Hospital Oxygen Supplies
Supply, Shortages and Sustainment

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Resources

The Hospital Oxygen Supply: An "O2K" Problem

James K Stoller MD, Mark Stefanak PE, Douglas Orens MBA RRT, and John Burkhart RRT

[Respir Care 2000;45(3):300–305]

Oxygen Supplies During a Mass Casualty Situation

Ray H Ritz RRT FAARC and Joseph E Previtera RRT

Respir Care 2008;53(2):215–224.

Oxygen Supplies in Disaster Management

Thomas C Blakeman MSc RRT and Richard D Branson MSc RRT FAARC

Respir Care 2013;58(1):173–182.

Shortages and Vulnerabilities of Hospital Oxygen Systems

Robert L Chatburn and Richard D Branson

Respir Care 2022;67(8):1002–1010.

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Oxygen Production

- Oxygen is separated from air, not chemically manufactured
- Cryogenic air separation is the dominant technology
- Texas Gulf Coast is the largest U.S. production hub
- Linde, Air Products, Air Liquide, and Messer dominate the industry

Oxygen Production

- Mims, Florida – aerospace liquid oxygen
- Brownsville, Texas – Gulf Coast industrial ASU
- Multiple on-site ASUs across U.S. industry
- Typical large ASU capacity: up to ~5,500 TPD
- Aside from medical grade oxygen – oxygen is widely used in manufacturing steel, petrochemical refining, aerospace and wastewater treatment
- Oxygen is delivered by cryogenic tanker trucks, rail tank cars, dedicated pipelines, liquid oxygen storage tanks

Disaster Issues

- Local vs. regional
- Effects on the hospital building
- Effect on local infrastructure (bridges, roads, power)
- A disaster as an event that produces ≥ 10 deaths or leaves ≥ 100 people homeless, displaced or injured (WHO)

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Dual Operational Vessels
Reserve Vessel

Daily Oxygen Use

Table 2. Oxygen Utilization Survey of Beth Israel Deaconess Medical Center*

Type of Use/Location	Number of Beds	Percent of Patients on O_2	Number of Patients on O_2	Average Flow (L/min)	Total Daily Use (L/d)	Total Daily Use (gallons/d)
Floors	320	30	96	4	552,960	170
Intensive care unit	65	70	49	4.5	315,900	97
Operating room	18	100	18	2	51,840	16
Postoperative recovery	23	100	23	4	132,480	41
Cardiac catheter suite	6	100	6	6	25,920	8
Cardiac catheter holding	16	100	16	4	69,120	21
Emergency department	51	35	18	4	102,816	32
Total accounted usage					1,251,036	384
Unaccounted usage					240,969	74

*Data obtained during a 1-day survey.

Ritz R. Respir Care 2008;53:215.

Daily Oxygen Use at UC

- Two large vessels
  - 5,180 gallons and 4,970 gallons (33,000,000 L)
- Reserve vessel
  - 1,330 gallons (4,300,000 L)
- Daily use – 300 gallons/day (977,000 L)
  - 17 days of operation
  - Refilled weekly – volume monitored to never be <half
  - Reserve vessel – 2 days

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Oxygen Usage with Common Delivery Devices

Table 2. Oxygen Delivery Devices

Device Type	Device	Flow(L/min)	Expected F_{IO_2}	Maximum O_2 Usage (L/min)
Adjustable O_2 Flow	Nasal cannula	1–6	0.22–0.40	6
	Simple mask	5–10	0.35–0.50	10
Adjustable F_{IO_2}	Entrainment mask	2–15	0.24–0.60	15
	High-flow nasal cannula	10–60	0.21–1.00	60
	Invasive or noninvasive mechanical ventilation (no leak)	5–15	0.21–1.00	15
	Noninvasive mechanical ventilation (with leak max 40 L/min)	45–55	0.21–1.00	55
Nonadjustable	Partial rebreather mask	≥ 10	0.40–0.70	15
	Non-rebreather mask	≥ 10	0.60–0.70	15

Respir Care 2022;67(8):1002–1010.

OXYGEN CONSERVATION STRATEGIES

Surges of patients with COVID-19 have led to oxygen shortages in many hospitals.

How can we wisely conserve oxygen at the bedside while providing optimum patient care?

Hospital Interventions

Look for equipment leakages.

