Acta Biomed 2023; Vol. 94, Supplement 3: e2023149 DOI: 10.23750/abm.v94iS3.14507

Original article

An overview of the studies on microbial air contamination in operating theatres and related issues over time: a useful tool for a multidisciplinary approach

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Abstract. *Background and aim:* Surgical site infection (SSI) is a major complication following surgery associated with increased morbidity and mortality, as well as increased health and not health costs. A variety of factors affect airborne contamination in operating theatres (OT). Following the Medical Research Council study showing a correlation between microbial air contamination and SSI incidence in prosthetic joint surgery ultraclean OTs have been recommended for this type of surgery, while OTs supplied by turbulent airflow plants are recommended for other types of surgery. The aim of this study was to illustrate the studies on this topic. *Methods:* Scopus was considered for articles published until January 2023 on OTs and air contamination in article title or abstract or keywords. Many issues were deepened: "microbial", "bacterial", "fungi", "viruses", "surgical site/wound infection", "monitoring/sampling", "air changes", "behaviour", "door openings", "particles", turbulent flow", "unidirectional flow". *Result:* Total papers published were 907 and 249 papers faced monitoring/sampling. A total of 313 papers investigated airborne bacterial contamination and 63 papers investigated fungal air contamination. There were 218 papers that have evaluated particle contamination in OTs. Many other issues were deepened. *Conclusions:* This study shows a picture of the studies on biological air contamination in OTs and related issues over time. We think that the results of our study will provide a useful tool to increase awareness towards a better sharing of aims, approaches, and results, above all in the interest of the patients, but also of the health services of the different countries. (www.actabiomedica.it)

Key words: Microbial air contamination, operating theatres, air sampling, ventilation, behaviour, airflow

Introduction

Worldwide, 313 million surgical procedures are performed each year (1). Surgical site infection (SSI) is a major complication following surgery and is associated with increased morbidity and mortality, as well as increased health and not health costs (2-4). Microbial contamination of the surgical site is a necessary precursor of SSIs and the air in operating theatres (OTs) represents an important vehicle for SSI-related microorganisms which can fall directly into the wound or land on exposed surfaces and subsequently be transferred into the wound (5-17).

Understanding factors that lead to compromised air quality in OTs and improving surgical safety is an ongoing challenge of high importance. A variety of risk factors affect the contamination level of the air in OT including types of medical procedures performed, occupancy levels, foot traffic, clothing, behaviour, and restoration in close environments (18-21).

Building design considerations also play a role including placing the OT in areas that are progressively

less contaminated. Additionally, OTs are typically under positive pressure as a preventive measure to inhibit the entrance of contaminants from less clean areas to cleaner areas. Airflow patterns in OT setting can be thwarted by door openings (22).

Following the Medical Research Council study showing a correlation between microbial air contamination and SSI incidence in prosthetic joint surgery ultraclean OTs have been recommended for this type of surgery, while OTs supplied by turbulent airflow plants are recommended for other types of surgery (23).

High-volume unidirectional air flow (UDAF) systems complying with DIN 1946-4:2016 standards (24) for the airflow rate and ceiling diffuser size unconditionally achieve ultra-clean air close to the wound site. Different studies show that high-volume UDAF systems perform as ultra-clean air systems and are superior to turbulent systems in reducing airborne bacteria levels close to the wound site (25-30). However, the protective role of UDAFs in reducing the rate of SSI is debated and World Health Organization (WHO) panel suggests, as conditional recommendation, that unidirectional ventilation systems should not be used to reduce the risk of SSI for patients undergoing total arthroplasty surgery (11). Most studies highlight air quality of the whole space in OTs, and only a few studies focused on the zone close to the wound. A recent study highlights the importance of specific risk zone close to the surgical wound bounded by the surgeons, the patient, and the surgical lights as the operating microenvironment (31).

Guidelines for the design and ventilation of OTs have been published, and threshold values have been proposed for both ultraclean and turbulent OTs (32-44). Preventive controls have been designed and are being improved upon to help OTs maintain clean air including filtered air changes, germicidal lamps, portable units containing HEPA, carbon filters (45-49). In addition, the monitoring of air quality in OTs is a useful tool to manage heating, ventilation air conditioning plants (HVAC) and to verify effectiveness of cleaning procedures and surgical team behaviours (50-54).

However, there is no international consensus on tolerable limits of microbial air contamination, and there are no generally accepted methods and frequencies for air sampling. Moreover, the usefulness of microbiological air monitoring methods is controversial (55-66).

The aim of this study was to illustrate the studies of interest over time on air contamination in OTs and its facets providing a picture of the spread of this topic among the scientists.

Methods

Based on our recent study (67), we searched Scopus for articles published until January 9, 2023, using the string [TITLE-ABS-KEY (operating AND theatres OR rooms AND air AND contamination)].

Precisely due to the nature of the topic and related issues of our study not exclusively reserved for the medical environment, only Scopus was considered as it covers a wider range of journals, aiding in both keyword research and citation analysis (68). Articles written in all languages were included. Many issues involving OT and air contamination were deepened crosschecking with i.e., "microbial", "bacterial", "fungi", "viruses", "surgical site/wound infection", "monitoring/sampling", "air changes", "behaviour", "door openings", "particles", turbulent flow", "unidirectional flow".

According to the case, the following variables were considered: years and related number of articles, sources of publications, subject areas, type of document published, type of journal, nationalities of the authors, institutions to which the authors belonged.

Results

The papers published were 907, the first in 1945, occasionally until 1962. A first increase of papers during the '70s and a new great increase during the last three years was observed. The last increase could be due to the COVID-19 pandemic that has contributed even more in highlighting this issue (Figure 1).

The top five countries of scientists that published papers on this topic in the order were United States, United Kingdom, Italy, Germany, Sweden, and France. The other countries were more detached (Figure 2). From pale brown to deep brown countries, the figure shows the countries with at least one author who have

