative studies to cosmetic and clinical dermatology [McBride *et al.* 2017, Xiong *et al.* 2021]. Journals with high CPP values reflect their ability to attract high-quality, impactful studies, shaping the direction of research in this field.

The recurring terms in the titles and abstracts of the exosomes papers

The graphical visualisation of recurrent terminology is based on the titles and abstracts of publications focusing on exosomes in dermatology. This analysis provides a comprehensive overview of recurring terms and their interconnections within exosome-related dermatological research. The identified terms can be categorized into several key groups: (a) cell types – including stem cells, mesenchymal stem cells, keratinocytes, and fibroblasts, which are crucial for understanding exosome interactions in dermatology [Liu *et al.* 2019, Jiang *et al.* 2024]; (b) biomolecules and structures – encompassing proteins and extracellular vesicles, which play fundamental roles in exosome functionality [Mangino *et al.* 2019, Flemming *et al.* 2020]; (c) processes and functions – covering essential concepts such as wound healing, cellular proliferation, signaling pathways, and various biological activities associated with exosomes [Ma *et al.* 2022, García-Silva *et al.* 2023]. This systematic categorisation enhances clarity and effectively aligns terms with their respective areas of relevance. It elucidates central themes, highlights emerging research directions, and underscores the interconnectedness of biological processes, therapeutic applications, and clinical studies. Moreover, these findings provide valuable insights that could guide future research by identifying both influential and underexplored key terms and concepts in the field. By identifying these pivotal areas, researchers can strategically direct their efforts toward deepening the understanding of exosomes in dermatology, thereby facilitating the discovery of novel therapeutic applications and innovative diagnostic tools for clinical implementation [Bai *et al.* 2024, Lee *et al.* 2024].

The recurring author keywords of the exosomes papers

This analysis reveals a network of interconnected clusters, each representing the multifaceted roles of exosomes in dermatology. These clusters provide a structured framework for understanding the diverse aspects of exosome research, with each highlighting a distinct thematic area. The topics span from intricate cellular mechanisms and disease associations to therapeutic applications and critical immunological functions [Flemming *et al.* 2024]. By examining recurring keywords, this study offers

a comprehensive perspective on the core concepts, dominant themes, and emerging trends in exosome research within dermatology. The strong interconnections among these terms underscore the dynamic and rapidly evolving nature of the field, which is poised to unveil novel insights into the fundamental roles of exosomes in skin health and dermatological disease management [Papadopoulos *et al.* 2024].

Furthermore, the findings emphasise the imperative for continued research. To fully harness the clinical and therapeutic potential of exosomes, further investigations are required to elucidate their mechanisms of action and drive the development of innovative treatment strategies [Theodorakopoulou *et al.* 2024, Tang *et al.* 2024]. Such advancements hold the potential to transform dermatological practice, opening new avenues for treatment and intervention that could significantly improve patient outcomes. As the field progresses, fostering interdisciplinary collaboration and embracing cutting-edge methodologies will be crucial in advancing both the understanding and application of exosomes in dermatology [Shi *et al.* 2022, De *et al.* 2024].

Major research domains of exosomes in dermatology

Exosomes, nanoscale extracellular vesicles secreted by a wide range of cell types, have garnered significant attention in dermatology for their pivotal roles in maintaining skin health and managing dermatological diseases [Pinto *et al.* 2025]. These vesicles mediate the intercellular transfer of bioactive molecules – including proteins, lipids, RNA, and DNA – which is fundamental to preserving skin homeostasis and functional integrity. Exosomes also play a crucial role in modulating immune responses and sustaining cutaneous immune balance, particularly within the context of inflammatory skin disorders. Recent studies have illuminated the diverse functional roles of exosomes and their promising therapeutic potential across multiple dermatological domains [Schur *et al.* 2025].

