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Original Article

Conventional and Digital Pleural Drainage Systems – Advantages and Disadvantages

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Abstract

Introduction: Pleural cavity drainage is a crucial component of the surgical management of patients with various chest diseases. Digital drainage systems are increasingly used in contemporary thoracic surgical procedure, which is likely a result of their effectiveness in achieving early postoperative ambulation, cutting down on hospital stays and lowering costs. The vast majority of thoracic surgeons worldwide prefer digital drainage systems to traditional ones. The advantages of the former, however, are disputed by some researchers.

Aim: The objective of this study was to compare the two types of pleural drainage mechanisms, conventional and digital, in terms of duration of pleural drainage in days, financial cost, and postoperative air leak duration.

Materials and methods: The study focused on 80 patients who underwent various thoracic surgical interventions in the Clinic of Thoracic and Abdominal Surgery at St George University Hospital in Plovdiv. They were divided into two groups: group 1 consisted of 42 patients who were postoperatively attached to a conventional non-mobile pleural drainage system, and group 2 consisted of 38 patients in whom a mobile digital pleural drainage system was used. The main analyzed data were duration of pleural drainage, duration of postoperative air leak, hospital stay, and financial costs.

Results: The average duration of pleural drainage, regardless of surgery and type of drainage system applied was 4.86±0.8 days. The average duration of pleural drainage in patients attached to the mobile digital drainage system was shorter than that in patients with a conventional pleural non-mobile drainage system, regardless of the type of surgery done. This difference was statistically significant in favor of the digital pleural drainage system. The study also found a statistically significant difference in terms of financial costs in favor of digital draining system. The average cost of a hospital stay for patients attached to a mobile digital drainage system was BGN 119.40±7.15, whereas the average cost of a hospital stay for patients connected to a traditional pleural drainage system (PDS) was BGN 159±10.50. Regarding the duration of postoperative air leak, the difference between the types of pleural drainage mechanism used was not convincing.

Conclusions: Digital pleural drainage systems provide clinicians with an opportunity to assess the postoperative air leak more precisely, track its dynamics, shorten hospital stays, reduce postoperative costs, and optimize the time to remove the chest drain. Based on these features, they will undoubtedly continue to enter everyday surgical practice.

Keywords

conventional pleural drainage systems, digital pleural drainage systems, financial costs, hospital stay, postoperative air leak

INTRODUCTION

The concept of drainage of the pleural cavity has been well known since ancient times. As early as the 5th century BC when Hippocrates wrote about open pleural drainage in a patient with pleural empyema[1], a number of mechanisms were developed until the advent of the digital pleural drainage system in 2007[2]. The main purpose of pleural drainage is the effective evacuation of air, blood, or other fluids from the pleural space, the restoration of cardiorespiratory function by expanding the lungs, and the elimination of mediastinal displacement, which can lead to hemodynamic instability.[3] The normal elastic lung is maintained in a fully expanded state by a number of mechanisms that determine subatmospheric intrapleural pressure of about −5 cm H_2O, which at the end of the inspiration reaches about −8 cm H_2O.[4,5] Any penetrating injury to the chest wall or entry and retention of air or fluids in the pleural spaces disrupts negative intrapleural pressure resulting in compression or collapse of the lungs. The evacuation of free air or fluids from the pleural space requires an airtight drainage system that promotes adequate drainage and maintains optimal negative pressure.[3] Pleural drainage systems (PDS) usually consist of the following components: pleural drain or catheter, connector/s, connecting drainage tube, collector, one-way valve system (underwater seal) and vacuum source.[6] There are several types of PDSs: the Heimlich valve, analogue three-collector systems, digital or electronic PDS and ordinary vacuum cylinders (for intrapleural drainage).[7] They can be summarized in two main types – conventional and digital pleural drainage systems.