Anesthesia machines may have slow leaks if left plugged in when not in use; rooms may have piped-in oxygen that has been left on.

Use NIV or HFNC, not both

When possible, attempt to conserve circuits by using either HFNC or noninvasive ventilation on a given patient who does not immediately require invasive ventilation.

Use a mask over high-flow cannula to reduce O2 loss

Placing a mask (like an O2 facemask or a surgical mask) over HFNC will reduce loss, may improve oxygenation, and could have infection control benefits in Covid-19 patients.

Alternate Care Site Interventions

Use liquid oxygen (LOX).

The ratio by volume of LOX to non-compressed oxygen is 860:1, so a lot of LOX can be stored in a small space.

Use an Oxymizer to conserve oxygen.

Its higher luminal diameter and reservoir can deliver up to 15 LPM while using ½ to ¼ of the oxygen from the tank.

Substitute distilled water for sterile water for humidification.

If sterile water is in shortage, the sterile water bottle can be filled with distilled water or sterile flush solutions instead.

Target conservative oxygen saturations.

Patients do not benefit from O2 saturations of >98%. Target 92-94% (rec 90%) for most patients.

Use one oxygen supply for multiple patients.

A Y-connector or an emergency manifold can connect multiple patients to a common cylinder or portable concentrator when necessary.

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Practical Equations

- Oxygen use by ventilator
  - Add bias flow if present

$$\boldsymbol{O_2 (L/min) = [tidal\ volume\ (L) \times respiratory\ rate\ (bpm)] \times \frac{FiO_2 - 0.21}{0.79}}$$

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Facilities Design Concepts

- No set design procedure of medical gas pipe sizing
- Surge tolerances built into systems may not match actual surge due to increased ventilator usage
  - Oxygen usage by other delivery systems must be considered (O_2, masks, cannula, high flow systems)
- Clinicians need a way to communicate with engineers to determine gas flow capacity in each location where ventilators are or will be used

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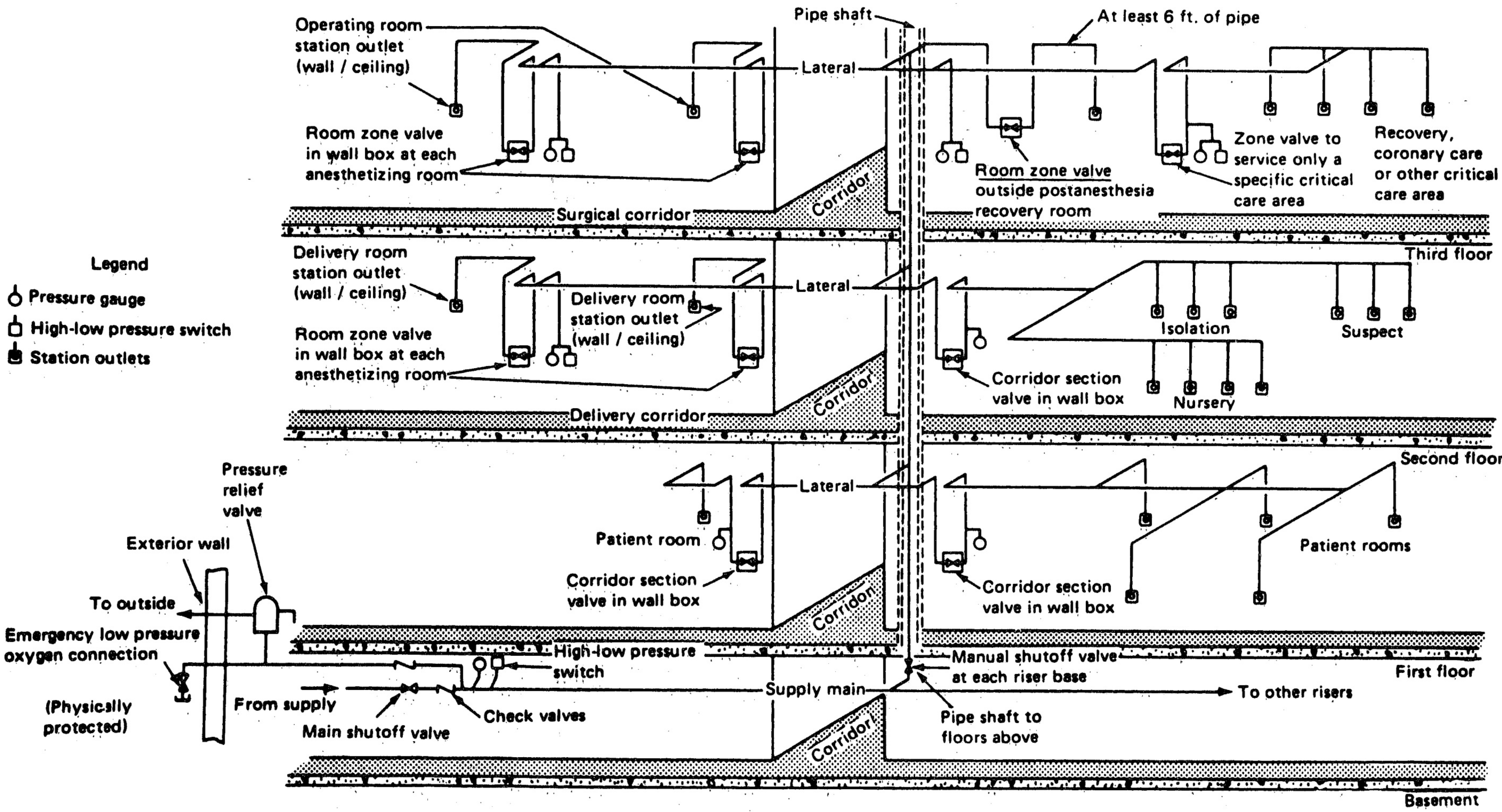
Vulnerabilities