Skin regeneration and wound healing

Exosomes, particularly those derived from stem cells, have shown significant potential in promoting wound healing by enhancing angiogenesis, stimulating cell proliferation, and modulating inflammatory responses. Exosomes isolated from human umbilical vein endothelial cells (HUVECs) have been reported to facilitate the proliferation and migration of keratinocytes and fibroblasts, both of which are critical for skin regeneration [Zhao *et al.* 2020]. Similarly, exosomes derived from umbilical cord mesenchymal stem cells (UC-MSC-Exo) promote the growth and migration of dermal fibroblasts, processes essential for effective wound repair [Zhu *et al.* 2022]. These exosomes not only support dermal fibroblast proliferation and migration but also contribute to nerve regeneration, an important component of functional tissue recovery [Zhao *et al.* 2020]. Furthermore, exosomes have been implicated in promoting collagen synthesis and extracellular matrix (ECM) remodeling by enhancing collagen maturation and facilitating ECM reconstruction – key factors in restoring the structural integrity and mechanical strength of healed tissue [Sun *et*

al. 2024]. Their regenerative potential has also garnered interest in the field of skin rejuvenation and anti-aging therapies. Exosomes have demonstrated effectiveness in repairing and regenerating damaged skin, accelerating the healing of complex wounds, and improving the outcomes of skin grafts. Notably, exosomes contribute to improved skin quality by promoting ECM remodeling and enhancing cellular migration. For instance, exosomes derived from umbilical cord mesenchymal stem cells (UCMSCs) have been shown to stimulate dermal fibroblast activity, resulting in increased collagen production and reduced expression of matrix metalloproteinases – enzymes associated with skin aging. By augmenting fibroblast function, exosomes facilitate the synthesis of collagen and elastin, two major components of the skin ECM, thereby improving skin elasticity and reducing the appearance of wrinkles [Oh *et al.* 2018, Wu *et al.* 2020].

Treatment of exomes in chronic dermatological diseases

Exosomes contribute to the pathogenesis and management of chronic inflammatory skin diseases, including psoriasis, atopic dermatitis, and systemic lupus erythematosus, by modulating immune responses, influencing disease-related cellular processes and demonstrating anti-inflammatory effects [Wang *et al.* 2019, Born and Khachemoun 2022, Montero-Vilchez *et al.* 2022, Thakur *et al.* 2023, Dukharan *et al.* 2025]. Moreover, exosomes have potential applications in treating systemic lupus erythematosus, systemic sclerosis, and vitiligo due to their ability to regulate gene expression and induce cell differentiation [Ghorbani *et al.* 2024, Dukharan *et al.* 2025]. Furthermore, exosomes may also be involved in pigment regulation, potentially providing novel therapeutic options for conditions such as vitiligo. Exosomes can influence melanogenesis, the process of melanin production in melanocytes. They carry microRNAs (miRNAs) and other molecules that can regulate the expression of melanogenesis-related genes and proteins such as tyrosinase (TYR), tyrosinase-related protein 1 (TYRP1), and microphthalmia-associated transcription factor (MITF) [Wong *et al.* 2020, Zao *et al.* 2020, Thakur *et al.* 2022].

Hair regeneration

Research suggests that exosomes may play a role in hair regeneration. Exosomes promote hair growth by enhancing intercellular communication by transferring bioactive molecules such as proteins, mRNA, and microRNA to target cells. This transfer can modulate various cellular functions and responses [Liu *et al.* 2019, Cheng *et al.* 2024]. Exosomes derived from dermal papilla cells (DPC-Exos) and other sources like mesenchymal stem cells (MSCs) have been shown to activate DPCs, which are crucial for hair follicle development and cycling [Kost *et al.* 2022]. Activation of DPCs promotes the transition of hair follicles from the telogen (resting) phase to the anagen (growth) phase, thereby stimulating hair growth [Kim *et al.* 2022]. Exosomes can also stimulate hair follicle stem cells (HFSCs), promoting their proliferation and differentiation. This is considered as essential for initiating and maintaining the hair

growth cycle. Exosomes have been found to promote angiogenesis, the formation of new blood vessels, which is vital for providing the necessary nutrients and oxygen to hair follicles, thereby supporting hair growth. These mechanisms collectively contribute to the stimulation and maintenance of the hair growth cycle [Queen and Avram 2024].

