RESEARCH PAPER

Mechanical Reliability of Hospital Oxygen Supply Systems and Its Impact on Respiratory Therapy

Saeed Mubarak Almatir[1*], Abdulaziz Mohammed Alghamdi[1], Abdulrahman Marzaq Alotaibi[1], Omar Hassan Harisi[1], Awadh Ali Alshehri[1], Mohammed Yousef Alhazmi[2], Abdulrahman Mohammed Alasmari[1], Ahmed Saeed Abdullah Alqahtani[1]

[1]Armed Forces Hospital Southern Region, Khamis Mushait, Saudi Arabia
[2]King Fahad Military Hospital, Khamis Mushait, Saudi Arabia
[1]Respiratory Therapist (Saeed Mubarak Almatir) | Email: saeed.almatir@gmail.com
[1]Respiratory Therapist (Abdulaziz Mohammed Alghamdi) | Email: Alghamdiabdulaziz@outlook.sa
[1]Respiratory Therapist (Abdulrahman Marzaq Alotaibi) | Email: Dhooom.alotaibi@gmail.com
[1]Respiratory Therapist (Omar Hassan Harisi) | Email: harisiomar97@gmail.com
[1]Respiratory Therapist (Awadh Ali Alshehri) | Email: awdh1416@hotmail.com
[2]Respiratory Therapist (Mohammed Yousef Alhazmi) | Email: mohalhazmi123@gmail.com
[1]Respiratory Therapist (Abdulrahman Mohammed Alasmari) | Email: abdulrhman.official2@gmail.com
[1]Respiratory Therapist (Ahmed Saeed Abdullah Alqahtani) | Email: ahmadsqahtani@gmail.com
***Corresponding Author:** Saeed Mubarak Almatir, Respiratory Therapist, Armed Forces Hospital Southern Region, Khamis Mushait, Saudi Arabia | Email: saeed.almatir@gmail.com

Abstract

Hospital oxygen supply systems are critical components of healthcare infrastructure, particularly in intensive care units (ICUs), emergency departments, operating rooms, neonatal units, and respiratory therapy services. The reliability of these systems depends on the coordinated performance of oxygen sources, storage facilities, pressure regulation devices, pipeline networks, valves, alarms, terminal units, and backup systems. Mechanical failures at any point in the oxygen delivery chain may result in pressure instability, interruption of oxygen availability, compromised ventilator performance, delayed respiratory interventions, and potentially serious patient-safety consequences.

Respiratory therapists (RTs) are among the healthcare professionals most directly affected by the reliability of hospital oxygen infrastructure because many respiratory interventions—including mechanical ventilation, high-flow nasal cannula therapy, non-invasive ventilation, oxygen therapy, and emergency resuscitation—depend on a stable medical gas supply. Mechanical and facilities engineering teams, meanwhile, are responsible for maintaining the infrastructure that supports these clinical activities.

This paper examines the mechanical reliability of hospital oxygen supply systems and its impact on respiratory therapy practice. It discusses major system components, common failure mechanisms, preventive and predictive maintenance, pressure and flow requirements, alarm systems, emergency preparedness, and interdisciplinary collaboration between respiratory therapists and engineering personnel. A reliability-centered approach integrating preventive maintenance, real-time monitoring, staff training, risk assessment, and contingency planning is proposed to enhance oxygen system resilience and patient safety.

Keywords: Medical oxygen, respiratory therapy, mechanical reliability, medical gas pipeline system, mechanical ventilation, patient safety, preventive maintenance, hospital engineering, oxygen supply.

How to cite this article: Saeed Mubarak Almatir, Abdulaziz Mohammed Alghamdi, Abdulrahman Marzaq Alotaibi, Omar Hassan Harisi, Awadh Ali Alshehri, Mohammed Yousef Alhazmi, Abdulrahman Mohammed Alasmari, Ahmed Saeed Abdullah Alqahtani. Mechanical Reliability of Hospital Oxygen Supply Systems and Its Impact on Respiratory Therapy. Int J Drug Deliv Technol. 2026;16(78s):1443-1451. DOI: 10.25258/ijddt.16.78s.195.

1. Introduction

Medical oxygen is an essential therapeutic gas used throughout modern healthcare facilities. Unlike many medications that are stored and administered individually, oxygen is frequently distributed through a centralized mechanical infrastructure capable of supplying numerous patients simultaneously. This infrastructure must continuously deliver oxygen at appropriate pressure, flow, purity, and availability.