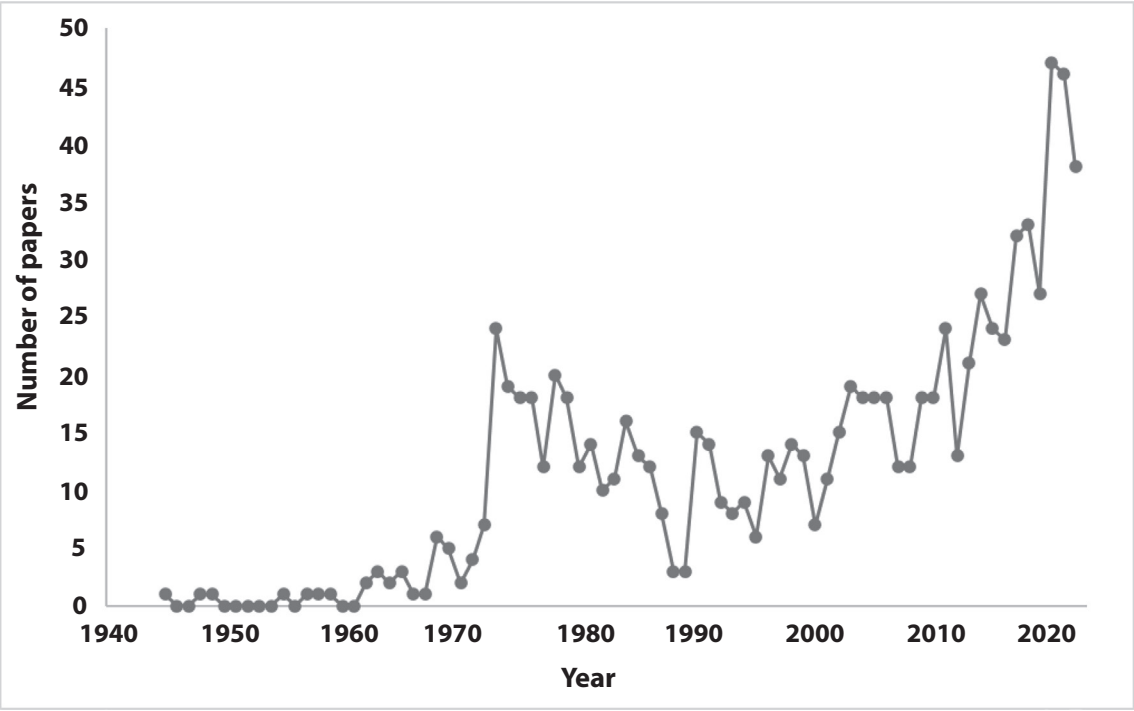

Figure 1. Number of papers published over time about operating theatres air contamination.

published at least one article on microbial air contamination in operating theatres.

Figure 3 shows the authors more involved in microbial air contamination in operating theatres studies.

Figures 4, 5 and 6 show the number of papers for each institution, the journals where papers were published and the subject areas, respectively.

Out of 907 papers published corresponding to the characteristics searched, 759 were original articles, 69 conference papers and 41 reviews (Figure 7).

A total of 249 papers faced monitoring or sampling from 1962, with only one paper until 1972 (Figure 8). The first five countries of the authors per number of papers were United States, Italy, Sweden, United Kingdom, and Germany (Figure 9). Among the 28 authors with at least 3 papers, 23 were Italians (Figure 10).

A total of 313 papers investigated air bacterial contamination; the trend of papers by year (data not shown) overlaps the trend of the Figure 2. A total of 63papers investigated air fungal contamination (Figure 11), with the first study published in 1968; only since 2001 this issue has been addressed regularly every year.

There were 218 papers that evaluated particle contamination in OTs from 1973, if we exclude the first published in 1945 (Figure 12). United States (49 papers) and Sweden (35 papers) were the countries with the highest number of papers, followed by Germany and Italy (21 papers) (Figure 13).

Only 31 papers assessed viral air contamination, mainly in the last few years (data not shown). A total of 316 papers evaluated the microbial air contamination in OTs related to surgical site/wound infections or infection; the first article was published in 1957. The trend of the published papers, even if with lower absolute numbers, overlaps that of Figure 2 (data not shown). The number of papers per country of authors involved in this issue are showed in Figure 14.

Air changes (79 papers), door openings (32 papers), and behaviours (25 papers) were other important issues deepened as shown in Figure 15, 16 e 17, respectively.

Table 1 shows the number of papers with authors from each country, according to the studies on operating theatres air contamination and air changes, door openings and behaviours, respectively.

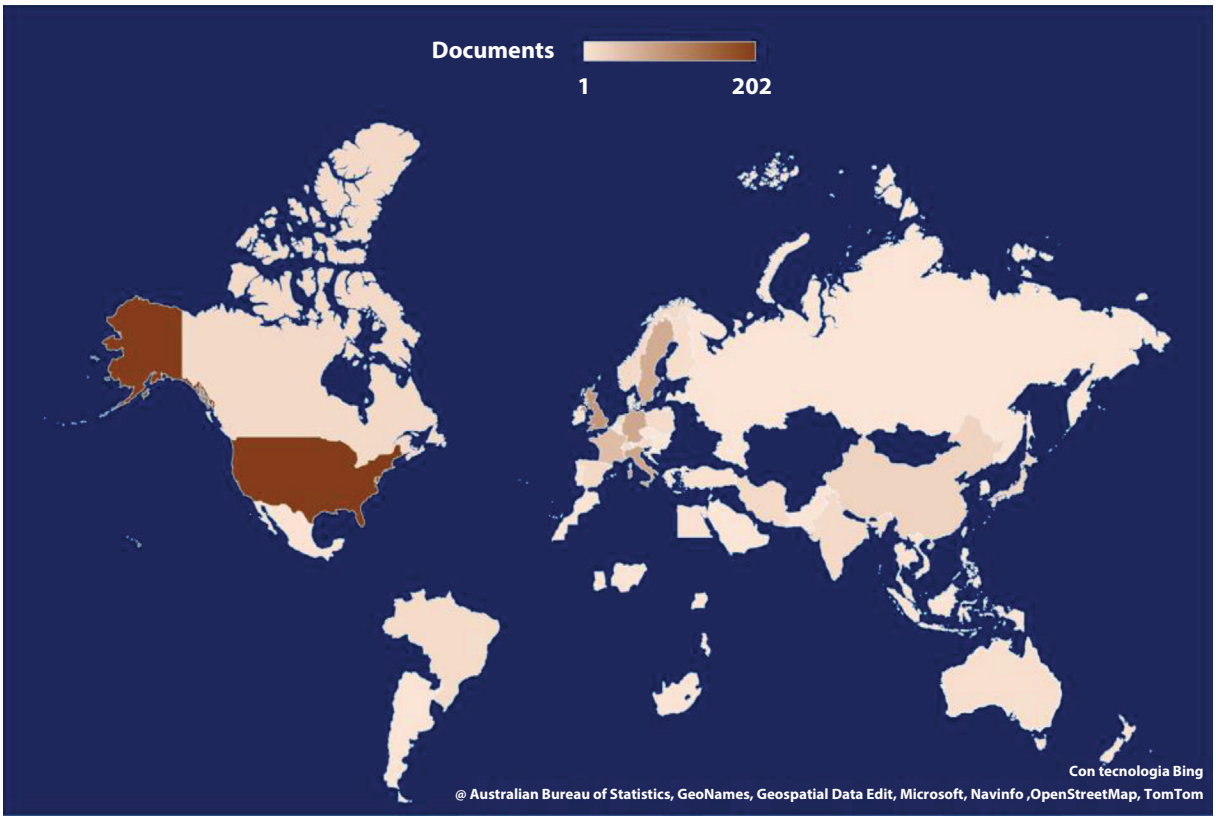

Figure 2. The map of countries with at least one author involved in research about operating theatres air contamination and related issues.

Table 2 shows the number of papers with authors from each country, according to the studies on OT air contamination and airflow and air changes. Microbial air contamination and airflow is an issue addressed by 239 articles from 1963 (data not shown).

Table 3 shows the number of countries with at least one author involved in studies about operating theatres air contamination per continent and the percentages compared to the total of countries by single continent.

