National Aeronautics and Space Administration

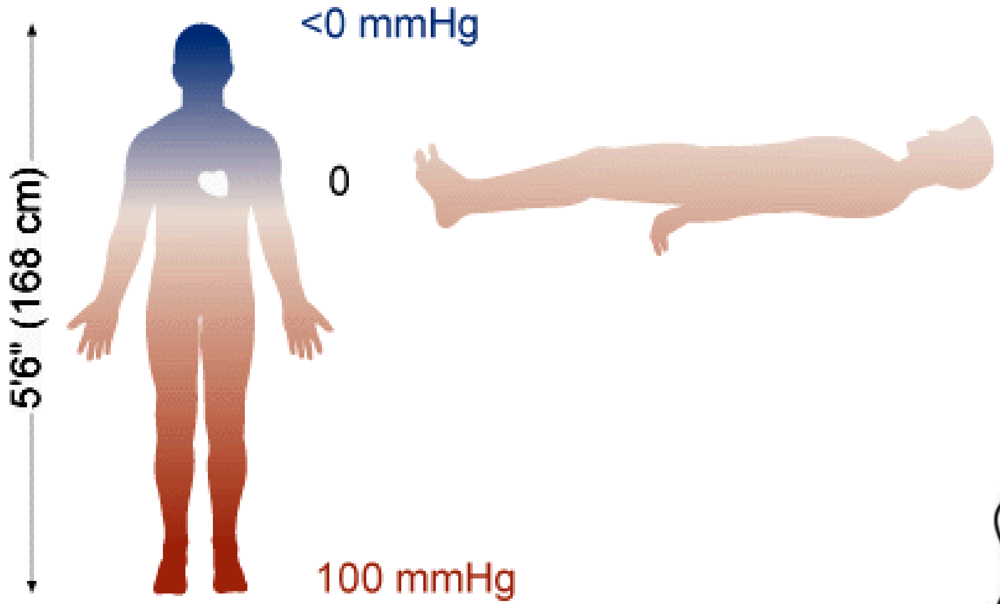
Standing Without Gravity: The Use of Lower Body Negative Pressure for Research and Rehabilitation in Spaceflight (#080)

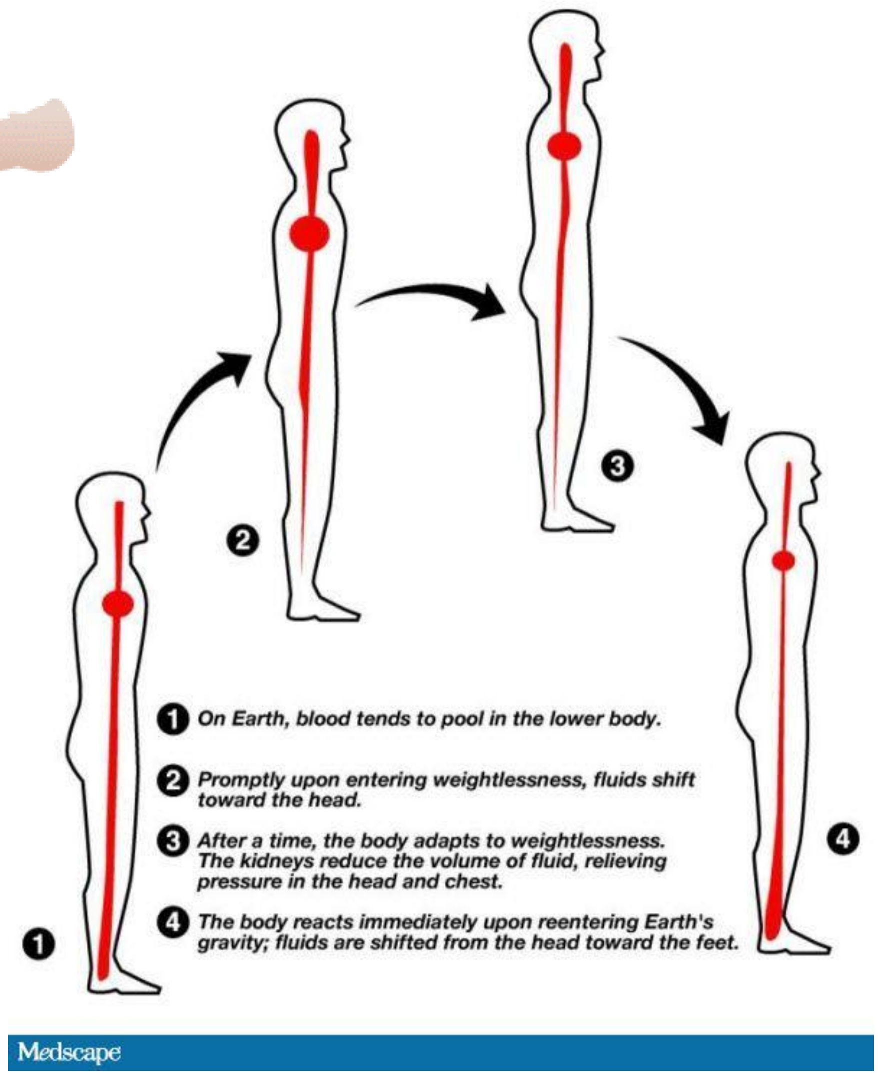
J.B. Charles, Ph.D.
M.R. Campbell, M.D.
M.B. Stenger, Ph.D.
S.M.C. Lee, M.S.