A. Conventional pleural drainage systems:

1. The Heimlich valve is a simple device consisting of a rubber valve that closes during inspiration, preventing air from entering the pleural space, and opens during expiration, allowing the evacuation of air or fluids from the pleural space. Heimlich valves are used for the ambulatory treatment of pneumothorax (including patients with persistent air leaks or tension pneumothorax).[8]
2. Vacuum cylinders – the drainage of the pleural fluid is performed by connecting the external one-way valve to a vacuum cylinder. The cylinders are supplied by the manufacturer with capacity of 1 L or alternatively, disposable vacuum drainage bottles – Redon (capacity 200 ml, 400 ml, and 600 ml) can be used.[9]
3. Three-chamber pleural drainage systems (Pleur-evac, Atrium) – they include a collection chamber, a water-seal chamber and a suction control chamber, which are interconnected. Fluids or air drain into the collection chamber. The water-seal chamber holds a column of water, which does not let air be sucked into the pleural space with inspiration. Finally, the vacuum chamber may use a wet (water column) or a dry (valve regulator) suction mechanism that allows the vacuum level to be adjusted. This suction chamber can be attached to continuous wall (external) suction or can be placed on water seal chest drain with no active suction mechanism (gravity drainage).[10]

Based on their mechanism of function, pleural drainage systems are classified as:

- 'wet-wet' systems, which rely on water to create a seal (wet-seal) and to set the amount of wall suction (wet-suction). They are also called underwater sealed drains (UWSD) and are very common. UWSD are subclassified depending on the number of chambers as in: 1) one-bottle systems where the Heber pipe is in direct continuity with the connecting tube; 2) multi-bottle systems where the water seal is physically separated from the fluid collection chamber, and 3) compact systems with a float valve on top of the water column which prevents water from spilling over.
- 'wet-dry' systems, in which water is used to make the seal while a mechanical component is used to set the amount of wall suction (dry-suction);
- 'dry-dry' systems that do not rely on water to make a seal. Here, mechanical or electronic components are built-in to establish the seal (dry-seal) and to set the amount of wall or independent suction.[10]

B. Digital drainage systems (Thopaz*, Atmos, Dentrex, Redax) are gradually invading the thoracic surgery practice. These devices have the ability to continuously record digital airflow, pleural secretion volume, and intrapleural pressure using digital sensors.[2,7,11] They maintain a pre-set intrathoracic pressure (usually 8 cm H_2O) and the device intervenes only when necessary to achieve the desired value. Pleural pressure, which can be constantly maintained by medical doctors, is independent of the device position. Thus, postoperative air leak can be evaluated objectively. These systems allow for the separation of fluid and air, and sub-atmospheric pressure is measured via the thinner of the two tubes. So, to monitor the sub-atmospheric pressure, it is very close to the pleural space, and the system works correctly, irrespective of where it is placed. Digital drainage systems give the patient the freedom to move without being attached to a wall vacuum mechanism. These electronic systems contribute to earlier chest drain removal and shorten hospital stay. In addition, in some cases, patients may even be discharged with a drain connected to a mobile system. The majority of thoracic surgeons worldwide prefer using digital drainage systems instead of the conventional ones. However, according to other researchers, there are controversial advantages of the first ones.[12]

AIM

Given the fact that there are controversial statements regarding the two types of pleural drainage mechanisms, the aim of our study was to compare them in terms of duration of pleural drainage in days, financial cost and postoperative air leak duration percentage.

MATERIALS AND METHODS

This is a single-center, prospective study. It focuses on a sample of 80 patients who underwent various thoracic surgical interventions in the Clinic of Thoracic and Abdominal Surgery at St George University Hospital in Plovdiv over the course of one year, from 01.04.2021 to 30.03.2022. All cases were divided into two groups: one consisting of 42 patients that were postoperatively attached to a continuous wall suction system, and another consisting of 38 patients attached to a mobile digital Thopaz pleural digital system. The main data we analyzed were the duration of pleural drainage, the duration of postoperative air leak, the hospital stay, and financial costs. Thirty-seven (46.25%) of the analyzed patients were female and 43 (53.75%) were male. The average patient age was 55.6±15.75 years. The patients with anatomical lung resection were 40%, 45% underwent surgery for primary spontaneous pneumothorax (chest tube drainage), and 15% underwent decortication due to pleural empyema. 47.5% of all patients were postoperatively connected to a mobile digital drainage system and 52.5% – to a conventional continuous wall suction system.