Conclusions

This study shows a picture of the studies on microbial air contamination in operating theatres and some related issues over time.

From 1945, 907 papers according to Scopus have been published, and an increase over the past ten years is evident. It is interesting to note that the authors involved in these issues mostly come from some countries of North America and Europe, and among these, some countries seem more sensitive than others to the issue of air contamination in OT. In part of South America, in almost all African countries and in many Asian countries this issue is not considered. This may appear attributable to the economic and socio-political conditions of some of them; however, the fact that there are no authors from 50% of European countries also lends itself to in-depth reflection. If the observations are narrowed down to verifying the environmental conditions through monitoring, an even more limited interest can be observed, and it is interesting that in this case the Italian authors are in the front row.

Most of the studies dealt with bacterial air contamination in OT, followed by a not much smaller number of papers on particle contamination, once again in the United States, but also in some Northern

Figure 3. The authors who have published at least 4 papers on air contamination in operating theatres.

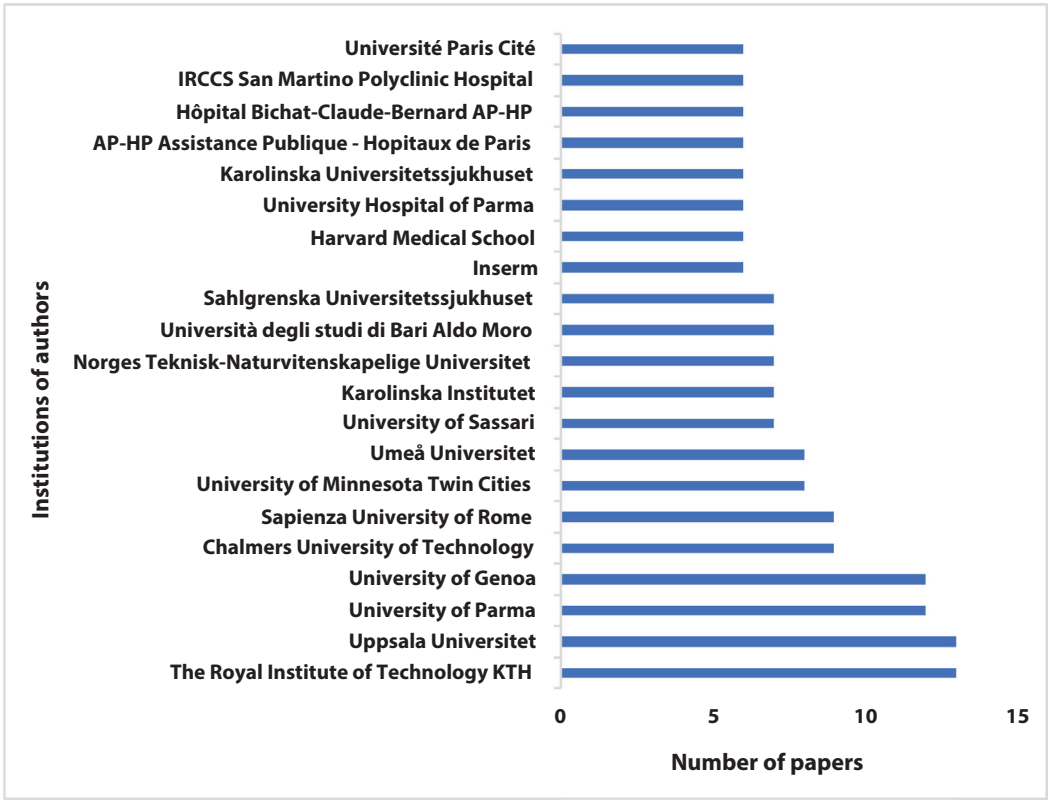

Figure 4. The institutions of authors publishing at least 6 papers about operating theatres and air contamination.

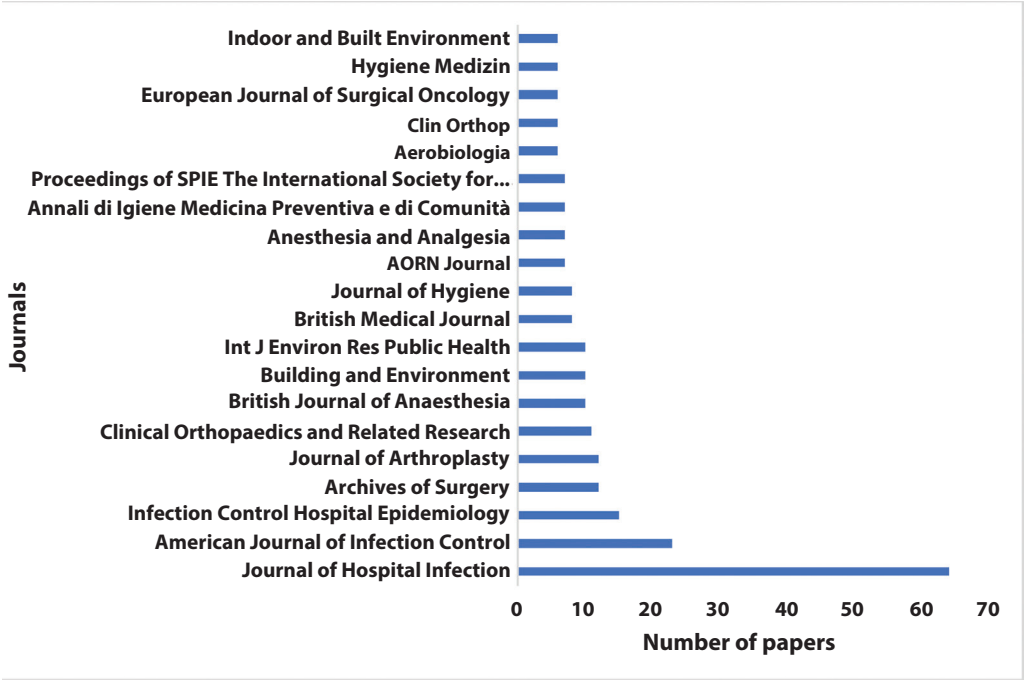

Figure 5. The top 20 scientific journals publishing about operating theatres and microbial air contamination.

