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Review

Recent Advances in Double-Lumen Tube Malposition in Thoracic Surgery: A Bibliometric Analysis and Narrative Literature Review

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Abstract: The thoracic surgery has increased drastically in recent years, especially in the light of the severe outbreak of 2019 novel coronavirus disease (COVID-19). Routine "passive" computed tomography of the chest screening of inpatients detects some pulmonary disease requiring thoracic surgeries timely. As an essential equipment for thoracic anesthesia, the double-lumen tube (DLT) in precise position is particularly important for anesthesia and surgery. With the continuous upgrading of the DLTs and the widespread use of the fiberoptic bronchoscopy (FOB), the position of DLT in thoracic surgery is gradually becoming more stable and easier to observe or adjust. However, for reasons such as transferring the patient to the lateral position, the DLT malposition still occurs in thoracic surgery, leading to lung isolation failure and hypoxemia during one-lung ventilation (OLV). Recently some innovative DLTs based on traditional have shown good results in reducing the incidence of DLT malposition, and some studies also found a lower malposition rate through improved intervention methods. This review aims to discuss and summarize the recent rates of left-sided DLT malposition, the reasons and effects of malposition, and to sum up current methods of reducing DLT malposition as well as prospects for possible approaches. Meanwhile, we use bibliometric analysis to summarize the research trends and hot spots of the DLT research.

Keywords: Double lumen tube; Malposition; Thoracic surgery; Airway management; One-lung ventilation; Fiberoptic bronchoscopy; Bibliometric analysis.

1. Introduction

Lung isolation and one-lung ventilation (OLV) are the basis of modern thoracic anesthesia and surgery [1], and the landmark invention of the double-lumen tube (DLT) allows for successful lung isolation and OLV under DLT intubation [1-3]. The DLT can effectively isolate the ventilation pathways of both lungs to ventilate separately at the bronchial level, resulting in full deflation of the operated lung and good exposure of the operative field to facilitate surgical operations, also preventing pus, bronchial secretions or blood from the operated lung entering the healthy lung [1]. These important functions may disappear once the DLT position is incorrect, so it is crucial to ensure the accurate position of DLT. Fiberoptic bronchoscopy (FOB) is the most effective and reliable method to observe the DLT position [2, 4-7], and Campos urged that the DLT position would be confirmed by a FOB both in supine and lateral position [3]. The classical standard of correct DLT position is defined by the FOB as follows: a clear view into the left upper and lower lobe bronchus through the endobronchial lumen with the bronchial cuff directly beneath the carina and the main left bronchus should be just visible through the tracheal lumen [4]. Now, with the Broncho-Cath in the fifth generation, the optimal position is that the ring-mark placed

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between the tracheal cuff and bronchial cuff is just located at the tracheal carina except for patients whose height was lower than 150 cm. Considering that currently the left-sided DLT is the optimum choice in thoracic surgery [3], this review only discusses the placement of DLT in the left bronchial lumen. This is mainly due to its reliability and higher "margin of safety", being defined by Benumof et al. [8] as the length of tracheobronchial tree over which it may be moved or positioned without obstructing airway. Bibliometric analysis, using mathematical and statistical methods to the quantitative analysis of publications, can assist researchers to quickly identify current trends in their field [9]. In order to comprehend the research trends and hot spots of the DLT, we conduct a bibliometric analysis by using the software CiteSpace.

2. The Bibliometric Analysis of Publications in DLT Research

A bibliometric analysis of all publications in DLT research from 1950 to the present was performed using CiteSpace (vision 6.1.R2), and all publications were obtained from the Web of Science core Collection (WOSCC), resulting in a total of 1172 publications after filtering out letters and removing reprints.

The network visualization of countries (Figure 1) shows that since 1950 to date, the United States is the most published country (281), followed by China (121) and Germany (111). In contrast to the developed countries of the United States and Germany, the first article on DLT from China did not be published until 1996. Since then the number of publications has been catching up with Germany, and it is not difficult to infer that this is related to the huge population base and the recent rapid development of medical care in China. In addition, the United States has the highest centrality (0.17), indicating that the United States has a significant influence in DLT research as the center of national cooperation and exchange with other countries. It is worth noting that although the research in China started late, the centrality in China is a staggering 0.14.