Insight into VIIP
12 May 2014
14:00, Indigo E

Aerospace Medical Association
85th Annual Meeting

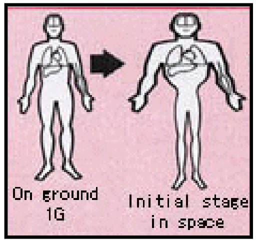
Headward fluid shift

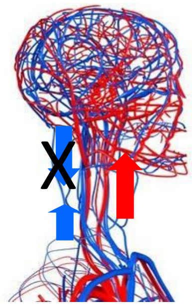




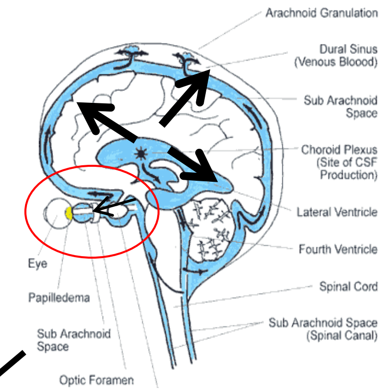
VIIP Proposed Pathophysiology

1. Weightlessness-induced headward fluid shift



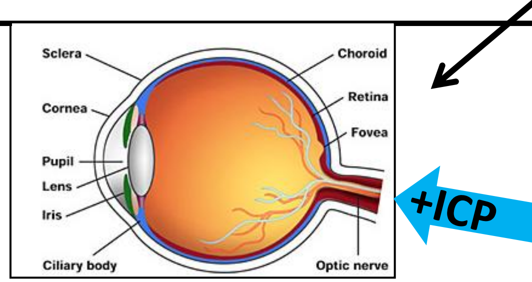


2. Fluid shift increases intracranial pressure (ICP)

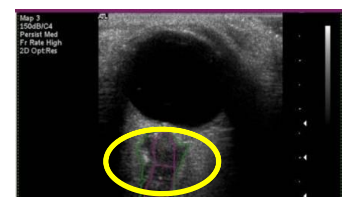


3. Elevated ICP & fluid shift transmitted to the eye

Hyperopic Shifts
Up to +1.75 diopters

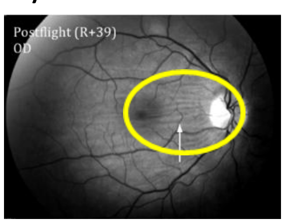


Increased Optic Nerve Sheath Diameter



"Cotton wool" Spots - Altered blood flow

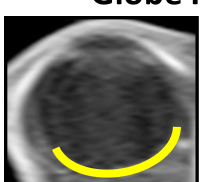
Choroidal Folds
Ridges in back of eye



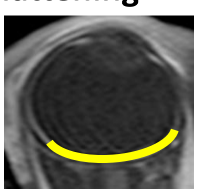
Optic Disc Edema
(Swelling)