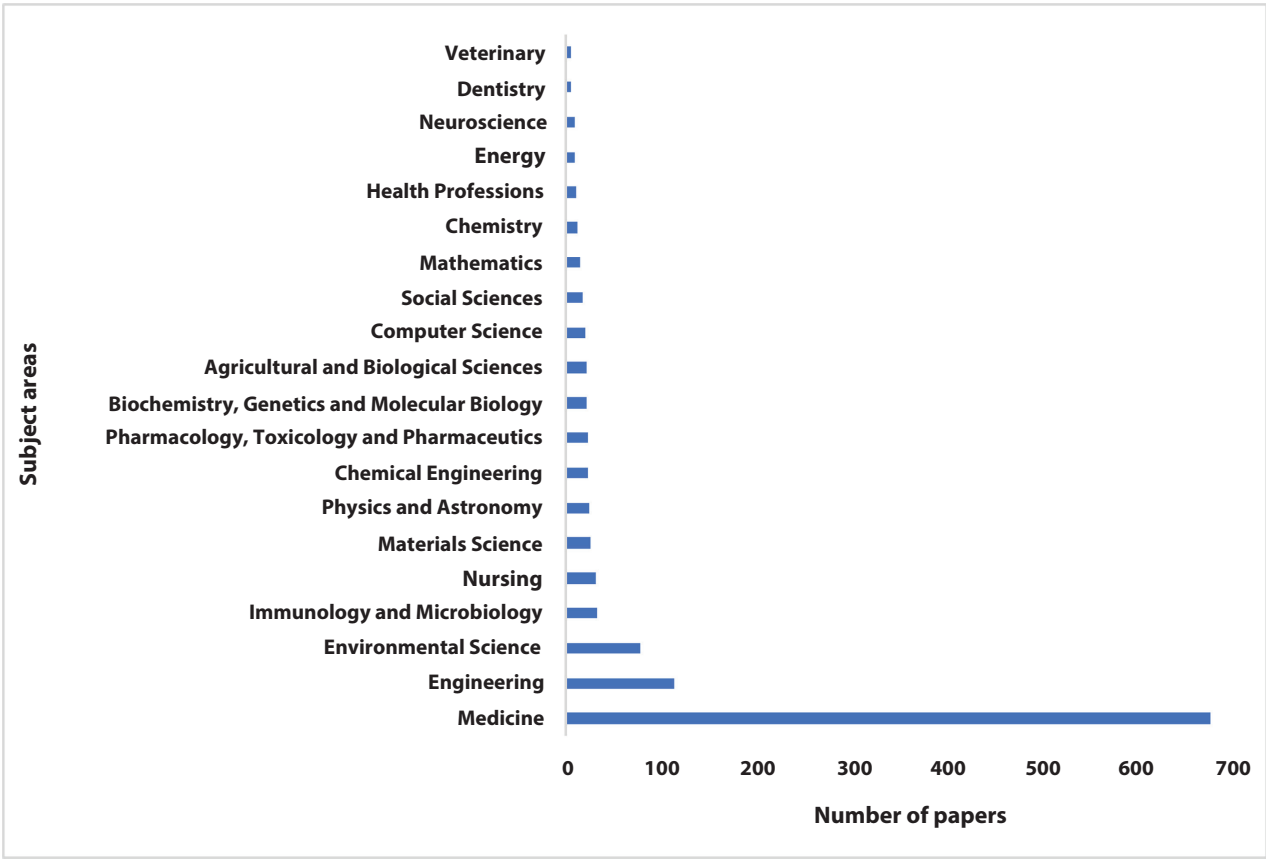

Figure 6. The subject areas addressed by operating theatres and microbial air contamination.

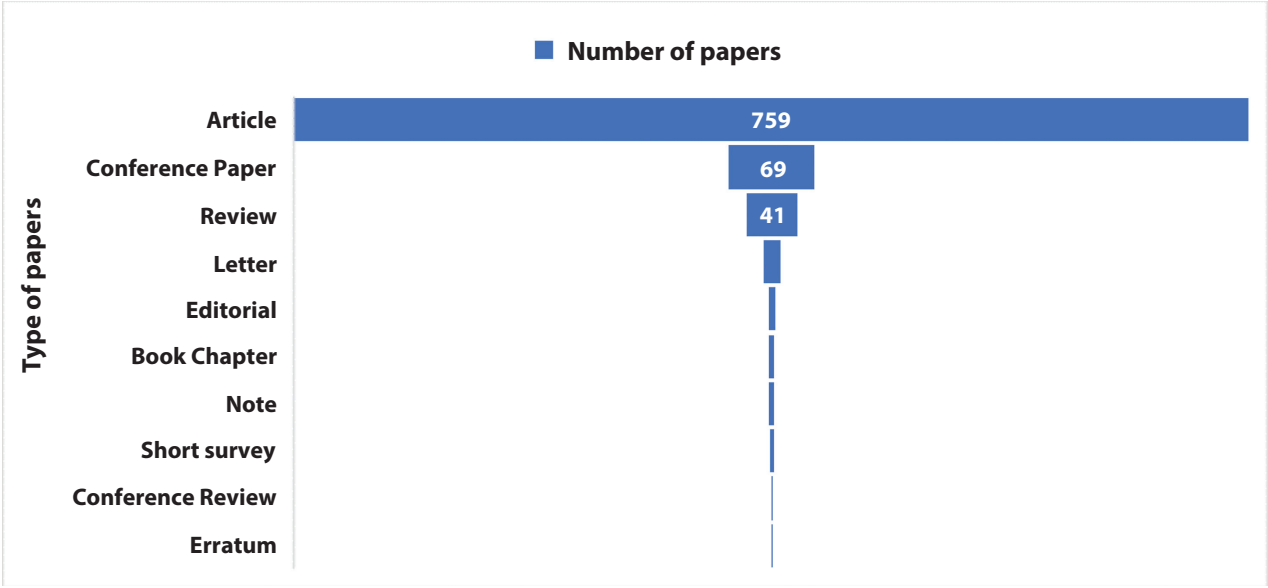

Figure 7. Type of papers published on operating theatres and microbial air contamination.