Aesthetic medicine and cosmetic applications

Exosomes are increasingly being investigated in cosmetic dermatology for their potential to enhance skin texture, reduce the appearance of wrinkles, and improve skin hydration and elasticity. A key mechanism underlying these effects is the ability of exosomes to stimulate collagen synthesis, which is essential for maintaining dermal structure and minimizing wrinkle formation. These effects are mediated through molecular signaling pathways such as PI3K/Akt and Notch [Nguyen 2024]. Additionally, exosomes exert anti-aging effects by inhibiting matrix metalloproteinases (MMPs), enzymes responsible for the degradation of collagen and elastin, thereby preserving skin firmness and preventing wrinkle development [Haykal *et al.* 2025]. They also modulate inflammatory processes associated with skin aging by delivering bioactive molecules that suppress inflammation and promote tissue repair [Cobb 2016; Thakur *et al.* 2023].

In clinical and aesthetic applications, exosomes have been used to improve skin texture, hydration, and elasticity – factors that collectively contribute to wrinkle reduction [Vyas *et al.* 2023]. Moreover, they help mitigate inflammation and cellular damage induced by ultraviolet (UV) radiation. For instance, exosomes derived from human foreskin fibroblasts have demonstrated protective effects against UVB-induced photoaging by reducing oxidative stress, enhancing DNA repair, and attenuating wrinkle formation [Park *et al.* 2023]. Topically applied platelet-derived exosome products have also shown significant improvements in skin health, including a reduction in fine lines and wrinkles. These formulations have been reported to be both safe and well-tolerated by users [Proffer *et al.* 2022, Weir *et al.* 2025]. Owing to their ability to regulate intercellular communication and stimulate extracellular matrix production, exosomes are emerging as promising candidates for advanced anti-aging skincare therapies. By delivering bioactive compounds directly to the skin, they promote regeneration and visibly reduce signs of aging, including wrinkles and skin laxity [Rodriguez *et al.* 2024, Wyles *et al.* 2024].

Diagnostic and therapeutic potential

Exosomes have emerged as promising diagnostic and prognostic biomarkers for a variety of skin diseases due to their ability to carry disease-specific molecular signatures. Secreted by diverse cell types, exosomes encapsulate proteins, lipids, and nucleic acids reflective of their cellular origin, making them valuable tools for disease detection and monitoring. Their potential in skin cancer diagnostics has been explored in the context of Merkel cell carcinoma (MCC) and malignant melanoma

(MM). Exosomes derived from MCC cells have been found to contain proteins associated with cellular motility, metastasis, and tumor progression, indicating their utility as biomarkers for both diagnosis and prognosis [Konstantinell *et al.* 2016]. Moreover, exosomes isolated from melanoma cancer stem cells (CSCs) and patient serum exhibit distinct metabolomic profiles, highlighting their potential in early diagnosis and disease surveillance [Palacios-Ferre *et al.* 2021]. Additionally, exosomal melanotransferrin has been identified as a plasma-detectable biomarker for melanoma, further supporting the clinical relevance of exosome-based diagnostics [Bonhoure *et al.* 2021].

Beyond their diagnostic utility, exosomes are being actively investigated as innovative drug delivery vehicles in dermatology, owing to their natural origin and ability to transfer functional biomolecules. They offer a targeted and efficient means of delivering therapeutic agents directly to skin cells, thereby enhancing treatment efficacy while minimizing off-target effects and adverse reactions. Exosomes exhibit high deformability and excellent permeability, properties that improve transdermal penetration and dermal retention of drugs, thereby increasing local bioavailability and patient compliance [Wang *et al.* 2023]. Their intrinsic biocompatibility and low immunogenicity further underscore their suitability for therapeutic applications, as they do not elicit significant immune responses [Dimik *et al.* 2023, Desai *et al.* 2024].

Furthermore, exosomes can be bioengineered to carry specific therapeutic cargos – including small molecules, nucleic acids, and proteins – enabling precise delivery to target tissues and optimizing clinical outcomes [Lv *et al.* 2015]. Their structural stability under physiological conditions and high compatibility with biological systems make them ideal candidates for advanced drug delivery strategies [Saka *et al.* 2025].

In conclusion, exosomes represent a versatile and powerful platform in dermatology, with wide-ranging applications in skin regeneration, treatment of dermatologic disorders, cosmetic enhancement, hair restoration, and both diagnostics and therapeutics. Nevertheless, continued research and clinical validation are essential to address current challenges and fully realize the therapeutic potential of exosome-based technologies in routine clinical practice [Yoshioka and Ochiya 2020].