Criteria for inclusion and exclusion

The study included adult patients who underwent anatomical (excluding pulmonectomy) lung resections, patients after decortication due to pleural empyema, and patients drained due to primary spontaneous pneumothorax. Exclusion criteria were: 1) evidence of previous or active COVID-19 viral infection, 2) history of previous thoracic surgery, 3) active bacterial or fungal lung infection, 4) administration of steroids (intravenous or oral), and 5) presence of uncontrolled diabetes mellitus or psychiatric comorbidity.

Statistical analysis

To process the data, we used the SPSS version – IBM SPSS Statistics for Windows (version 21; IBM Corp., Armonk, NY, USA). All data were collected and analyzed using Microsoft Excel (Microsoft, Redmond, WA, USA). The hypothesis testing methods used were the independent samples t-test, the Kolmogorov-Smirnov and Shapiro-Wilk tests, and the Mann-Whitney test. The average values are presented as mean ± standard deviation (X±SD). The statistical significance was considered at $p<0.05$.

RESULTS

Average duration of pleural drainage

Our study showed that the average duration of pleural drainage, regardless of the surgical intervention and the PDS type applied, was 4.86±0.8 days **(Table 1)**.

Table 1. Average duration of pleural drainage in different types of surgical interventions, regardless of the drainage system applied

Surgery	N	Duration in days (X ± SD)
Anatomical lung resection	32	4.68±0.53
Drainage	36	4.58±0.50
Decortication	12	6.16±0.93
Average duration	80	4.86±0.80

The hospital stay exceeded the duration of pleural drainage by one day – 5.9±0.8 days because of the mandatory 24 hours follow-up period after removing the drain. The drainage duration period in patients after decortication was longer (6.16±0.9 days) due to the observed more significant and prolonged postoperative air leak in these patients. In a large percentage of the postoperative air leak cases, it usually ceased within 1-4 days and could be diagnosed definitively only in patients attached to a digital drainage system. The mean duration of pleural drainage in patients attached to the digital drainage system was 4.63 days (95% CI 4.47-4.81) and 5.07 days (95% CI 4.80-5.40) in patients attached to a conventional wall vacuum system, regardless of the type of surgery performed **(Table 2)**.

Table 2. Average duration of pleural drainage in digital and conventional PDS, regardless of the performed surgical intervention

Type of drainage system/ duration of pleural drainage in days	N	Duration in days (X±SD)
Digital PDS	38	4.63±0.54
Conventional PDS	42	5.07±0.94

A statistically significant difference was found in favor of the digital pleural drainage system ($p<0.014$).

Financial costs in terms of hospital stay in the postsurgical period

Regarding the financial costs in the postoperative period, we revealed that the hospital stay of patients attached to the digital drainage system amounted to an average of 119.4±7.15 BGN*, while in patients with conventional PDS, the average cost of stay was 159±10.50 BGN **(Table 3)**.

Table 3. Average cost of hospital stay according to the type of PDS regardless of the intervention performed

Type of drainage system / financial cost in BGN*	N	Financial cost (X±SD) BGN
Digital PDS	38	119.4±7.15
Conventional PDS	42	159±10.50

*1 BGN = 0.51 EUR

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Postoperative air leak in relation of the type of surgery

The observed postoperative air leak in days in relation to the type of surgery performed is shown in **Table 4**. In a large percentage of the cases, air leak was not observed **(Fig. 1)**, and when it was diagnosed, it ceased within 1-4 days and it was possible to be definitively diagnosed and monitored mainly in patients attached to the digital drainage system.