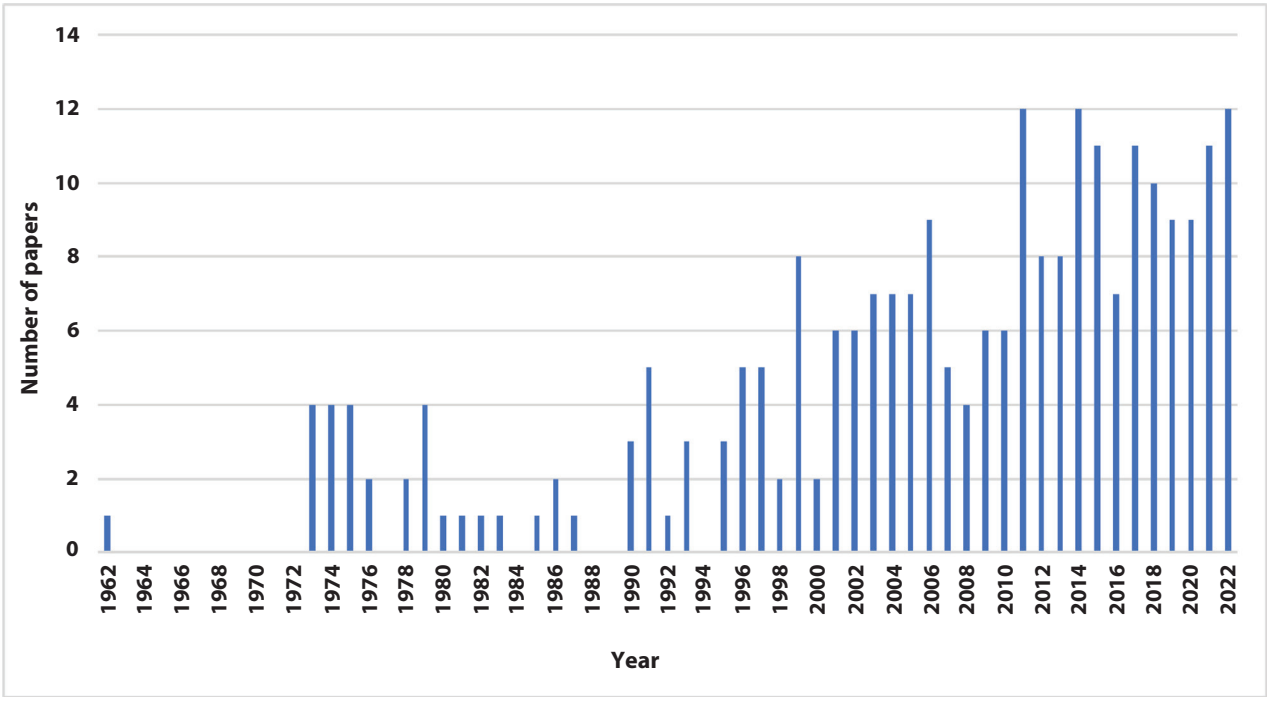

Figure 8. Papers on the monitoring/sampling of microbial air contamination in operating theatres.

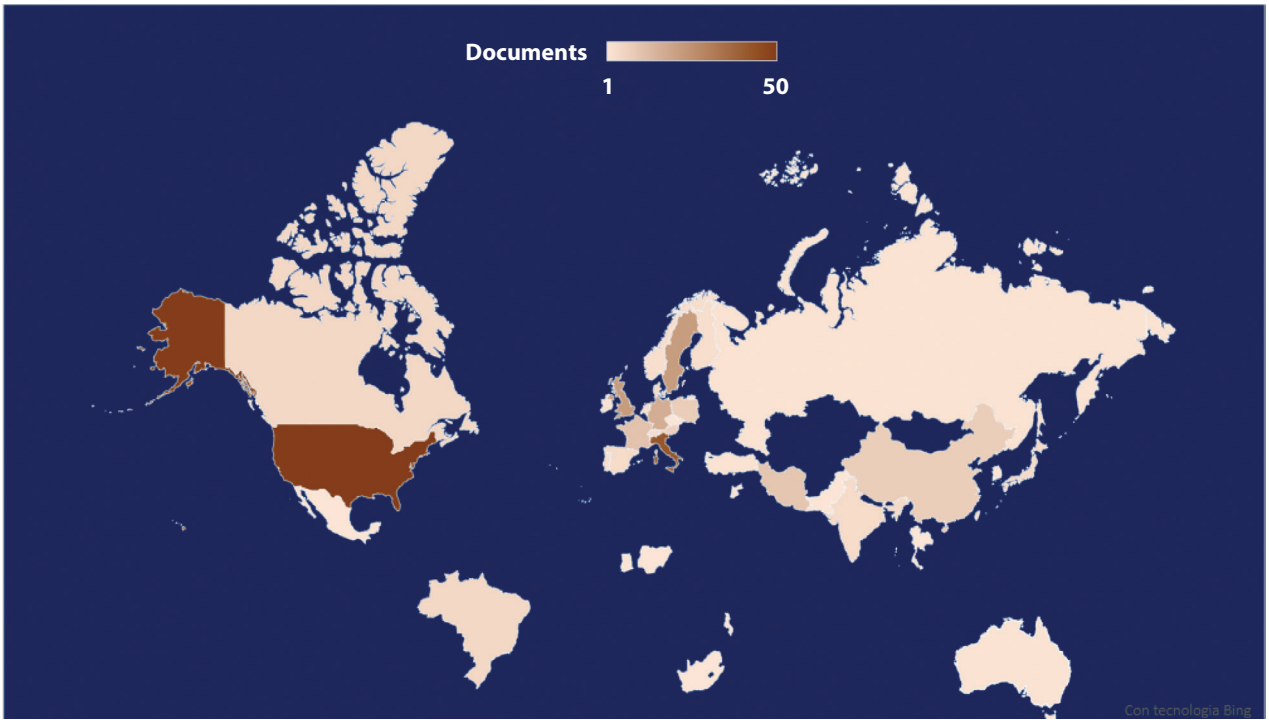

Figure 9. The countries of authors who addressed monitoring/sampling per number of papers.

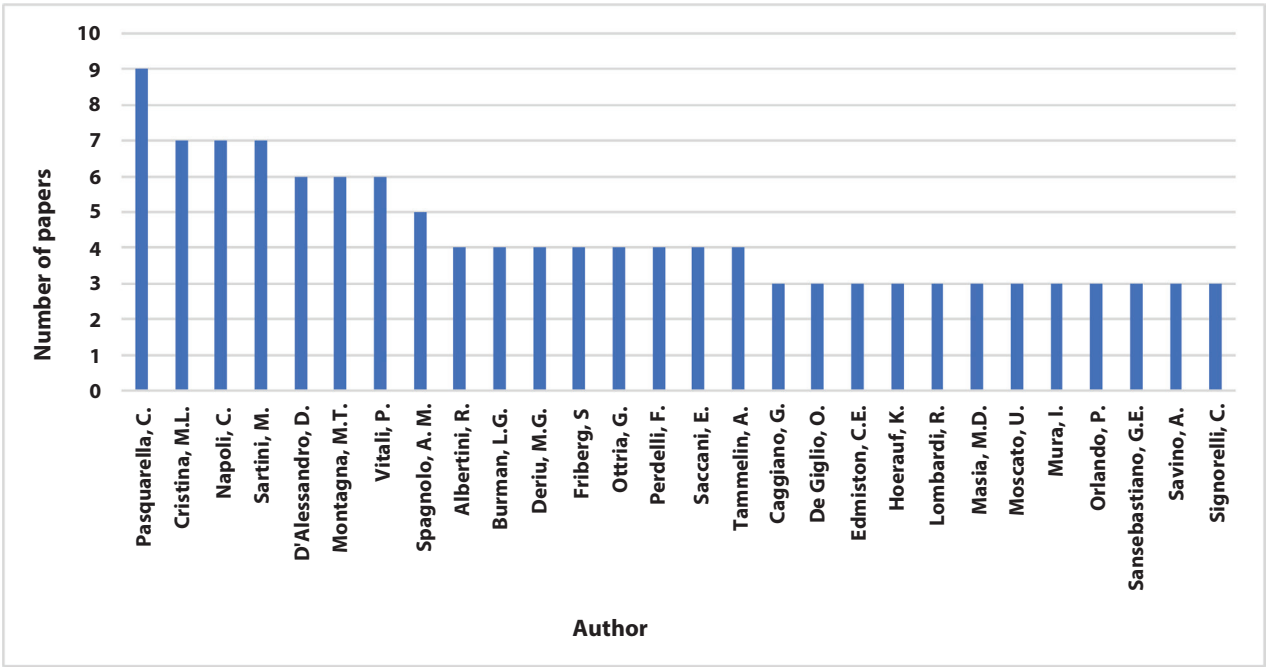

Figure 10. The authors with at least 3 papers on monitoring/sampling microbial air contamination in operating theatres.