Scotoma
Abnormal visual field

Globe Flattening



Normal Globe

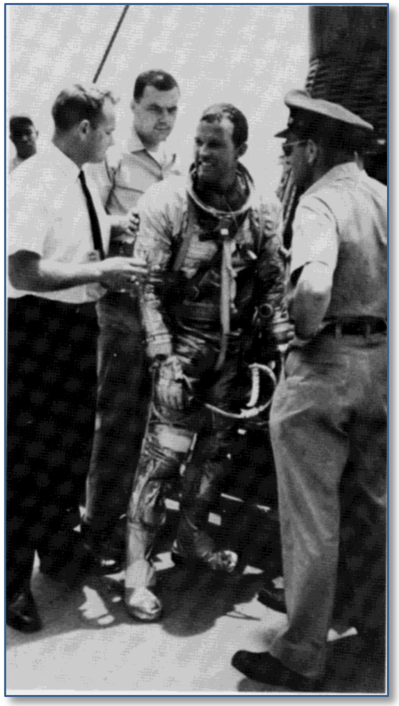


Flat Globe

Courtesy Christian Otto, MD, HRP VIIP Project Scientist, Feb. 2014

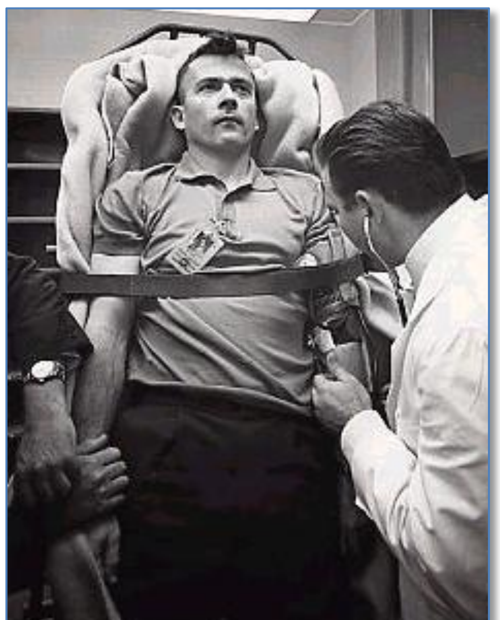
Orthostatic stress and spaceflight

- Orthostatic intolerance (OI) observed after 9-hr (1962) & 34-hr (1963) Mercury flights
- Gemini (1962) planned gliding landing, pilots seated upright, after up to 14 days in orbit
  - Would OI prevent pilots from flaring before touchdown?
  - Gemini program defaulted to water landing with no terminal piloting (1964)
    - Reduced concerns during parachute descent (only 4 min seated at 0.8 Gz)
    - But prolonged upright seated posture while afloat awaiting retrieval
  - In the end, OI not an operational problem: all astronauts who were hoisted to helicopter in horse-collar sling tolerated it without incident



How to reverse headward fluid shifting—using gravity

Technique	Description	Gravity dependent?	Advantages	Disadvantages	Spaceflight relevance?
Active standing	Free standing	Yes	Convenient	Skeletal muscle and vestibular involvement; falls possible	Clinical pre/post-flight OI assessment
Passive standing	Standing while leaning against wall	Yes	Convenient; falls less likely	Skeletal muscle, vestibular involvement	Shuttle clinical OI assessment, pre/post-flight
Head-up tilt	Tilt table, litter, etc.	Yes	Passivity	Requires equipment; residual skeletal muscle, vestibular involvement	Mercury, Gemini, Apollo, Shuttle clinical assessment, pre/post-flight



How to reverse headward fluid shift—without gravity

Technique	Description	Gravity dependent?	Advantages	Disadvantages	Spaceflight relevance?
Thigh-cuff inflation	Occlusion cuffs	No	Passivity; no skeletal muscle or vestibular involvement; simple equipment	Requires equipment; small volume of sequestration	Possible OI countermeasure. Gemini 5, 7; "Braslet" on Mir, ISS
Cuirass	External compression of abdomen	No	Passivity; no skeletal muscle or vestibular involvement; simple equipment	Requires equipment; pressure transmission effects	
Upper body positive pressure	Decompression of upper body	No	Passivity; no skeletal muscle or vestibular involvement; insensitive to seals	Enclosed head limits access, mobility, performance	Possible OI countermeasure (Evaluated at NASA Ames)
Lower body negative pressure	Decompression of abdomen and legs	No	Passivity; no skeletal muscle or vestibular involvement; maximal volume shift	Requires equipment including 1 seal; pressure transmission effects	Salyuts, Skylab, Mir, Shuttle, ISS (Russian segment)
Leg negative pressure	Decompression up to thigh	No	Passivity; no skeletal muscle or vestibular involvement; partial volume shift	Requires equipment including 2 leg seals; small volume of sequestration	
Abdominal negative pressure	Decompression of abdomen	No	Passivity; no skeletal muscle or vestibular involvement; partial volume shift	Requires equipment including 3 seals, or AGS-in-LBNP; pressure transmission effects	