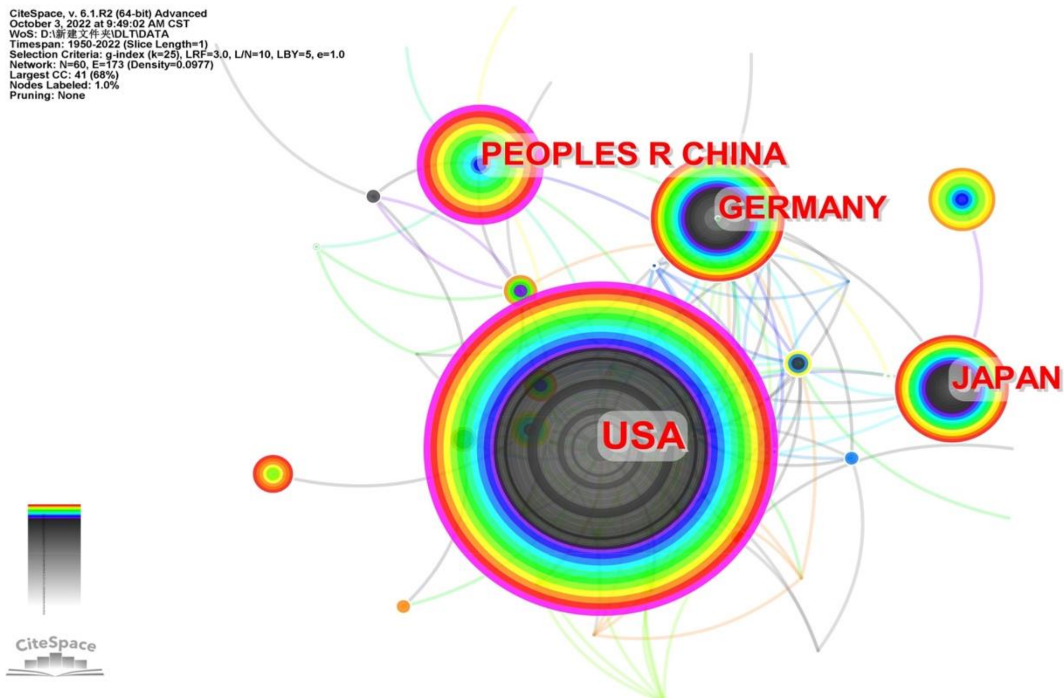

Figure 1. The network map of collaborating countries in DLT research. Annular size, reflecting the number of publications; purple circle size, reflecting the intensity of centrality (generally considered to be meaningful when greater than 0.1), and centrality is reflecting the degree to which a node is connected to other nodes throughout the network.

From the keyword clustering analysis (Figure 2), co-occurrence of the keywords suggested nineteen clusters that represent the hot topics. What can be seen that the current research of scholars on DLT mainly focuses on thoracic surgery, DLT size, airway

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management, and independent lung ventilation. However, there is a paucity of studies on DLT malposition.