The importance of oxygen infrastructure becomes particularly evident in critical care environments. Mechanically ventilated patients may be completely dependent on the continuous availability of medical gases. High-flow nasal cannula systems can also require substantial gas flows, while operating rooms, emergency departments, neonatal ICUs, and respiratory wards may simultaneously create significant demand.

The COVID-19 pandemic highlighted the vulnerability of hospital oxygen infrastructure when unusually large numbers of patients required high-flow oxygen simultaneously. Even when adequate quantities of oxygen were technically available, limitations involving storage, vaporization, pipeline capacity, pressure regulation, or distribution could affect the ability to deliver oxygen effectively.

Consequently, oxygen-system safety should not be evaluated only according to the quantity of oxygen stored. Mechanical reliability must be considered throughout the entire supply chain, from the primary oxygen source to the patient’s bedside terminal.

Respiratory therapists have an important position within this system. They operate oxygen-dependent devices and are often among the first clinical professionals to recognize abnormalities such as low supply pressure, unexpected ventilator alarms, inadequate flow, or abnormal device performance.

This creates an important interface between **clinical respiratory therapy and mechanical engineering**. Effective collaboration between these disciplines can improve early fault detection, emergency response, equipment reliability, and ultimately patient safety.

2. Overview of Hospital Oxygen Supply Systems

A hospital oxygen supply system generally consists of several interconnected components designed to provide continuous oxygen availability.

2.1 Primary Oxygen Sources

Hospitals may obtain oxygen through:

- Liquid oxygen storage systems
- Compressed oxygen cylinder manifolds
- Oxygen concentrator systems
- Pressure swing adsorption (PSA) oxygen-generation plants
- Combinations of these technologies

Large hospitals frequently use bulk liquid oxygen because of its capacity to support high clinical demand.

The selection and design of the oxygen source should account for hospital size, peak oxygen consumption, number of critical-care beds, anticipated emergencies, redundancy requirements, and the availability of external oxygen suppliers.

3. Mechanical Components Affecting System Reliability

The reliability of oxygen delivery depends on more than the primary oxygen source. Multiple mechanical components are involved between storage and bedside delivery.

Important components include:

- Storage tanks or cylinder manifolds
- Vaporizers
- Pressure regulators
- Pressure-reducing stations
- Isolation valves
- Check valves
- Pipeline networks
- Zone valve boxes
- Pressure sensors
- Area and master alarm systems
- Terminal outlets
- Emergency oxygen connections
- Backup oxygen sources

A failure involving one component can potentially influence multiple clinical areas.

Pressure Regulator Failure

Pressure regulators maintain appropriate downstream pressure. Malfunction can produce either excessive or inadequate pressure, both of which can affect medical equipment.

Valve Failure or Incorrect Valve Position

Isolation valves allow sections of a pipeline to be isolated during maintenance or emergencies. Accidental closure or incorrect operation may interrupt oxygen delivery to entire clinical areas.

Vaporizer Capacity Limitations

In liquid oxygen installations, oxygen must be converted from liquid to gaseous form before distribution. Extremely high demand can challenge vaporization capacity, particularly when system capacity has not been designed for unusually high simultaneous consumption.

Alarm System Failure

Alarm systems provide early warning of abnormal pressure or supply conditions. Failure of alarms may delay recognition of mechanical problems until bedside devices begin alarming.

Terminal Outlet Problems

Damaged or obstructed terminal outlets can cause local problems even when the central oxygen infrastructure is functioning correctly.

6. Relationship Between Oxygen Pressure and Respiratory Equipment

Mechanical ventilators and other respiratory devices are designed to operate within specified gas-supply parameters established by their manufacturers.

Stable oxygen pressure contributes to accurate blending and reliable equipment operation. Significant deviations can potentially affect delivered oxygen concentration, flow performance, and device functionality.

For this reason, abnormal ventilator performance should not automatically be assumed to represent failure of the ventilator itself.

For example, malfunction of a pressure regulator may cause inadequate downstream pressure. A pipeline leak can progressively increase oxygen consumption and reduce system efficiency. Incorrectly positioned isolation valves can interrupt oxygen delivery to an entire clinical zone.

Therefore, reliability assessment should examine the complete system rather than individual components independently.

4. Mechanical Reliability and Respiratory Therapy

Respiratory therapists routinely operate equipment that depends directly or indirectly on pressurized medical gases.