How to reverse headward fluid shift—without gravity

Technique	Description	Gravity dependent?	Advantages	Disadvantages	Spaceflight relevance?
Thigh-cuff inflation	**Occlusion cuffs**	**No**	**Passivity; no skeletal muscle or vestibular involvement; simple equipment**	**Requires equipment; small volume of sequestration**	**Possible OI countermeasure. Gemini 5, 7; "Braslet" on Mir, ISS**
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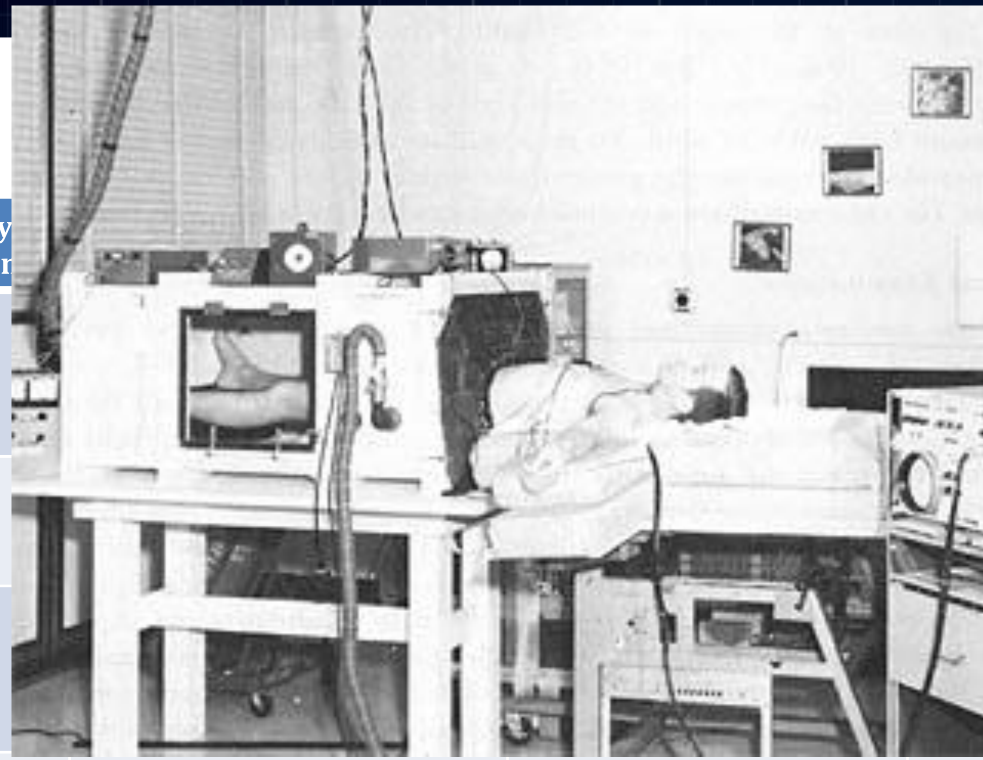
How to reverse headward fluid shift—without gravity



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How to reverse headwar without gravity

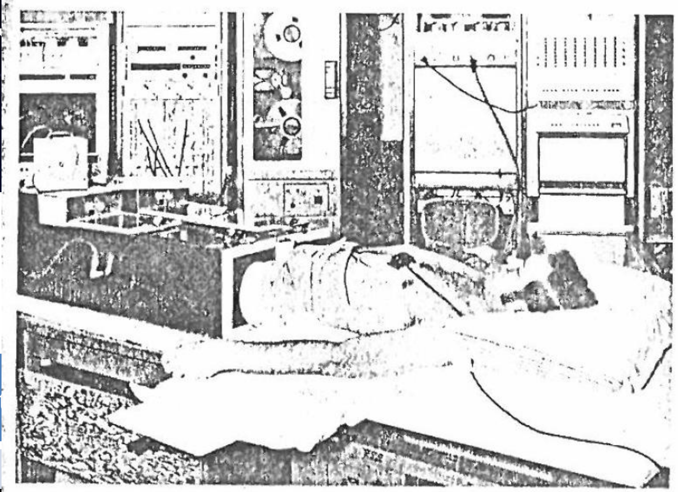

Fig. 1. A view of the leg negative pressure device with subject in place.

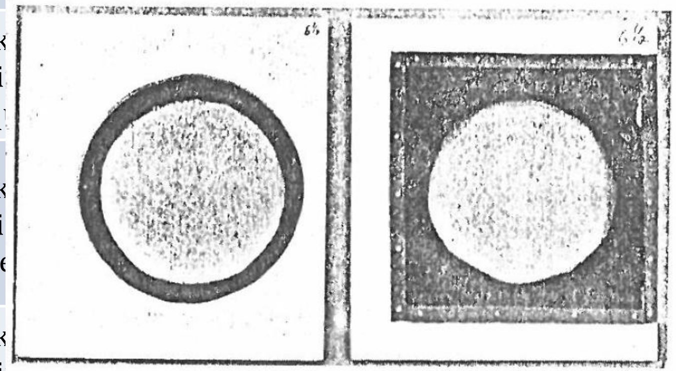

Fig. 2. A close-up view of one leg seal, showing both sides. The rubber dam material served to provide the final skin air seal.