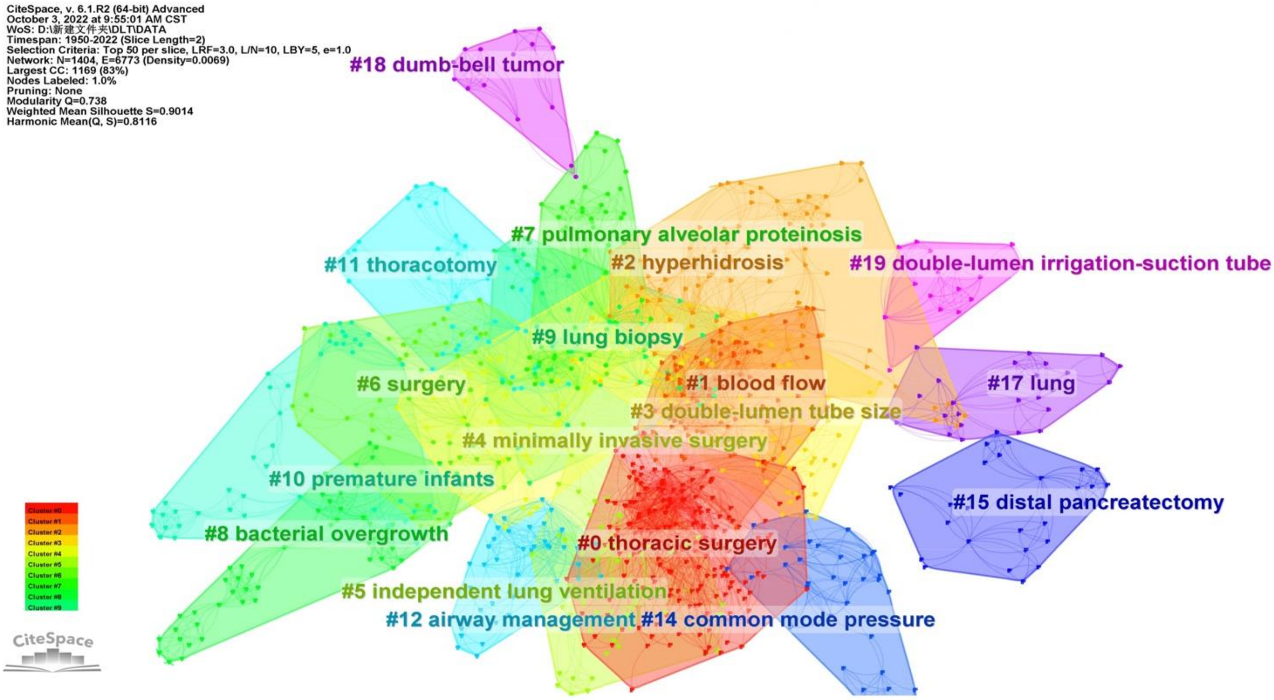

Figure 2. The clustered network map of keywords on DLT research.

Burst keyword detection indicates frequently cited words over a period of time. In the map of keyword bursts (Figure 3), we can see that bronchial blocker is currently the more popular study (strength = 14.98), which may be related to the fact that the bronchial blocker always be compared to DLT in many studies. In addition, OLV (10.52), DLT placement (5.48), and injury (5.52) have also been the research hotspots in recent years, and these are closely related to DLT malposition.