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Choke Points in Medical Gas Plumbing

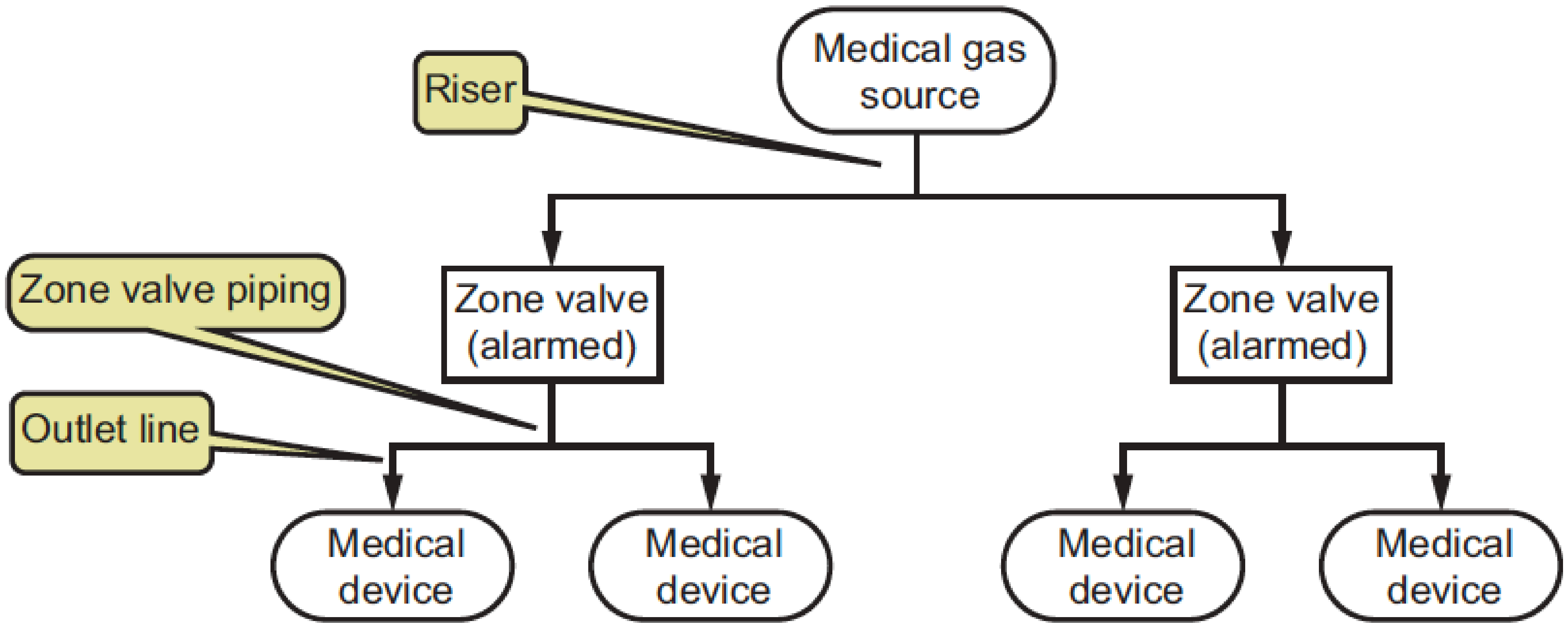

Table 1. Example of the Relations Among Pipe Diameter, Pressure Drop, and Flow Capacity

Pipe Size (inch)	Pressure Drop/100 Ft (psig)	Capacity (L/min)
1¼	1.02	2,700
1½	1.02	4,300
2	0.64	7,000
2	0.60	12,000
3	0.53	18,000

Respir Care 2022;67(8):1002–1010.

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Vulnerabilities

- The average age of US hospitals is 27 years
- Many are much older and include piping from earlier construction
- These systems (often retrofitted) may not have the capacity to provide 50 psig at high flows demanded by some current devices
- UC – first building 1823 – 2 buildings in use that are over 100 years old

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Facilities Design Concepts

- Medical oxygen is stored in liquid form
  - Limitations in flow due to plumbing resistance