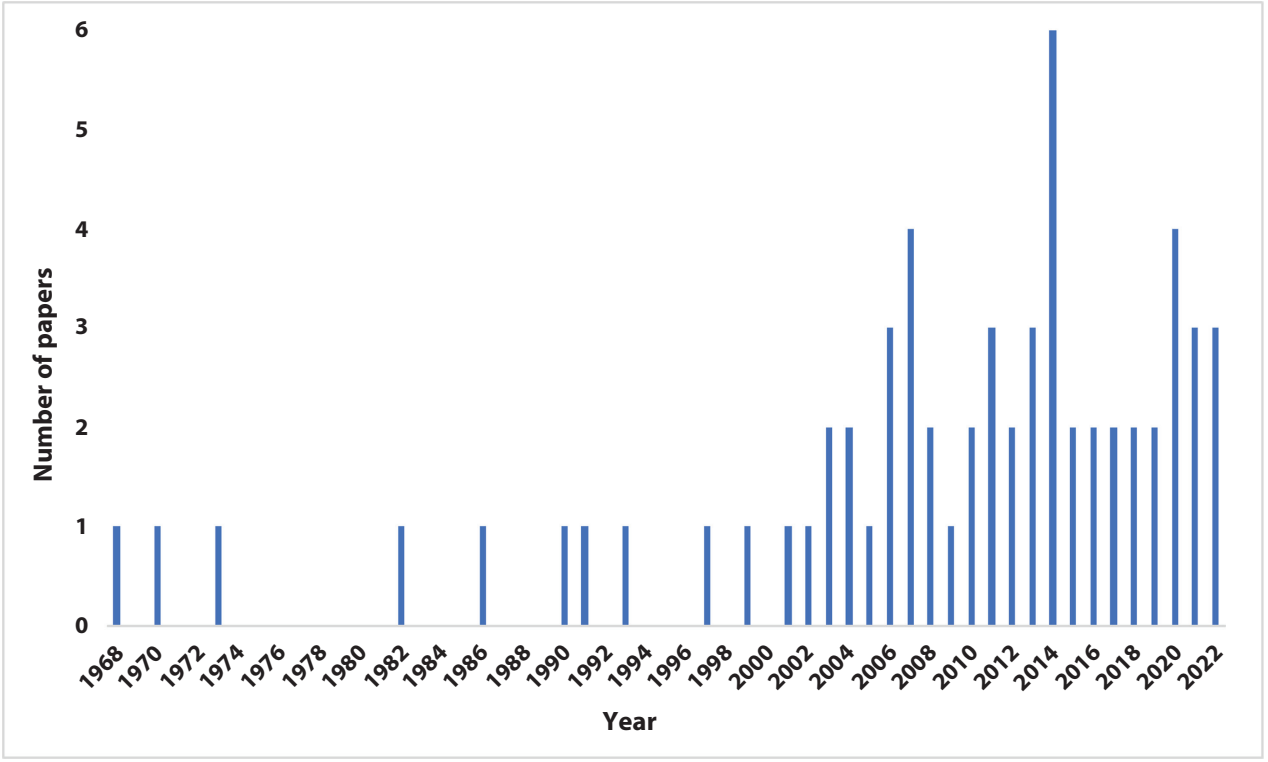

Figure 11. Papers per year that investigated air fungal contamination in operating theatres.

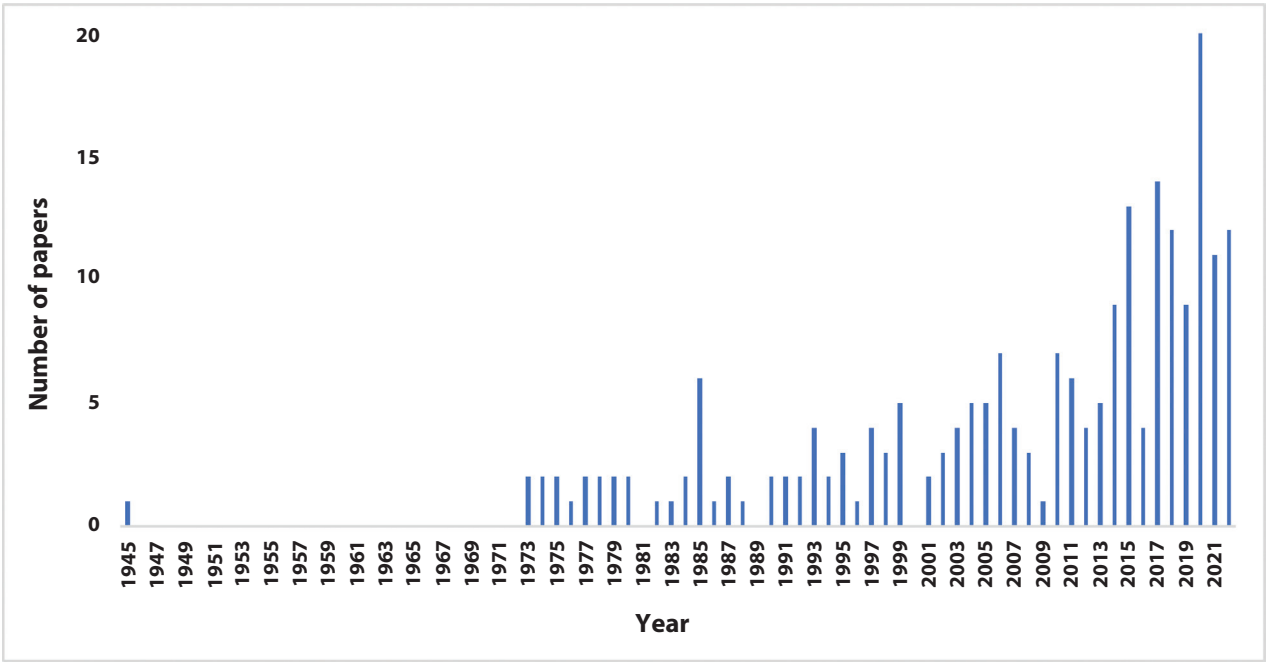

Figure 12. Papers on particle air contamination in operating theatres.

Figure 13. The countries and papers on particle air contamination in operating theatres.