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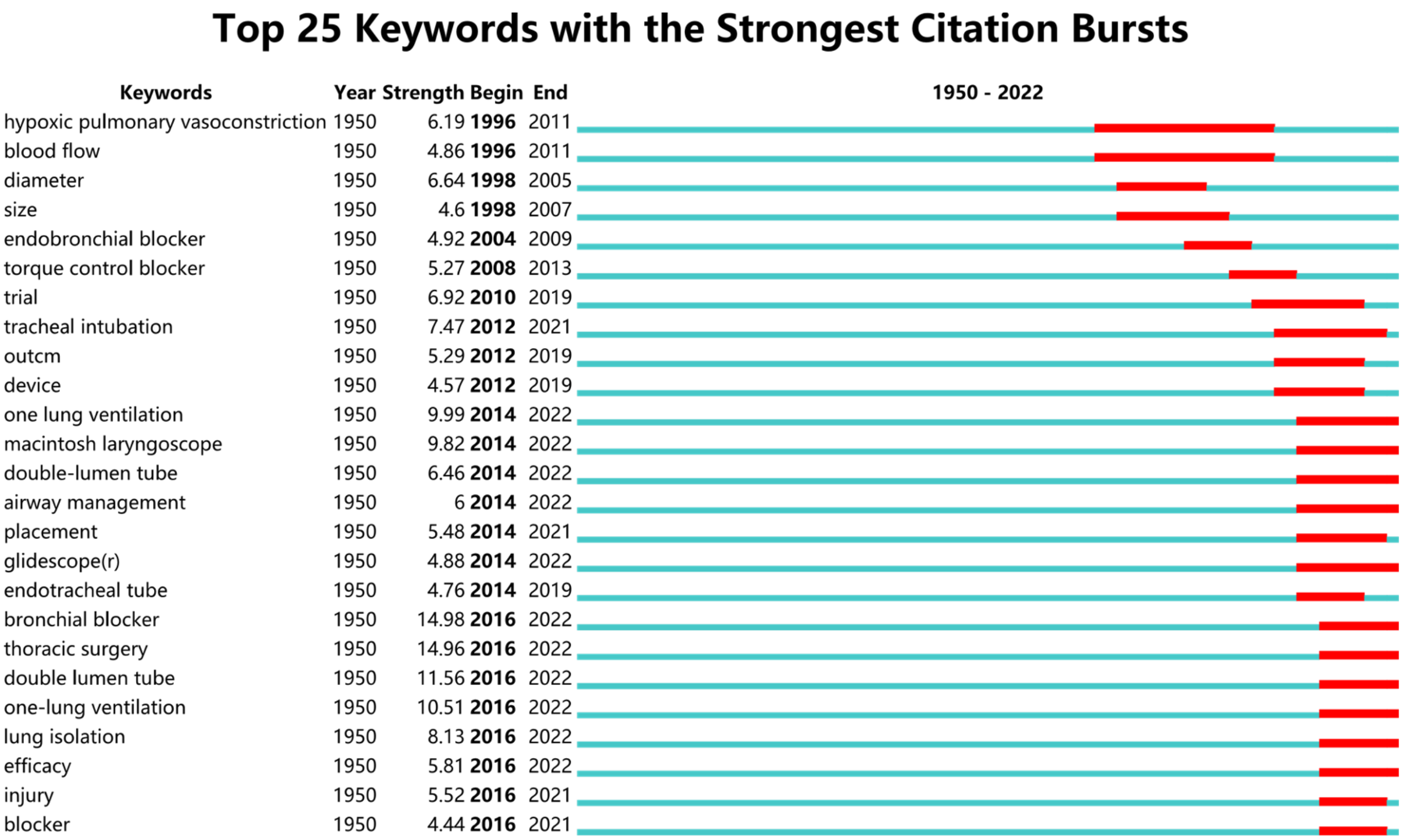

Figure 3. Keywords with the strongest citation bursts in publications on DLT research. The bold red grid represents the time interval of the burst.

3. The Definitions of DLT Malposition

Different studies have different definitions of DLT malposition, it can be defined as tube position that if not corrected might lead to clinical problems, such as defined by Campos et al. [10] as a bronchial cuff more than halfway out or not visible in the entrance of mainstem bronchus, or in opposite bronchus, or unable to distinguish tracheal/bronchial anatomy. Malposition also can be defined as a deviation from the optimal placement to provide an easy quantitative measure, and the deviation mainly focused on 0.5 cm or 1.0 cm [6, 11-14].

Specifically, Inoue et al. [11] defined DLT malposition as the tube must be pushed in or out more than 1.0 cm to correct its position, since the authors indicated that Japanese patients they studied were small and a 1.0 cm deviation might be critical. Furthermore, Klein et al. [6] considered that the DLT malposition occurred when it had to move more than 0.5 cm to correct its position, and severe malposition was defined as the inability to clearly see the left upper/lower lobe bronchus or intratracheal dislocation of more than one half of the endobronchial cuff. In my opinion, it may be more reasonable to set the deviation of DLT malposition at 1.0 cm, as Desiderio et al. [15] reported that DLT moved about 1.0 cm in 40 of 50 patients after lateral positioning.

4. The Recent Incidence of DLT Malposition

According to recent studies, the DLT malposition rates vary greatly, which may be related to the differences in specifications of DLTs, definitions of malposition, and intervention measures. The rates of left-sided DLT malposition in relevant studies over the last 20 years or so are shown in Table 1.

Table 1. The rates of left-sided DLT malposition.