  - Limitations in rate of usage due to icing on evaporation coils

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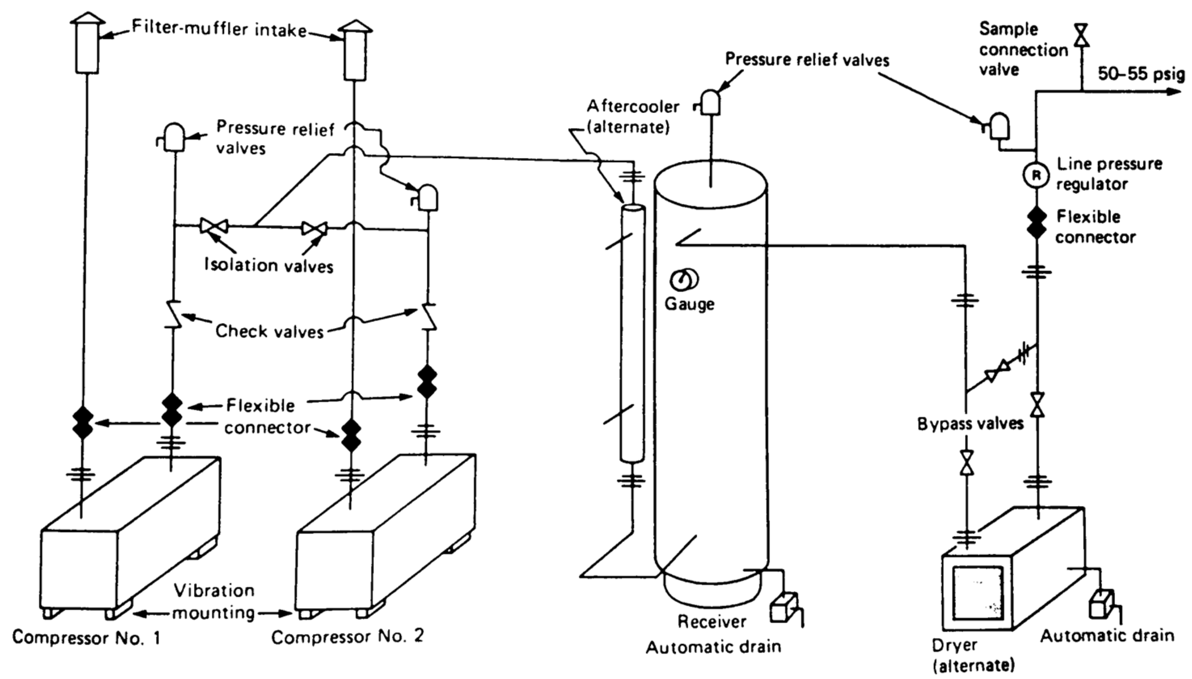
Facilities Design Concepts

- Air is supplied by huge air compressors with dryers to remove water vapor
  - Failure of dryers will lead to water in piping system that can damage ventilators



Branson R, Hess D, Chatburn R. Resp Care Equipment 1995

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Have A Back-up Plan

- In order to back fill the entire system with enough oxygen to supply our facility for 24 hours it would require approximately 142 H cylinders.
- Our facility has the ability to store about 10% of what is needed for 24 hours of oxygen usage. (2.4 hours – you have to have a plan – not a good plan).
- National Fire Protection Association safety regulations storing oxygen:

  ≥ 3,000 cubic feet requires lockable doors, storage racks or chains, indirect heat (if required), and dedicated ventilation.