Technique	Description	Gravity dependent?	Advan		Spaceflight relevance?
Thigh-cuff inflation	Occlusion cuffs	No	Passivity; no sk or vestibular i simple eq		Possible OI ountermeasure. ini 5, 7; "Braslet" on Mir, ISS
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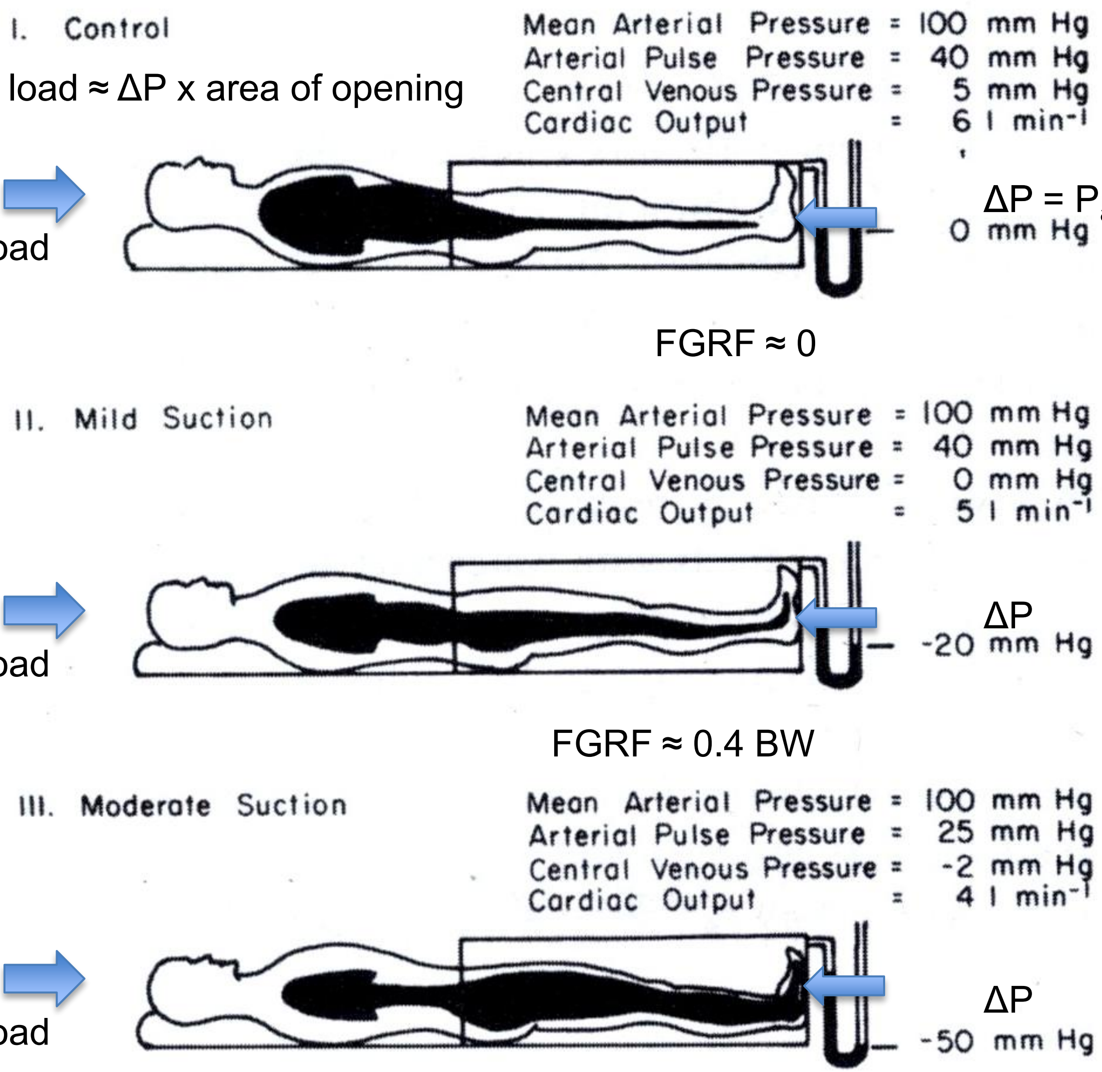
Physics and physiology of LBNP