Challenges and future directions

One of the major challenges is the scalable production of exosomes with consistent quality and biological activity. Standardisation of methods for the isolation and characterisation of exosomes is fundamental for their clinical implementation [Matsuzaka and Yashiro 2022, Wu *et al.* 2023]. The scalable production of exosomes with consistent quality and biological activity is a significant challenge. Exosomes are inherently heterogeneous, which complicates their isolation and characterization. Strategies to minimize this heterogeneity are crucial for obtaining more homogenous vesicle populations [Doyle and Wang 2019]. Exosomes are unstable and require preservation at ultralow temperatures. Standardisation is fundamental for the clinical implementation of exosomes [Greening *et al.* 2015]. By addressing these

challenges and standardising methods, the scalable production of exosomes with consistent quality and biological activity can be achieved, paving the way for their clinical applications. Despite promising preclinical results, the clinical application of exosomes faces challenges such as standardisation of isolation techniques, scalability, and regulatory approval. There is a need for standardised protocols for exosome isolation, characterisation, and delivery methods to ensure consistent and effective therapeutic outcomes [Fais *et al.* 2016].

Plant-derived exosomes, especially those originating from Damask roses (*Rosa × damascena* Herrm.) offer an exceptionally fascinating and promising therapeutic alternative. Damask roses is a botanically and economically significant hybrid with therapeutic, cosmetic, and culinary applications [Boskabady *et al.* 2011, Ahmed *et al.* 2019]. Its rich phytochemical profile, combined with aromatic and medicinal benefits, makes it an essential plant in diverse medical usage from centuries [Trendafilova *et al.* 2023, Charoimek *et al.* 2024]. Scientific research and biotechnological improvements are essential for maximizing its potential in modern medicine and sustainable agriculture like the rose stem cell exosome (Rose exosome patent by ExoCoBio Inc., Seoul, (KR) US20210121393A1). Besides the exosomes derived from Damask rose (*Rosa × damascena* Herrm.), which find prominent applications in dermatology and aesthetic medicine, the potential utilization of various plant-derived exosomes appears to be highly promising in numerous medical disciplines, as demonstrated by the subsequent examples. Exosomes derived from grapes (*Vitis vinifera* L.) possess the capacity to transport small RNA molecules and polyphenols, which have been investigated for their anti-inflammatory and antioxidant properties. These beneficial effects may prove advantageous in the management of chronic diseases [Barzin *et al.* 2023]. Green tea (*Camellia sinensis* (L.) Kuntze) has been recognized for its ability to deliver therapeutic compounds, such as catechins, which are implicated in cancer prevention and skin treatment [Hyun *et al.* 2025]. Wheat (*Triticum aestivum* L.) exhibits the potential to enhance the delivery of RNA and proteins, thereby serving as vehicles for transgene delivery in gene therapy applications. Exosomes from olive (*Olea europaea* L.) have garnered attention as carriers for drug delivery, showcasing their pharmacological properties and skin UV protection [Wang *et al.* 2024]. Further, exosomes derived from potato (*Solanum tuberosum* L.), pomegranate (*Punica granatum* L.), lettuce (*Lactuca sativa* L.), and alfalfa (*Medicago sativa* L.) may play significant roles in targeted cancer therapy and the delivery of phytochemicals with therapeutic effects like prevent collagen degradation in UVB-irradiated cells, indicating potential for skin protection and repair [Lee *et al.* 2023]. Moreover, exosomes from white mulberry (*Morus alba* L.) have been associated with anti-inflammatory applications, while those from ginger (*Zingiber officinale* Roscoe) are being explored for delivering therapeutic agents in cancer treatment [Barzin *et al.* 2023]. Exosomes derived from turmeric (*Curcuma longa* L.) are also being investigated for their applications in targeted cancer therapies [Taverna *et al.* 2016]. Additionally, basil (*Ocimum basilicum* L.) has potential

therapeutic applications in the management of chronic diseases, and exosomes from cabbage (*Brassica oleracea* L.) may serve as vehicles for anticancer agents [You *et al.* 2021]. Exosomes from chrysanthemum (*Chrysanthemum × morifolium* (Ramat.) Hemsl.) are being examined for their role in treating lung diseases, while those from papaya (*Carica papaya* L.) demonstrate promising anti-inflammatory properties. Lastly, bael fruit (*Aegle marmelos* (L.) Corrêa) is considered for its potential in therapeutic delivery systems [Zhao *et al.* 2024].