  > 300 cubic feet to < 3,000 cubic feet requires lockable doors and passive ventilation.

  < 300 cubic feet (12–13 standard E cylinders) may be stored without any restrictions as an operational supply to support clinical operations.

Backfill/Emergency LOX Connection

Connection to allow a portable LOX to feed the hospital (assuming intact oxygen piping)

- Stoller JK. Hospital Supplies: An O2K Problem. Respir Care 2000;45:300.
- Only 63% of surveyed hospitals had an emergency oxygen inlet.
- (1) Hospitals use bulk liquid oxygen systems (with primary and reserve liquid reservoirs) as the main central supply source, with manifolded cylinders as backup.
- (2) Mishaps regarding the main supply line from the bulk oxygen reservoir were reported by 16% (5/32) of responding institutions.
- (3) Most main and reserve tanks were contiguous and fed through a single line to the hospital facility suggests ongoing risk for interruption of an oxygen supply by line mishaps (e.g., street repair).
- (4) Contingency planning to lessen the risk of an interrupted supply should involve back-up systems with physically separated feed lines, as well as tanks of manifolded cylinders along the course of the main hospital oxygen circuit line.

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Manifold Systems

Manifold Systems

ACAD EMERG MED • June 2009, Vol. 16, No. 6 • www.aemj.org

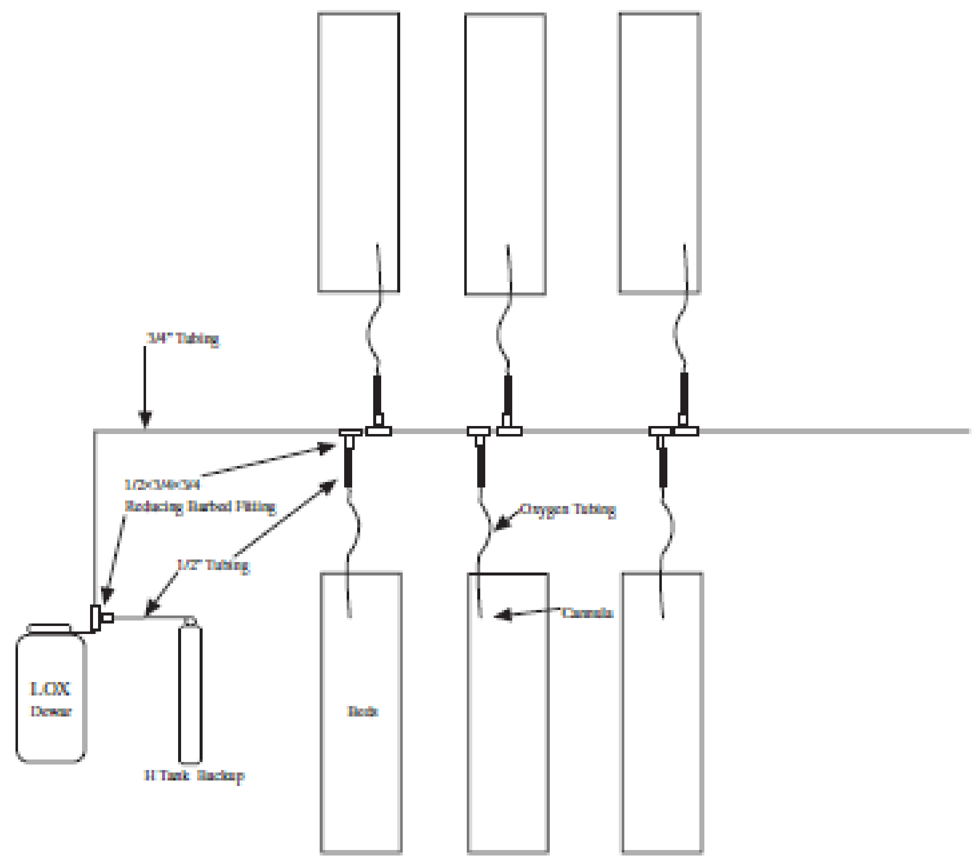

Figure 1. Improvised oxygen system layout. LOX = liquid oxygen.