ΔP load ≈ ΔP x area of opening



ΔP load

$\Delta P = P_{ambient} - P_{LBNPD}$

FGRF ≈ 0

ΔP load

ΔP

P_{LBNPD} ≈ 230 m (770 ft) above sea level

FGRF ≈ 0.4 BW

Blood volume shift ≈ 0.6 ℓ

f(ΔP, time @ ΔP)

ΔP load

ΔP

P_{LBNPD} ≈ 600 m (1970 ft) above sea level

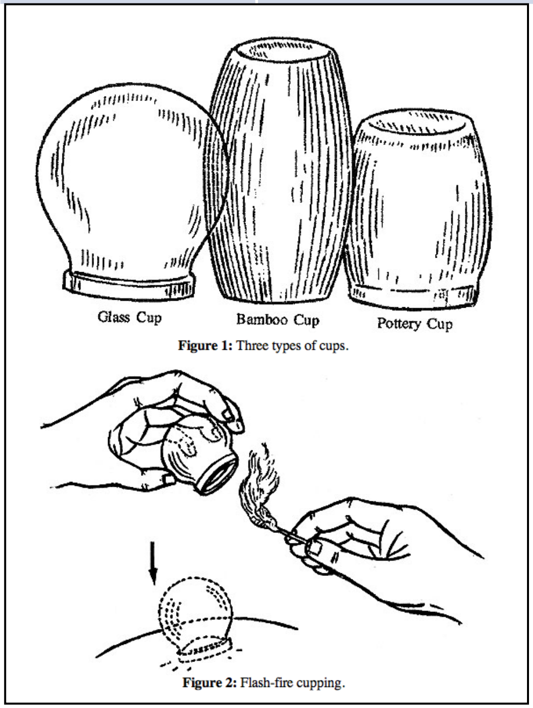
FGRF ≈ BW

"LBNP … provides a non-gravity dependent way to shift fluid from the upper to lower body."
Buckey, 2006.

Sources: Rowell, 1986; Buckey, 2006; Smith, 1990.

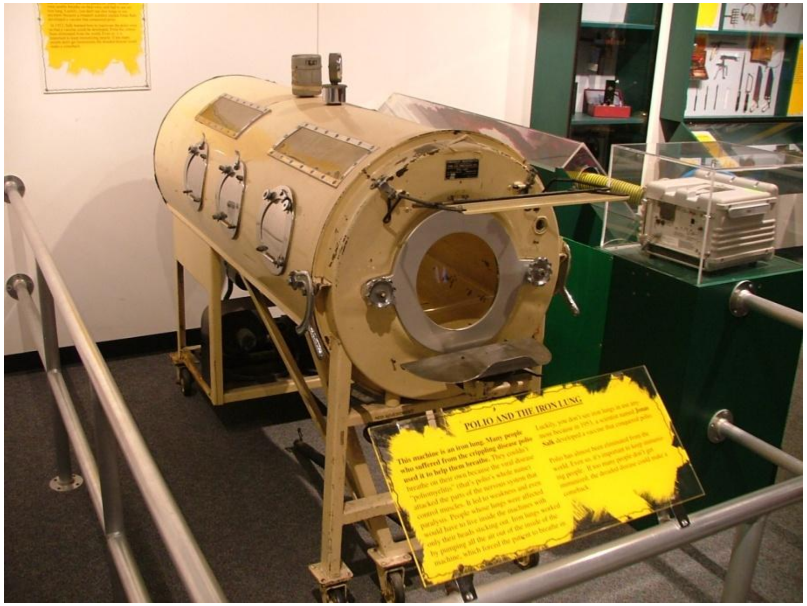
Foundation of LBNP

Date	Location	Event	Author	Notes
1550 BCE	Egypt	Cupping		
1000 BCE	China			
400 BCE	Greece		Hippocrates	



Dharmananda, Subhuti. Cupping. http://www.itmonline.org/arts/cupping.htm, March 1999 (accessed 26 June 2014).

Lower (whole) body negative pressure



Iron Lung
St. Louis Science Center, 2006

Brown, 1966 (Greenfield, 1963)

J. Physiol. (1966), **183**, *pp.* 607–627 607
With 12 *text-figures*
Printed in Great Britain

CIRCULATORY RESPONSES TO SIMULATED GRAVITATIONAL SHIFTS OF BLOOD IN MAN INDUCED BY EXPOSURE OF THE BODY BELOW THE ILIAC CRESTS TO SUB-ATMOSPHERIC PRESSURE

BY ELLEN BROWN, THE LATE J. S. GOEI, A. D. M. GREENFIELD* AND G. C. PLASSARAS†

From the Cardiovascular Research Institute and the Department of Medicine, University of California School of Medicine, San Francisco, Cal., U.S.A.