Examples include:

- Mechanical ventilators
- High-flow nasal cannula systems
- Non-invasive ventilation devices
- Oxygen flowmeters
- Oxygen blenders
- Nebulization systems
- Resuscitation devices
- Anesthesia and respiratory support equipment

A reliable oxygen supply should maintain adequate pressure and flow even when demand changes rapidly.

If supply pressure decreases substantially, oxygen-dependent equipment may generate alarms, alter delivered gas concentrations, or fail to achieve prescribed treatment parameters.

For critically ill patients, even short interruptions can become clinically significant.

5. Major Failure Modes and Their Respiratory Therapy Impact

Several mechanical problems may compromise oxygen delivery.

Pipeline Leakage

Leaks may occur because of damaged piping, deteriorated joints, faulty terminal outlets, or maintenance-related damage. Persistent leakage increases oxygen consumption and may contribute to pressure deterioration during high-demand periods.

components according to applicable standards, manufacturer instructions, regulatory requirements, and facility risk assessments.

Maintenance activities may include:

- Inspection for pipeline leakage
- Functional testing of pressure regulators
- Inspection of valves
- Verification of alarm functionality
- Inspection of terminal units
- Monitoring of oxygen source performance
- Testing of backup supply arrangements
- Calibration of relevant pressure sensors
- Documentation of abnormalities and corrective actions

Maintenance records should be retained and periodically analyzed to identify recurring problems.

9. Predictive Maintenance and Smart Monitoring

Traditional maintenance is increasingly being supplemented by condition-based and predictive approaches.

Modern oxygen infrastructure can incorporate sensors capable of continuously measuring parameters such as:

- Pipeline pressure
- Oxygen flow
- Storage level
- System consumption
- Equipment status
- Alarm frequency

Historical data can then be analyzed to identify abnormal patterns.

For example, an unexplained gradual increase in baseline oxygen consumption may suggest leakage. Repeated pressure fluctuations may indicate regulator problems or inadequate system capacity.

Artificial intelligence and machine-learning techniques could eventually enhance these

Respiratory therapists should consider three broad categories when troubleshooting:

1. Patient-related causes
2. Device or circuit-related causes
3. Medical gas supply-related causes

Recognizing the third category can considerably shorten the time required to identify infrastructure-related failures.

---

7. High-Flow Oxygen Therapy and Infrastructure Demand

High-flow nasal cannula therapy has increased substantially in acute respiratory care. Individual systems can require high gas flow, and simultaneous treatment of numerous patients can substantially increase institutional oxygen demand.

This creates an important interaction between respiratory therapy practice and mechanical infrastructure.

Engineering teams should understand clinical oxygen utilization patterns, while respiratory departments should understand infrastructure limitations.

During periods of high respiratory demand, hospitals should evaluate:

- Number of patients receiving high-flow therapy
- Oxygen flow per patient
- Number of mechanically ventilated patients
- Pipeline pressure trends
- Bulk oxygen inventory
- Vaporizer performance
- Reserve oxygen availability
- Expected duration of increased demand

This information can support proactive capacity management.

8. Preventive Maintenance

Preventive maintenance is fundamental to medical oxygen system reliability.

A structured program should include scheduled inspection and testing of critical mechanical

System Component / Indicator	Potential Mechanical Problem	Possible Impact on Respiratory Therapy	Recommended Control
Pressure regulators	Abnormal downstream pressure	Ventilator or respiratory-device alarms and impaired performance	Scheduled inspection, testing, and pressure monitoring
Pipeline network	Leakage or obstruction	Reduced pressure/flow and increased oxygen consumption	Leak detection and preventive maintenance
Zone isolation valves	Accidental closure or mechanical failure	Complete oxygen interruption within a clinical zone	Valve identification, restricted access, and staff training
Alarm system	Sensor/alarm malfunction	Delayed recognition of supply failure	Routine alarm testing and escalation protocols
Terminal outlets	Leakage, obstruction, or damage	Inadequate oxygen delivery to individual beds	Routine inspection and prompt reporting

systems by predicting equipment degradation before complete mechanical failure occurs.

10. Risk Assessment

Hospitals should conduct formal risk assessments of medical oxygen infrastructure.

The assessment should consider both the probability of failure and its clinical consequences.

A component supplying an outpatient area may have a different risk profile from a component supplying an ICU containing multiple mechanically ventilated patients.

Risk-based prioritization allows maintenance resources to focus on components whose failure could have the greatest impact on patient safety.

Failure Mode and Effects Analysis (FMEA) can be particularly useful. Potential failure modes are identified, their consequences are evaluated, and preventive controls are developed before an adverse event occurs.