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Study (year)	Specification of DLT	Definition of malposition	Malposition number/total	Rate (%)
Campos et al. [10] (2006)	Broncho-Cath	Bronchial cuff more than halfway out or not visible in the entrance of mainstem bronchus, or in opposite bronchus, or unable to distinguish tracheal/bronchial anatomy	8/22	36.4
Inoue et al. [11] (2004)	Broncho-Cath	1.0 cm deviation from an optimal placement	49/151	32.5
Kwon et al. [12] (2019)	Broncho-Cath	1.0 cm deviation from an optimal placement	17/48	35.4
	Human Broncho	1.0 cm deviation from an optimal placement	18/52	34.6
Seo et al. [13] (2012)	Broncho-Cath	1.0 cm deviation from an optimal placement	32/50 (with pillow) 14/50 (no pillow)	64.0 28.0
Klein et al. [6] (1998)	Broncho-Cath	0.5 cm deviation from an optimal placement	80/163	49.1
Yoon et al. [14] (2005)	Broncho-Cath	0.5 cm deviation from an optimal placement	6/50 (wear neck brace) 24/50 (no neck brace)	12.0 48.0
Suzuki et al. [31] (2007)	Broncho-Cath	3-point malposition scale: 0, the tube looked to be in the same position as in the previous examination; 1, the tube was not in exactly the same position, but the bron-chial lumen was not malpositioned; and 2, the cuff looked as if it was going to become herniated or dislodged.	13/26 (cuff with air *) 6/26 (cuff with saline **)	50.0 23.1
Onifade et al. [29] (2020)	Broncho-Cath	The Authors not explained	12/25	48.0
	VivaSight DLT	The Authors not explained	4/25	16.0
Schuepbach et al. [27] (2015)	Broncho-Cath	The Authors not explained	6/20	30.0
	VivaSight DLT	The Authors not explained	5/19	26.3
Heir et al. [28] (2018)	Broncho-Cath	The Authors not explained	14/42	33.3
	Vivasight DLT	The Authors not explained	13/38	34.3

* inflated with 1.2 ml of saline in endobronchial cuff; ** inflated with 2 ml of air in endobronchial cuff. DLT: double-lumen tube.

5. The Reasons for DLT Malposition

There are many reasons for DLT malposition, generally including shifting the patient from supine to lateral position, neck flexion or extension, coughing and surgical manipulation [14, 16-18].

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Desiderio et al. [15] found that after 50 patients were shifted from supine to lateral position, the tracheal movement in 40 patients with an average of 0.92 cm and the bronchial movement in 37 patients with an average of 0.92 cm. Thus they emphasized the necessity of using a FOB to check the DLT position after lateral positioning. Furthermore, they also found that DLTs moved with lateral positioning regardless of endobronchial cuff inflation, ruling out such speculation that DLT was relatively fixed due to endobronchial cuff inflation. High rates of DLT malposition in patients after lateral positioning were also found in studies by Klein et al. [6], Inoue et al. [11], Maruyama et al. [19]. Therefore, it is crucial to protect the DLT position as gently as possible during shifting the patient to the lateral position, and to reconfirm the DLT position by using a FOB after lateral positioning then to OLV.

6. The Complications of DLT Malposition

About 40% of DLT-related complications are due to DLT malposition [20]. If not promptly identified and remedied, malposition can lead to even life-threatening complications, including poor lung isolation, hypoxemia during OLV, postoperative hypoxia, atelectasis, high airway pressure, secretion accumulation, airway lacerations, and high infection rates [7, 11, 20-23].

Inoue et al. [11] found that patients with DLT malposition after lateral positioning were more likely to develop hypoxemia during OLV (28 of 29 patients), even after correction of the DLT position by using a FOB. They suggested that the occurrence of hypoxemia in patients should be predicted in advance and checked the location of DLT first when hypoxemia occurred.

Araki et al. [24] noted in their article that endobronchial cuff pressure decreased significantly when the DLT happened malposition, even more sensitive than changed in pressure-volume loops or capnograms. Under-inflated endobronchial cuffs with low pressure may cause air leakage, obstructing the surgical field and interfering with operation [25]. Thus we should recognize the effect of DLT malposition on endobronchial cuff pressure. However, the intraoperative monitoring of cuff pressure measurement is controversial, as the bronchial cuff volume should be inflated as minimally as the cuff could be sealed even if the volume and pressure would be over the normal values.