No statistically significant results ($p>0.5$) were found regarding the duration of postoperative air leak according to the type of pleural drainage system used. However, it is noteworthy that in patients attached to the digital drainage system, diagnosing and monitoring air leak in the postoperative period does not create difference in contrast to patients attached to the wall vacuum system. When comparing the duration of postoperative air leak in patients after decortication with that of the other patients, regardless of the type of drainage system to which they were attached, a value of $p<0.05$ was calculated. However, we believe that due to the small number of patients who underwent decortication **(Table 4)**, this result cannot be categorized as one that has statistical significance.

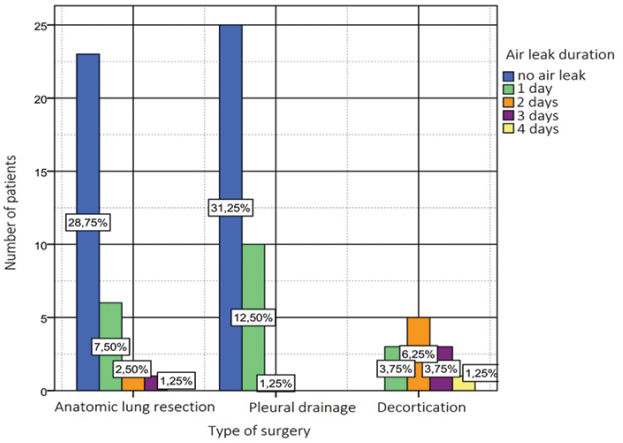

Figure 1. Postoperative air leak duration percentage in relation to the type of surgery performed.

DISCUSSION

In conventional PDS, timely detection of air leak and measurement of its volume are not easy, creating disagreement even amongst experienced clinicians.[12] In some patients, air leak is low and difficult to diagnose using a conventional pleural drainage system. In such cases, it is necessary to perform the so-called 'leak test' with subsequent control radiography before removal of the thoracic drain.[13] This additionally prolongs the hospital stay and increases its cost. Due to the non-definite data on the presence or absence of air leak in patients attached to a conventional drainage system in our study, a 'leak test' was performed routinely with subsequent control radiography before removing the thoracic drain. This was one of the reasons for the increase in costs for patients with conventional PDSs.

It has been shown in another study that postoperative immobilization of patients attached to a conventional PDS is associated with a number of complications, some of which are life-threatening (atelectasis, pneumonia, thromboembolism).[14] In contrast to this finding no life-threatening complications were observed in the study group. Digital pleural drainage systems are mobile and small in size which favors early mobilization and rehabilitation of the patient.[15] In cases in which patients attached to a conventional pleural drainage system need to be relocated for examination or for any other reason, the thoracic drain must be clamped in order to prevent fluids or air from flowing back to the pleural cavity, as well as the collector chamber should always be positioned below chest level. Moreover, when postoperative air leak is present, it has been demonstrated that drain clamping may also be the cause of tension pneumothorax.[3] This risk is absent in patients attached to a digital drainage system. Their transport is facilitated and secured with unchanged intrapleural pressure.[16]

There are several studies in the world literature comparing the effectiveness, indications, and benefits of conventional and digital pleural drainage systems.[17-19] While some authors claim that using a digital pleural drainage system encourages early postoperative ambulation, shortens hospital stays, and lowers costs, other authors assert that using a digital thoracic drainage system after anatomic lung resection did not reduce the time needed to place a chest tube.[13] On the other hand, conventional pleural drainage systems have a number of features that are considered to be a serious disadvantage and are making their use less frequent. Wall vacuum systems in hospitals do not always provide reliable negative pressure. Proper pressure adjustment in PDS with a water column creates difficulties.