(*Received* 26 *July* 1965)

SUMMARY

1. Exposure of the body from iliac crests to feet of a horizontal subject to a pressure 70 mm Hg below atmospheric causes a displacement of about 10 g of blood/kg total body weight from the upper to the lower part of the body. Much of this blood is returned very rapidly at the end of suction.

2. During suction, the changes in the circulation resemble those during a foot-down tilt. After suction, the changes resemble to some extent those following the Valsalva manoeuvre.

3. The overshoot of forearm blood flow following suction is caused by variations in the activity of adrenergic vasoconstrictor nerves. The receptors for this reflex have not been identified, but their stimulation depends upon a rapid and large return of blood to the central circulation.

INTRODUCTION

Local exposure of the forearm (Greenfield & Patterson, 1956), hand (Coles & Patterson, 1957) and calf of the leg (Coles, Kidd & Moffatt, 1957) to subatmospheric pressure causes the local content of blood to be increased. In the calf of the leg, exposure to a pressure 70 mm Hg below atmospheric leads to an increase in volume, attributable to accumulation of blood, of about 5·5%. This is of the same order as may be caused by venous congestion with a cuff at 70 mm Hg.

Venous congestion of two or more limbs shifts sufficient blood (Brown, Hopper, Sampson & Mudrick, 1951) to simulate the effects on the remain-

* Present address: Department of Physiology, St Mary's Hospital Medical School, London, W. 2.
† Present address: Therapeutic Clinic, School of Medicine, University of Athens, Greece.

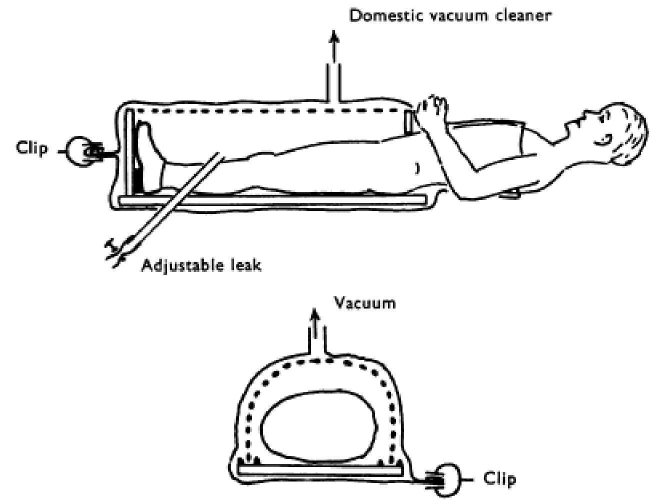


Fig. 1. Apparatus for exposing the parts of the body below the iliac crests to subatmospheric pressure.

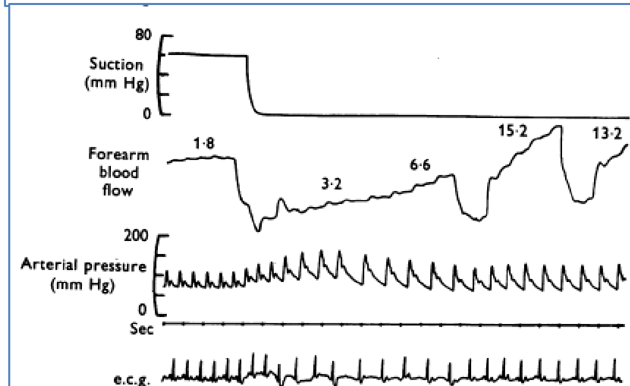


Fig. 2. Events following suction at −60 mm Hg for 2 min. Subject R.L.

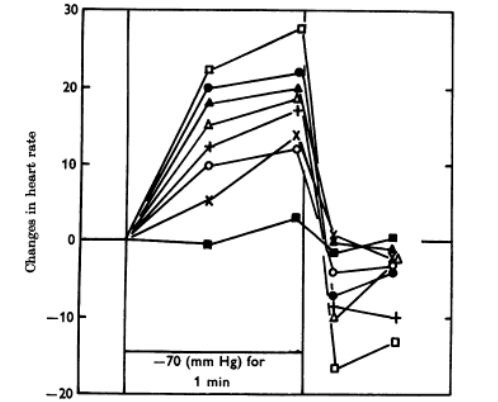


Fig. 4. Average changes in heart rate over 10 sec periods starting at 25th and 50th sec of suction, and at 5th and 25th sec after suction, and represented as changes from the resting heart rate. ● G.P., ○ R.L., ▲ R.F., △ J.G., ■ J.H., □ J.S., × M.M.H., + D.G.