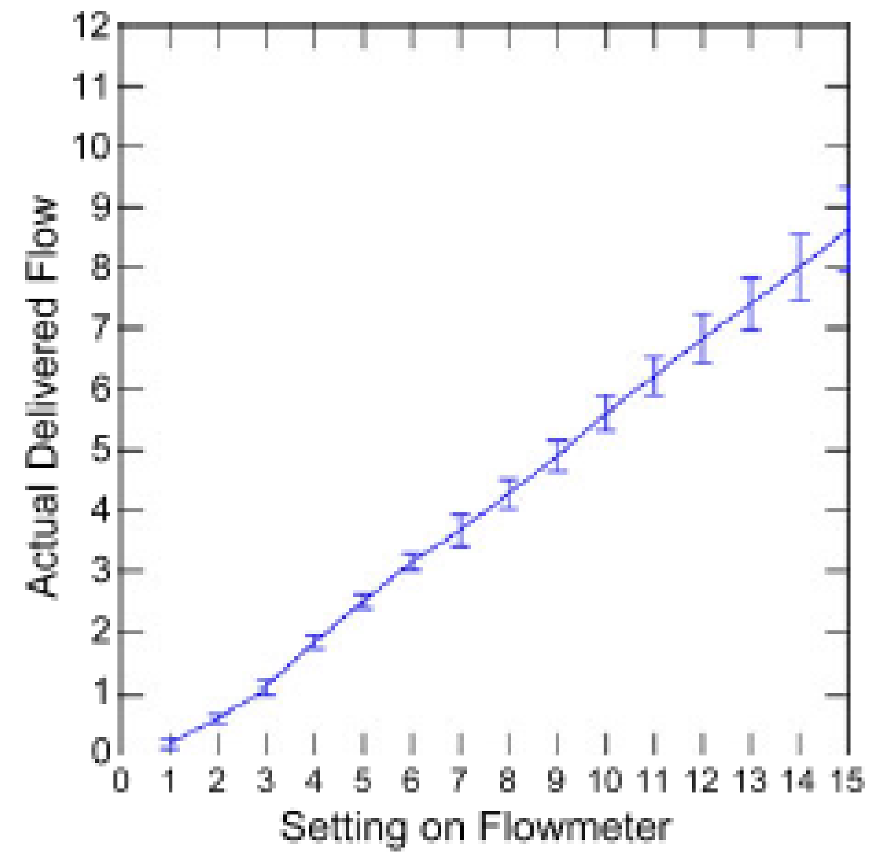

Figure 2. Standard flow meter measurements of oxygen delivered at 20 psi. Mean ± standard error.

Little CM, Acad Emerg Med 2009;16:558.

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Table 1. Compressed Gas Cylinder Specifications*

Cylinder Type	Size	Service Pressure (psi)	Cubic Feet	Liters
Portable	B	2,015	5.8	164
	C	2,015	8.8	249
	D	2,015	14.7	416
	E	2,015	24	679
	E (HP)	3,000	35	991
	M	2,015	110	3,113
Fixed	H	2,015	220	6,226
	K	2,015	266	7,528

*Commonly found portable and stationary oxygen cylinders. Note that a cylinder's compressed gas volume may differ slightly depending on the manufacturer of the cylinder.


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WARNING
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OR
OPEN FLAMES ALLOWED