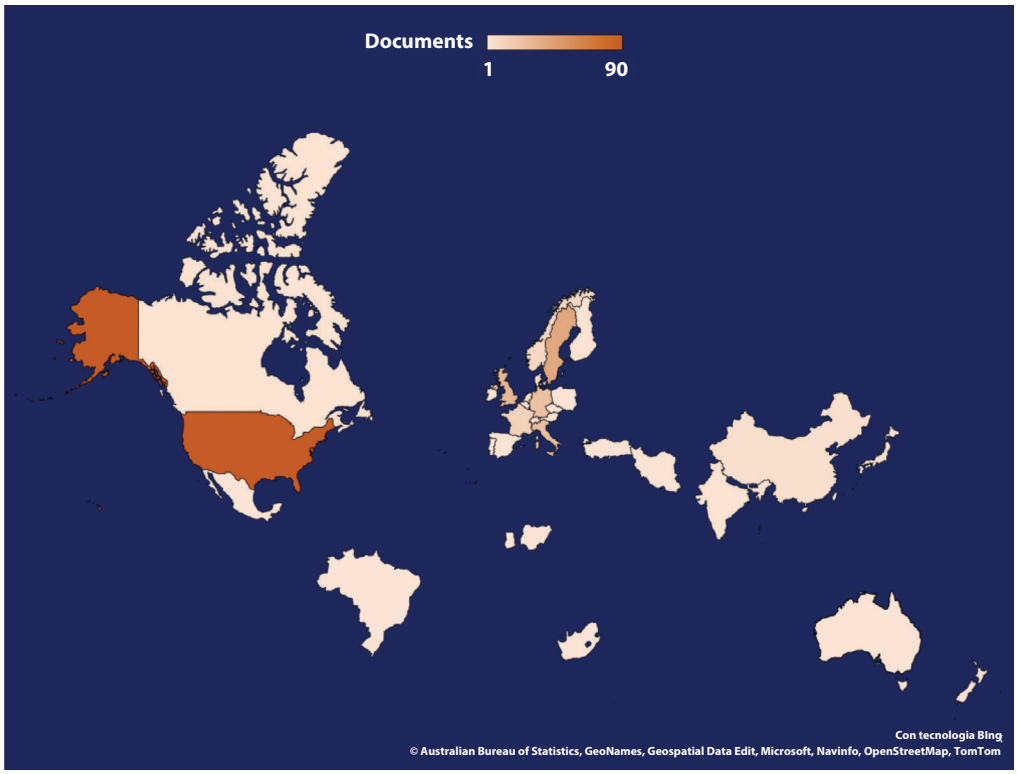

Figure 14. The countries and papers on microbial air contamination in operating theatres in relationship with surgical site/wound infections.

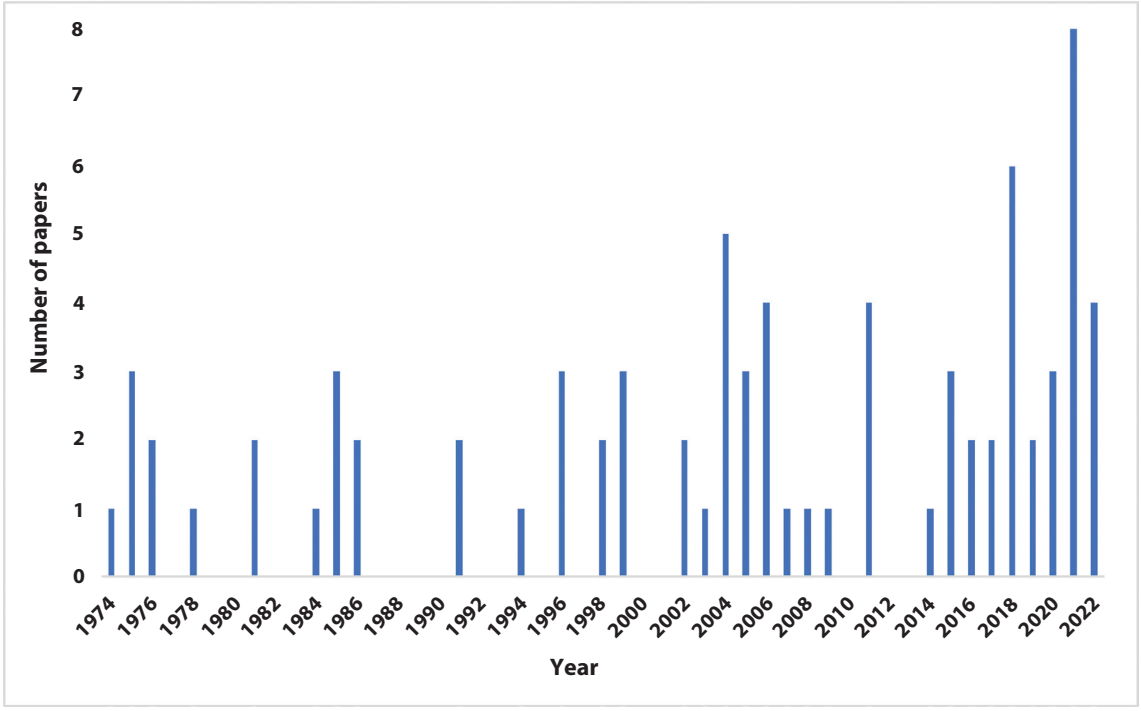

Figure 15. Number of papers per year that addressed operating theatres, microbial air contamination and air changes.

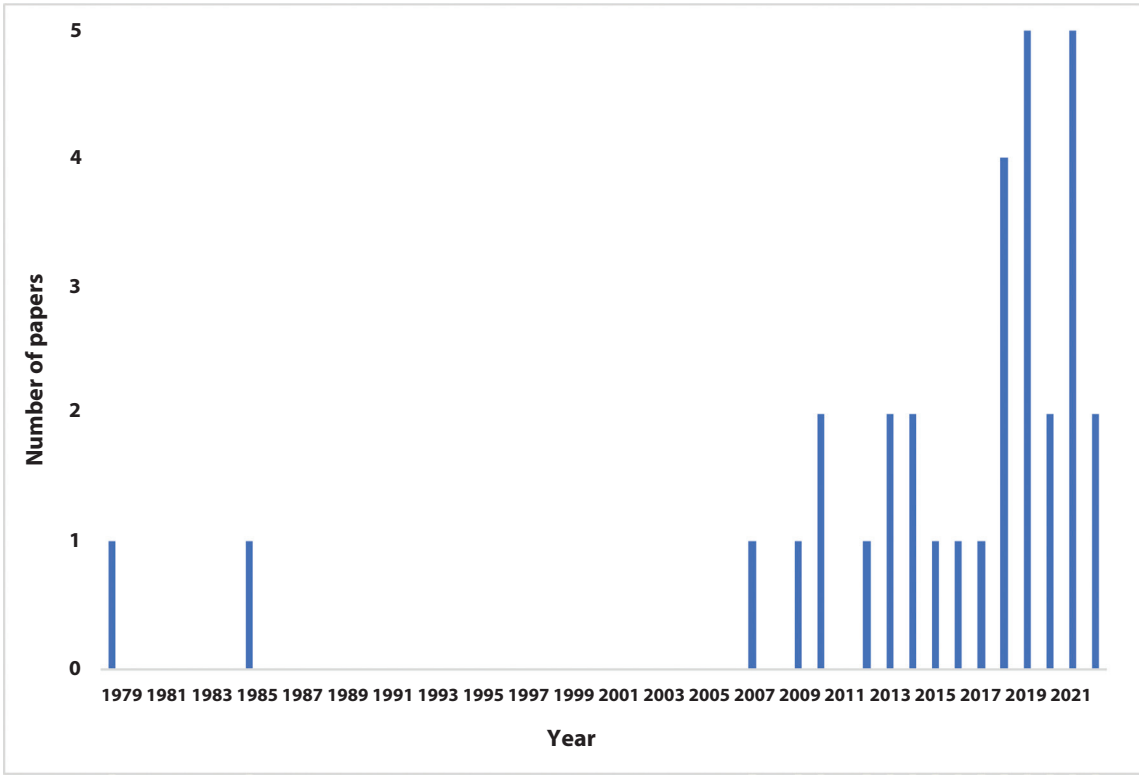

Figure 16. Number of papers per year that addressed operating theatres, microbial air contamination and door openings.