Table 4. Duration of postoperative air leak in relation to the type of surgery performed

Type of operation	Air leak duration in days					Total cases
	No postoperative air leak	1 day	2 days	3 days	4 days	
Anatomical resection	23	6	2	1	0	32
Pleural drainage	25	10	1	0	0	36
Decortication	0	3	5	3	1	12
Total cases	48	19	8	4	1	80

The airflow in the thoracic drain changes with the changes in the vacuum values of the wall aspiration system, the negative pressure becomes unstable due to water loss.[20] In a single-chamber PDS, the negative intrapleural pressure also increases with the increasing airflow.[21] In digital PDSs, these disadvantages are absent. Their adjustment and setting of the desired negative pressure is much easier.[15] The desired and set parameters are not affected by a change in the patient's position. Some PDSs even have a self-cleaning function in case of drain blockage, there are alarm mechanisms when any functional issues appear, as well as systems to prevent backflow of pleural secretions.[22]

Our results found a statistically significant difference in favor of the digital pleural drainage systems.

We demonstrated that the average duration of pleural drainage in a digital system was shorter than that in a conventional PDS (4.6 vs. 5 days), regardless of what surgical intervention is performed. This finding is in concordance with the study by Zhou et al., who also reported that digital chest drainage reduced the duration of chest tube placement by 0.72 days[16] and with the study by Gilbert et al. (analog system – 5.6 days; digital = 4.9 days)[17]. However, this variation in days, while numerically and statistically different, may not reflect actual differences since the distinction is slight in clinical practice. A similar study also concluded that a digital system was superior in contrast to a conventional one and was associated with a shorter duration of chest tube placement (3.6 vs. 4.7 days).[10] These data are in contrast with the observation of Takamochi et al., who found no statistically significant difference between the digital thoracic drainage system and a traditional thoracic drainage system with regard to the duration of chest tube placement (median 2.0 vs. 3.0 days).[13]

The results of our study suggest that this type of devices turned out to reduce significantly the financial costs in the postoperative period. We attribute this result partially to the necessity for an air leak test and mandatory follow-up chest radiography prior to drain removal in patients attached to a conventional vacuum system due to difficulties in diagnosing and recording postoperative air leak. A big significant difference in postoperative costs was found as well by other researchers when they compared digital with conventional chest drainage systems (443.16 euros to 138.73 euros; p=0.004).[16]

Postoperative air leak is one of the most common complications after lung surgery.[23] According to some studies, this complication occurs in up to 75% of patients depending on the surgery performed.[12] In 5%-10% of patients, air leak lasts for more than five days, then it is classified as persistent or prolonged postoperative air leak (PPAL).[24] PPAL is the most common reason prolonging hospital stay, leading to a significant increase in financial costs and is associated with a number of cardiopulmonary postoperative complications.[25] Therefore, it is necessary to optimize post-operative approaches for faster recovery and early patient mobilization. Prolonged postoperative air leak was not observed in the patients included in our study. We concluded that in most patients, air leak was not detected, and when it was observed, it ceased within 1 to 4 days. These results were similar to others that proved air leak duration was 1.0 vs. 2.2 days when using digital chest system compared to conventional systems.[10]

Regardless of its origin, PPAL requires longer pleural drainage, which can be performed using conventional or digital pleural drainage system.[26] Digital drainage systems use electronic sensors to measure changes in pressure and thus allow continuous quantification of air leak and graphically represent its fluctuations over time.[2,27] That is why the air leak in our study was possible to be definitely diagnosed mainly in patients with the digital drainage system applied. According to Takamochi K, the values of peak air leak and its fluctuations in time recorded by digital drainage systems have a prognostic value for the occurrence of prolonged postoperative air leak after lung resection.[28] There are devices that provide data on dynamic intrapleural pressure values and have the ability to adjust the applied negative pressure according to the fluctuations in the intrapleural pressure, maintaining a preset value within 0.1 cm H_2O. There are studies in support of the fact that large fluctuations in intrapleural pressure during the postoperative period are associated with a higher incidence of PPAL.[29] Thus, by maintaining relatively stable intrapleural pressure values, digital drainage systems can reduce the duration of postoperative air leak.[30] The possibility to record the volume of air leak and the amount of pleural secretion in real time, as well as their previous values favors the early removal of the chest drain and shorten the hospital stay.[12,18,25,28,31] This, in turn, undoubtedly has a financial impact.[31]

CONCLUSIONS

Digital pleural drainage systems provide clinicians with an opportunity to assess more accurately important clinical and economical parameters. They shorten slightly hospital stays and reduce significantly postoperative costs. Relying on these features, we assume that digital drainage devices may undoubtedly continue to invade everyday surgical practice.