During OLV, a left-sided DLT with deeply position that the total tidal volume is directed to only one lobe, may result in barotrauma due to high airway pressure and excessive tidal volume, though vital capacity is several times larger than tidal volume [21]. As reported by Siddik et al. [26], a patient with atrial septal defect repair developed high airway resistance and inaudible breath sounds in both lung fields after left-sided DLT intubation and ventilation, then occurred rapid-rate atrial fibrillation with hypotension. After they pulled the DLT back 2 cm the bilateral breath sounds and oxygen saturation returned to normal, then used a FOB to confirm the position. The intraoperative diagnosis was left pneumothorax and released by pleural opening, then the atrial fibrillation converted to sinus rhythm and blood pressure returned to normal. They thought that rapid-rate atrial fibrillation with hypotension probably as a complication of the pneumothorax. The malposition of the DLT in this case, though being a cardiac surgery, resulted in the left-sided pneumothorax which likely caused rapid-rate atrial fibrillation with hypotension, reminding us that the diagnosis of pneumothorax should be taken into account during OLV despite the low incidence.

7. Current intervention methods of reducing DLT malposition

DLT malposition rates have significantly reduced with the update in DLT types, the routine visual observation and positioning by using the FOB, and the innovation in intervention methods.

The VivaSight DLT (VS-DLT), a novel DLT with an integrated high-resolution imaging camera inserted at the end of the tracheal port, enables good visualization of the trachea and carina continuously to identify DLT position without using a FOB [27-30]. The

VS-DLT has a video imaging device and light source at the distal end of the tracheal lumen, providing continuous monitoring and recording throughout the surgery, allowing for early identification of tube malposition. A recent randomized controlled trial (RCT) by Onifade et al. [29] found that the malposition rate in the VS-DLT group (16.0%) was significantly lower than the conventional DLT group (48.0%), though previously Schuepbach et al. [27] and Heir et al. [28] found no statistically significant. However, none of those studies with the VS-DLT did the authors provided the definition of DLT malposition. With the advantages of successful intubation, less intubation time, rapid detection of malposition, and rapid repositioning, the VS-DLT is worthy of attention. Compared to conventional DLT, the VS-DLT with the larger outer diameter may be more likely to cause minor airway damage in patients, such as hoarseness, sore throat, and blood in the trachea and rung, but there is no sufficient data to confirm this. Admittedly, the continuous visualization of the DLT position brings a great guarantee for the accurate position of the DLT and the safety in thoracic surgery.

For patients with neck flexion or extension leading to DLT malposition, a study by Seo et al. [13] found that the incidence of DLT malposition was lower in patients who removed the headrest before lateral positioning compared to those who used the headrest all the time. They explained that patients without headrest had minimal neck flexion during lateral positioning. Furthermore, Yoon et al. [14] demonstrated that the use of neck brace limiting head and neck motion minimized DLT malposition during supine to lateral position.

In addition, Suzuki et al. [31] found that the DLT malposition rate was reduced in the saline group (inflated with 1.2 ml of saline in endobronchial cuff) compared to the air group (inflated with 2 ml of air in endobronchial cuff), with a malposition rate of 23.1% (6/26) in the saline group and 50.0% (13/26) in the air group. However, this method may have large limitations as authors only discussed the patients receiving nitrous oxide which rarely used recently due to its adverse effects.

8. New attempts of DLTs and intubating methods

Takahashi et al. [32] pointed out that the SmartCuff can automatically and continuously maintain the pressure of two cuffs at the initial set pressure, slowing the rate of decline in tidal volume and effectively restoring initial tidal volume after DLT malposition. However, this study was performed on an artificial intubation model not on clinical surgery, and there was no statistically significant on DLT malposition rates. Excessive cuff pressure can damage the mucous membranes of the trachea and bronchial tree [24], while air leakage from under-inflation of the endobronchial cuff can obstruct the operative field [25]. Araki et al. [24] suggested that monitoring of endobronchial cuff pressure can help for early detection of subclinical malposition of DLT. Therefore, the clinical application of the SmartCuff, an automatic retention pressure control device, for anesthesia in thoracic surgery may contribute to reducing DLT malposition and avoiding the lower tidal volume due to malposition.