11. Key Reliability Indicators and Respiratory Therapy Impact

System Component / Indicator	Potential Mechanical Problem	Possible Impact on Respiratory Therapy	Recommended Control
Central oxygen source	Depletion or supply interruption	Loss of oxygen availability to multiple units	Automatic reserve supply and continuous inventory monitoring

Respiratory therapists can therefore function as an important clinical early-warning layer within the hospital oxygen safety system.

13. Role of Mechanical and Facilities Engineering Teams

Engineering personnel are responsible for maintaining the mechanical infrastructure required for safe oxygen distribution.

Their responsibilities typically include:

- Preventive maintenance
- Pipeline inspection
- Pressure monitoring
- Valve management
- Alarm-system testing
- Capacity assessment
- Mechanical troubleshooting
- Coordination with medical gas suppliers
- Maintaining system drawings and documentation
- Planning system upgrades
- Emergency restoration of supply

Engineering teams should also communicate planned maintenance to affected clinical departments before manipulating valves or other components that could influence oxygen availability.

14. Interdisciplinary Collaboration

The relationship between respiratory therapists and engineering personnel should extend beyond emergency troubleshooting.

Hospitals can establish multidisciplinary medical gas safety teams involving:

- Respiratory therapy
- Mechanical/facilities engineering
- Biomedical engineering
- Nursing
- Anesthesia
- Intensive care
- Safety management
- Infection prevention when relevant
- Hospital administration

System Component / Indicator	Potential Mechanical Problem	Possible Impact on Respiratory Therapy	Recommended Control
Backup oxygen system	Insufficient capacity or failure to activate	Inability to maintain therapy during primary-system failure	Emergency testing and reserve-capacity assessment
Oxygen flow/pressure monitoring	Inadequate surveillance	Failure to identify increasing demand or developing faults	Continuous monitoring and centralized dashboards

12. Role of Respiratory Therapists

Respiratory therapists should not be expected to perform specialized mechanical maintenance of centralized oxygen systems. However, they have an important clinical surveillance role.

Their responsibilities may include:

- Recognizing abnormal ventilator or oxygen-device behavior
- Checking bedside gas connections during troubleshooting
- Reporting suspected pressure abnormalities
- Identifying unexpected changes affecting multiple devices
- Supporting emergency oxygen conservation strategies
- Participating in oxygen-system emergency exercises
- Communicating changes in respiratory oxygen demand to relevant departments

Regular meetings can review oxygen consumption, mechanical failures, alarm events, maintenance findings, and near misses.

This approach converts oxygen-system management from a purely technical engineering responsibility into an integrated patient-safety program.

15. Emergency Preparedness

Every healthcare facility using centralized oxygen should maintain a documented emergency response plan for oxygen-system failure.

Potential scenarios include:

- Primary oxygen source failure
- Pipeline rupture
- Major oxygen leakage
- Pressure-regulation failure
- Fire-related isolation
- Bulk supply depletion
- Natural disasters
- Unexpected mass-casualty demand

Emergency planning should clearly define responsibilities.

Engineering personnel should identify and isolate mechanical failures, while respiratory therapists prioritize patients according to oxygen dependency and coordinate temporary respiratory support.

Portable oxygen cylinders or alternative sources should be strategically available for high-risk areas.

16. Simulation and Training

Emergency protocols are effective only when staff understand how to implement them.

Hospitals should periodically conduct multidisciplinary simulation exercises involving a hypothetical oxygen-system failure.

A scenario could simulate sudden loss of central oxygen pressure in an ICU. Respiratory therapists would respond to ventilator alarms and secure alternative oxygen sources, while engineering personnel investigate the pipeline system and restore supply.

Post-simulation evaluation can identify weaknesses such as:

- Delayed communication
- Insufficient portable oxygen
- Unclear responsibilities
- Difficulty locating isolation valves
- Inadequate staff knowledge
- Failure of escalation procedures

Corrective actions should then be incorporated into emergency planning.

17. Quality Indicators

Hospitals can monitor measurable indicators to evaluate oxygen-system reliability.

Potential key performance indicators include:

- Number of unplanned oxygen interruptions
- Number of medical gas pressure alarms
- Percentage of preventive maintenance completed on time
- Number of reported oxygen-system leaks
- Average response time to oxygen infrastructure alarms
- Number of respiratory therapy incidents associated with gas supply
- Percentage of successful backup-system tests
- Number of staff completing medical gas emergency training

Monitoring these indicators allows healthcare organizations to identify trends and evaluate improvement initiatives.