These exosomes not only draw on the rich traditions of phytotherapy and medicine but also align with contemporary trends in seeking environmentally friendly alternatives that are suitable for individuals desiring to avoid animal-derived ingredients [Harding *et al.* 2013, Chen *et al.* 2022]. While both plant-derived exosomes and animal-derived exosomes share fundamental similarities in their function, they differ significantly in their biogenesis, composition, applications, and potential benefits. Thus plant-derived exosomes seem to provide an excellent substitute for the controversial use of exosomes sourced from human or animal tissues. Plant-derived exosomes appear to be an alternative to animal-derived exosomes, as the utilisation of plant sources does not pose ethical or environmental concerns [Qiaoli *et al.* 2023]. Their production aligns with sustainable development principles, being eco-friendly and renewable, as they are derived from plants and food waste. Additionally, they are vegan and cruelty-free, making them suitable for plant-based medicine and cosmetic applications. Moreover, plant-based exosomes face fewer regulatory constraints, as plant-derived products have a well-established history of safe use [Alzahrani *et al.* 2023]. Nevertheless, the availability of high-quality scientific research evaluating their efficacy remains limited, suggesting the need for further exploration. An intriguing and yet to be fully explored topic is the interplay between laser therapy and its potential influence on the transdermal penetration of exosomes. Furthermore, there is significant interest in whether laser therapy can reduce recovery times and amplify the long-term therapeutic effects when exosomes are administered post-procedure [Lovisololo *et al.* 2022]. Exosomes have shown significant potential in improving outcomes after laser therapy by enhancing wound healing, reducing inflammation, and promoting tissue regeneration. Further research and clinical trials are needed to fully understand their mechanisms and optimize their use in various medical fields [Kwon *et al.* 2020].

Conclusions

This study underscores the rapidly expanding and interdisciplinary landscape of exosome research in dermatology, marked by a sharp increase in publications and citations in recent years. Exosomes have emerged as versatile entities involved in skin regeneration, immune modulation, and disease diagnosis, reflecting their growing clinical and therapeutic relevance. The prominence of key contributors such as China and the United States, alongside rising outputs from European Institutions, highlights global engagement while revealing opportunities for broader international

collaboration. Exosomes play a pivotal role in wound healing, particularly by promoting angiogenesis, fibroblast activation, and extracellular matrix remodeling. In chronic inflammatory and autoimmune skin disorders, exosomes modulate immune responses and influence disease-specific cellular pathways, offering potential avenues for novel therapies. Their applications extend to aesthetic dermatology, where they improve skin elasticity, reduce wrinkles, and counteract photoaging through mechanisms involving PI3K/Akt and Notch signaling pathways. The diagnostic and prognostic potential of exosomes is evidenced by their disease-specific molecular signatures, notably in skin cancers such as melanoma and Merkel cell carcinoma. Furthermore, their biocompatibility, low immunogenicity, and ability to be engineered as targeted drug delivery vehicles underscore their therapeutic promise. Plant-derived exosomes, exemplified by those from Damask rose and other botanicals, present a sustainable and ethically favorable alternative for dermatological and cosmetic applications. Despite this promise, challenges remain regarding the standardisation, scalability, and regulatory approval necessary for clinical translation. Future research should also explore synergistic modalities, such as the integration of laser therapy to enhance exosome delivery and efficacy. Overall, exosomes represent a transformative platform in dermatology, offering innovative solutions across regenerative, diagnostic, therapeutic, and cosmetic domains.

Conflict of interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used ChatGPT to assist with grammar and language review. Afterward, the authors carefully revised and edited the content as needed, assuming full responsibility for the final publication.

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Supplementary materials

Suppl. 1 - contain a total of 171 publication in bibliographic file format .txt:

1. Lu, Lu and Bai, Wei and Wang, Miao and Han, Chunle and Du, Huanqing and Wang, Na and Gao, Mengya and Li, Dan and Dong, Fengwei and Ge, Xiaohu. Novel roles of bovine milk-derived exosomes in skin antiaging. *JOURNAL OF COSMETIC DERMATOLOGY*. 2024; 23 (4) :1374-1385. DOI: 10.1111/jocd.16112.
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