In addition, the new ANKOR DLT" invented by Dr. Young Jun has an additional "carina cuff" that is situated at the point between the distal opening of the tracheal lumen and the beginning point of bronchial cuff, to avoid further advancement by being blocked by the carina after inflating the cuff [33]. Searching for ANKOR DLT in PubMed will bring up results for "andor DLT", click "Search for ANKOR DLT instead (2 results)" to find the articles related to ANKOR DLT. It is more suitable for anesthesiologists with limited experience in lung isolation or patients with severe destruction of lung parenchyma, massive pulmonary secretions, and hemothorax. Namo et al. [34] found in their study that during positioning DLT the difference in depth between placement and target was < 10 mm in 87 of 87 patients (100%) with ANKOR DLT intubation (83 patients < 5 mm), while 40 of 84 patients (48%) with conventional DLT had a difference of < 10 mm (26 patients < 5 mm). They indicated that compared to traditional DLT, ANKOR DLT tended to be placed closer to the target depth in a more appropriate position, and it placement also with less time consuming and less traumatic. However, there is no study to observe and compare the malposition rate of ANKOR DLT. Whether this DLT helps to reduce the rate of DLT malposition or whether it is worth promoting remains to be considered.

Patients with the passive movement from supine to lateral position after DLT intubation are likely to lead to DLT malposition. A recent study has also occurred that shifting patients to lateral position increased endobronchial cuff pressure due to changes in gravity and the curvature or length of the left main bronchus [35]. Thus, we envisage whether it would be possible to assist patients in the surgically required lateral position before induction of anesthesia then to intubate DLT in lateral position, which would directly avoid the possible adverse effects of lateral positioning. After reviewing related articles, very few references to lateral DLT intubation can be found. Martinez et al. [36] mentioned in their article that an essential and unique issue for non-intubated thoracic surgery (NIVATS) was the mastering of lateral position intubation for emergencies. Patients in NIVATS were likely to require to DLT intubation, and lateral intubation was not difficult according to their experiences. In addition, Ajimi et al. [37] reported a case of successful left-sided DLT intubation in the right lateral position for a patient with tracheal compression caused by a large mediastinal tumor. OLV was performed safely during thoracoscopic surgery without ventilatory failure or hypoxemia. DLT intubation in lateral position may be an effective new attempt to reduce the incidence of DLT malposition in thoracic surgery. And theoretically, the step of using the FOB again to confirm the DLT position after the lateral position can be eliminated. Next, we will design and conduct a RCT to explore the efficacy and clinical value of this intervention.

9. Conclusions

Currently the number of thoracic surgeries continues to increase, and recent studies have shown that DLT malposition still happens in thoracic surgery, possibly due to shift patients from supine to lateral position, resulting in failure lung isolation and hypoxemia during OLV. The renovation of the DLTs and the routine use of the FOBs do provide a guarantee for thoracic anesthesia and surgery, but the occurrence of DLT malposition and the associated infection risks associated with multiple FOB use cannot be ignored. Recently some innovative DLTs and improved intervention methods have shown good results in reducing the incidence of DLT malposition. Moreover, many new clinical attempts have not been proven to reduce DLT malposition, but given their particular advantages, performing studies on DLT malposition may yield positive results.

After reviewing relevant articles, we envisage a new method that places patients in the surgically required lateral position before anesthesia induction then to DLT intubation in lateral position. We will conduct a RCT to explore the efficacy and clinical value of the lateral DLT intubation, which could be a breakthrough in DLT intubation methods. For anesthesiologists who have never tried the lateral DLT intubation, this procedure seems awkward and difficult. However, with flexible intubation techniques and proper DLT shaping, this process is not as challenging as anticipated according to our preliminary pre-experiments. Lateral intubation can not only directly avoid DLT malposition caused by patient position conversion, but also reduce the multiple use of FOB to confirm DLT position. Surgeons can start surgery as soon as the DLT is positioned correctly, eliminating the need to move the patient and speeding up the procedure. Enhanced recovery after surgery (ERAS) is what physicians are looking for and what patients desperately need. We expect to reduce or even avoid the occurrence of DLT malposition, which is more in line with the ERAS concept.

Furthermore, by using a bibliometric analysis, we found that the United States holds significant power in DLT research and is the center of national cooperation. However, there are not many studies on DLT malposition, but closely associated with malposition, the OLV, DLT position and airway injury are still hot topics of research.

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