Limitation of the study

The study's findings must be viewed in light of two major limitations that could be addressed in future research. First, when assessing the postoperative air leak, the study focused on a smaller sample size of patients after decortication compared to the other patients, regardless of the type of drainage system to which they were attached. We believe that the small number of patients who underwent decortication made statistical analysis and identifying significant relationships in the data impossible. This could be useful in future studies. Second, other methods of pleural drainage were not covered in this study. However, they are not

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used in our clinic, which may explain why they were not included in the research, which would have strengthened the comparative analysis.

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Competing Interests

The authors have declared that no competing interests exist.

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Традиционные и цифровые системы плеврального дренажа – преимущества и недостатки

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Резюме

Введение: Дренирование плевральной полости является важнейшим компонентом хирургического лечения больных с различными заболеваниями органов грудной клетки. Цифровые дренажные системы всё чаще используются в современных торакальных хирургических процедурах, что, вероятно, является результатом их эффективности в обеспечении ранней послеоперационной ходьбы, сокращении времени пребывания в больнице и снижении затрат. Подавляющее большинство торакальных хирургов во всём мире предпочитают цифровые дренажные системы традиционным. Однако преимущества первого метода оспариваются некоторыми исследователями.

Цель: Целью данного исследования было сравнение двух типов механизмов плеврального дренажа, традиционного и цифрового, с точки зрения продолжительности плеврального дренажа в днях, финансовых затрат и продолжительности послеоперационной утечки воздуха.

Материалы и методы: В исследовании приняли участие 80 пациентов, перенёсших различные торакальные хирургические вмешательства в клинике торакальной и абдоминальной хирургии Университетской больницы Святого Георгия в Пловдиве. Они были разделены на две группы: 1-ю группу составили 42 пациента, которым в послеоперационном периоде была подключена традиционная неподвижная плевральная дренажная система, 2-я группа – 38 пациентов, у которых применялась мобильная цифровая плевральная дренажная система. Основными анализируемыми данными были продолжительность плеврального дренирования, продолжительность послеоперационной утечки воздуха, пребывание в стационаре и финансовые затраты.

Результаты: Средняя продолжительность плеврального дренирования независимо от операции и типа примененной дренажной системы составила 4.86 ± 0.8 дня. Средняя продолжительность плеврального дренирования у пациентов, подключенных к мобильной цифровой дренажной системе, была короче, чем у пациентов с традиционной плевральной немобильной дренажной системой, независимо от типа проведённого хирургического вмешательства. Эта разница была статистически значимой в пользу цифрового плеврального дренажа. Исследование также выявило статистически значимую разницу с точки зрения финансовых затрат в пользу цифровой системы слива. Средняя стоимость пребывания в стационаре для пациентов, подключенных к мобильной цифровой дренажной системе, составила 119.40 ± 7.15 лв., тогда как средняя стоимость пребывания в стационаре для пациентов, подключенных к традиционной плевральной дренажной системе (PDS), составила 15910.50 лв. Что касается продолжительности послеоперационной утечки воздуха, то разница между типами использованных механизмов плеврального дренажа не была убедительной.

Заключение: Цифровые системы плеврального дренирования дают клиницистам возможность более точно оценить послеоперационную утечку воздуха, отслеживать её динамику, сократить сроки пребывания в стационаре, снизить послеоперационные затраты и оптимизировать время удаления дренажа из грудной клетки. Благодаря этим особенностям они, несомненно, будут и дальше входить в повседневную хирургическую практику.

Ключевые слова

традиционные плевральные дренажные системы, цифровые плевральные дренажные системы, финансовые затраты, пребывание в стационаре, послеоперационная утечка воздуха