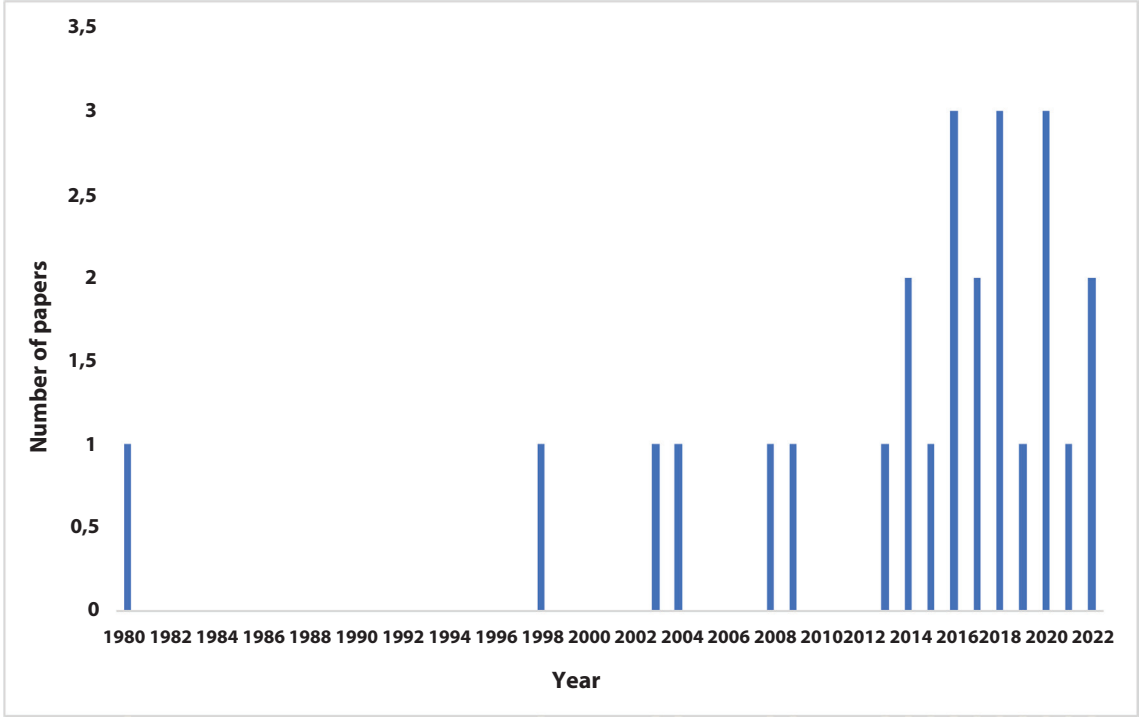

Figure 17. Number of papers per year that addressed operating theatres microbial air contamination and behaviours.

Table 1. Number of papers (at least 2) with authors from each country, according to the issue covered.

Door openings		Behaviours	
Country	**Papers number**	**Country**	**Papers number**
Sweden	9	Italy	5
United States	8	France	4
Italy	5	Japan	4
Norway	4	Portugal	2
China	3	Sweden	2
Denmark	2	United States	2
France	2		

Table 2. Number of papers with authors from each country involved in operating theatres air contamination and air flow (at least 4 papers), and operating theatres air contamination and air changes (at least 2 papers).

Air flow		Air changes	
Country	**Papers number**	**Country**	**Papers number**
United States	55	United States	18
United Kingdom	28	Sweden	8
Germany	27	United Kingdom	7
Sweden	26	Germany	4
Italy	20	Italy	4
France	12	China	3
Norway	7	France	3
China	6	Indonesia	3
Japan	5	Japan	3
Switzerland	5	Canada	2
Austria	4	India	2
Denmark	4	Iran	2
Poland	4	Poland	2
Spain	4	Taiwan	2

Table 3. Countries with authors involved in studies about operating theatres air contamination per continent and percentages on total of countries by continent.

Continents	Number of countries with authors	Number of Countries/Continent	Percentage
Europe	24	48	50%
Asia	20	49	41%
Africa	7	54	13%
America	5	50	10%
Oceania	2	14	14%

European countries. Very few studies dealt with fungal air contamination and even fewer were the studies on viral air contamination.

The interest in microbial air contamination and surgical site infection started in 1957, with the first research followed by the important studies by Charnley (5) and subsequently by Lidwell (23) with the randomised study on the effect of ultraclean air in OT on surgical infection in the total hip or knee replacement.

Much more recent was the interest in studies on microbial air contamination in OT linked to important issues such as behaviour, opening of doors and type of air flow. The latter is very topical linked to the WHO conditional recommendations not to use unidirectional airflow ventilation systems to reduce the risk of surgical site infection for patients undergoing total arthroplasty surgery (11).

Most of the articles were published in medical journals; however, about 20% of studies was also published in technical journals. It would be interesting to know the articles referred to studies in which engineers, or in any case scientists in the technical field, and researchers in the medical and biological fields, have participated with a multidisciplinary approach. This aspect is not trivial (69), as the difficulties of fully understanding the importance of monitoring and verifying, for example, air quality in OT not only in at rest condition may be linked to the fact that norms and guidelines are often based almost exclusively on considerations of a technical nature and not, if not minimally, to biological or medical observations.

From the observations of this study, the need to work with a multidisciplinary approach to the topics covered clearly appears and, above all it would be important to concentrate efforts on issues related to air contamination in OT and relationship on SSI also as a function of behaviours, types of airflow ventilation system of the air used and other possible variables.

This study is not a systematic review and is based only on Scopus database, therefore some papers may have been missed. However, we think that analysis of the results of our study will provide a useful tool to identify the evolution of interest in studies on air contamination in operating theatres and related issues to increase awareness towards a better sharing of aims, approaches and results, and thinking at European level to propose a project to deepen the topic towards standardised approach, above all in the interest of the patients, but also of the health services of the different countries.

Acknowledgements: The authors are grateful to Mrs. Rosslynne Milburn for her linguistic advice.

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Author Contribution: All the authors: 1) contributed to the design of the article; 2) drafted and revised the article critically for inte lectual content; 3) approved the version to be published; 4) agreed for all aspects of the article in ensuring that questions related to the accuracy or integrity of any part of the paper are appropriately investigated and resolved.

Ethic Committee: not applicable

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Received: 23 March 2023
Accepted: 12 April 2023
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