18. Discussion

Hospital oxygen should be viewed simultaneously as a therapeutic agent and a critical infrastructure service. Safe respiratory therapy therefore depends not only on clinical expertise but also on the mechanical reliability of the systems supplying therapeutic gases.

Hospitals should also consider centralized digital dashboards capable of displaying oxygen storage, pressure, consumption, and alarm information to authorized personnel. In high-risk facilities, predictive analytics may provide additional opportunities for detecting abnormal consumption or mechanical deterioration.

A major strength of reliability-centered oxygen management is its interdisciplinary nature. Respiratory therapists understand bedside oxygen demand and clinical consequences, while mechanical engineers understand infrastructure capacity, pressure regulation, distribution, and failure mechanisms.

Combining these perspectives improves system resilience.

20. Conclusion

Mechanical reliability of hospital oxygen supply systems is directly connected to the safety and effectiveness of respiratory therapy. Failures involving oxygen sources, regulators, pipelines, valves, alarms, or terminal units can disrupt oxygen-dependent treatment and place critically ill patients at risk.

Respiratory therapists represent an essential clinical interface between patients and medical gas infrastructure. Mechanical and facilities engineers provide the technical expertise necessary to maintain reliable oxygen generation, storage, regulation, and distribution.

Hospitals should therefore adopt an integrated reliability model combining preventive maintenance, continuous monitoring, redundancy, emergency preparedness, staff training, risk assessment, and multidisciplinary collaboration. Strengthening cooperation between respiratory therapists and engineering teams can improve early detection of oxygen-system abnormalities, reduce unplanned interruptions, enhance emergency response, and contribute to safer respiratory care.

References

1. World Health Organization. *Oxygen Sources and Distribution for COVID-19 Treatment Centres: Interim Guidance*. Geneva: World Health Organization; 2020.
2. World Health Organization. *Technical Specifications for Pressure Swing Adsorption (PSA) Oxygen Plants*. Geneva: World Health Organization; 2020.
3. World Health Organization, UNICEF. *WHO-UNICEF Technical Specifications and Guidance for Oxygen Therapy Devices*. Geneva: World Health Organization; 2019.

Another important consideration is the changing nature of oxygen demand. Hospitals designed many years ago may now support substantially larger numbers of ventilators, high-flow devices, and critical-care beds. Therefore, historical system capacity should not automatically be assumed to remain adequate.

Engineering assessment should periodically compare infrastructure capacity with current and anticipated clinical demand.

Digital monitoring provides another opportunity for improvement. Continuous measurement of pressure, flow, and oxygen consumption can provide earlier detection of developing problems than periodic manual inspection alone.

Ultimately, the goal should be to move from reactive maintenance—repairing systems after failure—to proactive reliability management based on prevention, monitoring, risk analysis, and interdisciplinary preparedness.

19. Recommendations

Healthcare organizations should establish comprehensive medical oxygen reliability programs that integrate engineering and respiratory therapy. Priority actions should include routine mechanical inspection, continuous monitoring of critical pressure and supply parameters, verification of backup oxygen capacity, periodic pipeline capacity assessments, formal reporting of gas-supply abnormalities, multidisciplinary FMEA, and emergency simulations.

Respiratory therapy departments should participate in infrastructure planning whenever substantial changes in oxygen-dependent technologies or bed capacity are anticipated.

4. National Fire Protection Association. *NFPA 99: Health Care Facilities Code*. Quincy, MA: NFPA.
5. International Organization for Standardization. *ISO 7396-1: Medical Gas Pipeline Systems—Part 1: Pipeline Systems for Compressed Medical Gases and Vacuum*. Geneva: ISO.
6. International Organization for Standardization. *ISO 10083: Oxygen Concentrator Supply Systems for Use with Medical Gas Pipeline Systems*. Geneva: ISO.
7. World Health Organization. *Foundations of Medical Oxygen Systems*. Geneva: World Health Organization.
8. World Health Organization. *Oxygen System Planning Tool and Technical Resources for Medical Oxygen Systems*. Geneva: World Health Organization.
9. American Association for Respiratory Care. Clinical practice resources and standards related to oxygen administration and respiratory care. Irving, TX: AARC.
10. The Joint Commission. Medical equipment, utility systems, emergency management, and environment-of-care requirements applicable to healthcare facilities. Oakbrook Terrace, IL: The Joint Commission.