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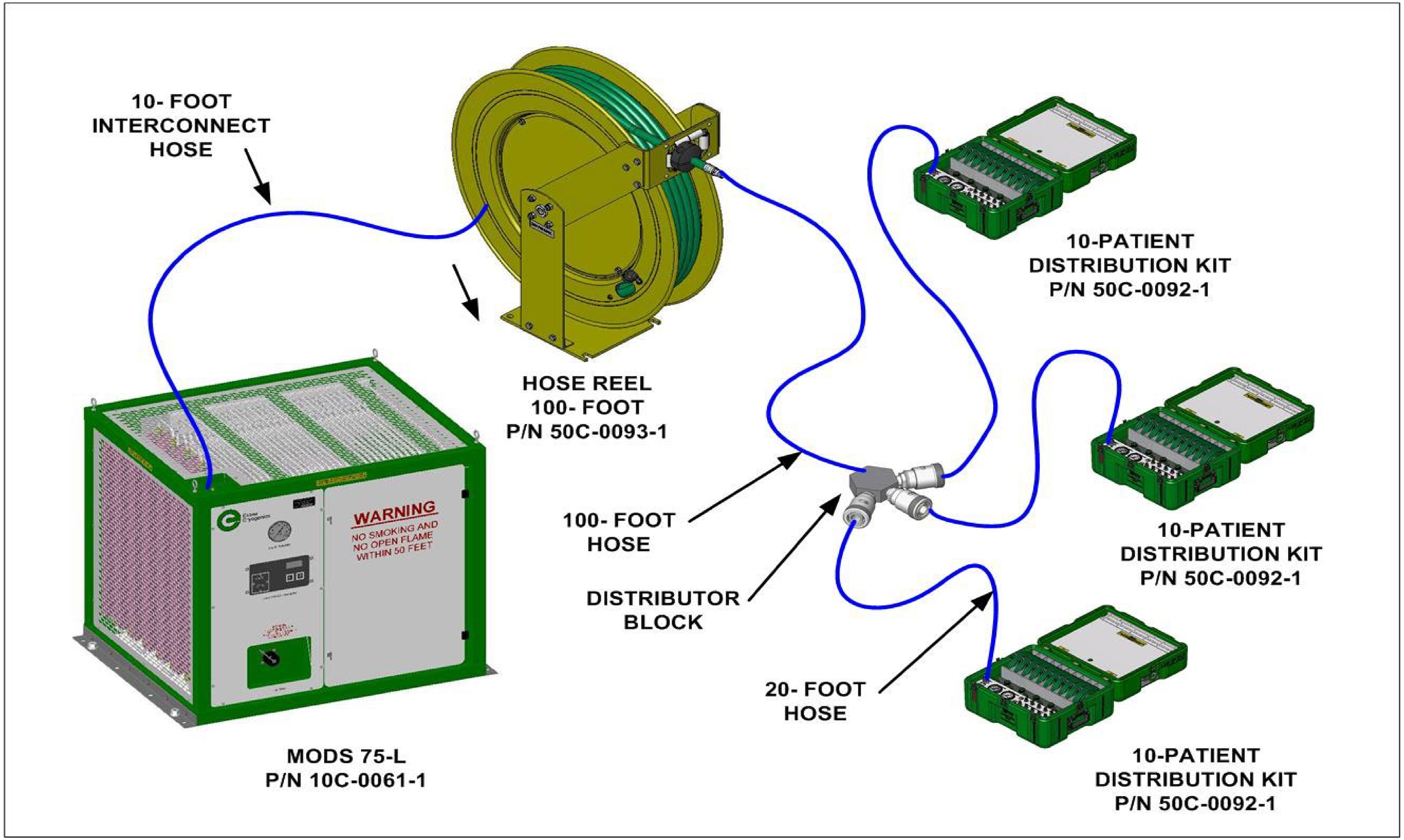
MODS Schematic



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MODS-75 Comparison

MODS-75 COMPARED TO H AND T TANKS			
	MODS-75	H TANK	T TANK
MAX CAPACITY (GAS LITERS)	64,500	7,079	8,495
USABLE CAPACITY	64,000	5,322	7,079
# TANKS REQUIRED		12	9
WEIGHT (approximate)	395 lbs	1400 lbs	1250 lbs
FOOT PRINT (approximate)	7.5 sq ft	> 7 sq ft	> 6 sq ft

Practical Suggestions

1. Consider testing location gas capacity by placing running ventilators with test lungs
2. Turn off oxygen to manual resuscitators until used
3. Use minimal FiO_2 for adequate oxygenation
4. Reduce use of high flow nasal cannula for oxygen delivery
5. Turn off oxygen to anesthesia workstations

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Take-Home Messages

- Accurate prediction of medical gas consumption during extreme surges requires a combination of both clinical and engineering information
- The limiting factor for COVID-19 ventilation surge may not be the available ventilators
- Medical oxygen and air supply systems may not be able to handle the increased usage of both oxygen and air

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