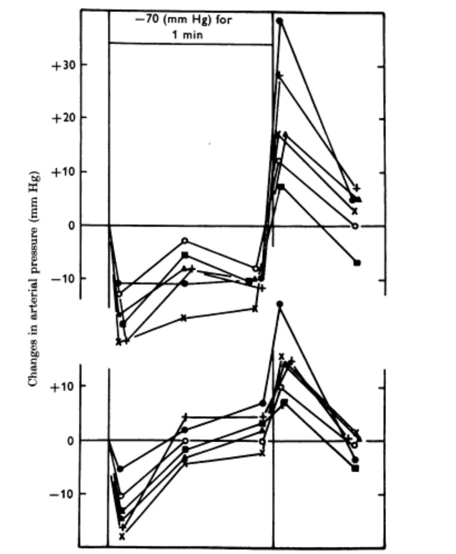


Fig. 6. Changes in systolic and diastolic arterial pressures from their previous resting values during and after suction for 1 min at −70 mm Hg. The lowest values at the start of suction, and the highest after suction are shown, and also the values at the middle and end of suction, and 30 sec after suction. ● G.P., ○ R.L., ▲ R.F., ■ J.H., × M.M.H., + D.G.

Stevens and Lamb, 1965

Effects of Lower Body Negative Pressure on the Cardiovascular System*

PAUL M. STEVENS, M.D., and LAWRENCE E. LAMB, M.D., F.A.C.C.

Brooks Air Force Base, Texas

WITH the onset of manned space flight much attention has been devoted to the study of the effects of weightlessness on cardiovascular reflexes and the problem of orthostatic intolerance. Orthostatic intolerance is defined as an individual's inappropriate response to assuming the upright posture, manifested by excessive increases in heart rate, hypotension and increases in incidence of syncopal reactions. Following weightlessness,[1-3] immersion,[4] inactivity[5] and prolonged bed rest[6,7] significant changes occur in cardiovascular regulatory mechanisms, causing orthostatic intolerance. This has been demonstrated repeatedly in the laboratory and has been noted following prolonged space flights. Evaluation of orthostatic intolerance and its mechanisms has mainly used the standard tilt table to induce orthostatic hypotension. Although variability in orthostatic intolerance is noted in normal people, the effect is magnified by prolonged exposure to any condition which decreases the gravitational effect on the longitudinal axis of the body.

During weightlessness the normal stimulation secondary to changes of position is absent allowing deterioration of normal cardiovascular reflexes. This creates no problem during weightlessness, but upon re-exposure to gravity the reflex mechanisms may no longer be adequate to maintain orthostatic tolerance, resulting in what is called "orthostatic deconditioning."

Antigravity suits are effective in counteracting orthostatic intolerance and hypotension secondary to one or several G's.[6] The positive pressure of the "G-suit" compresses the lower extremities, decreasing venous pooling, effectively increasing central blood volume and venous return to the heart. It is assumed that the application of negative pressure to the lower limbs would induce pooling in these areas, decreasing venous return to the heart, and simulate the effects of quiet standing or upright tilting, thus stimulating the reflexes normally activated by gravity.

This concept led to this study of the cardiovascular responses to various degrees of negative pressure applied to the lower limbs to determine the similarity to orthostatic stresses.

MATERIAL AND METHODS

Thirty-eight healthy, male, active duty Air Force personnel with no previous history of cardiovascular disease or orthostatic intolerance were the subjects. Their mean age was 23 years (range 17 to 34), the mean height 175 cm., mean weight 71.3 kg. and the mean body surface area 1.85 M^2.

A negative pressure device was constructed so that up to 80 mm. Hg negative pressure could be applied to the lower half of the body from the umbilicus down. This device consisted of a solid wooden box 61 by 46 by 152 cm. A harness was rigged within its proximal end so that the supine subject in the box could comfortably sit in the harness and the negative pressure would not pull him into the box excessively. The harness prevented the feet from touching the bottom of the box. A rubber seal was provided at the opening which fitted tightly around the waist level at the level of the umbilicus. The seal was tight enough to prevent a significant leak and still not be too uncomfortable. The chest, upper abdomen, arms and head were outside of the box. The subject, once inserted, rested in a supine position (Fig. 1 and 2).

The vacuum was achieved by the use of a standard vacuum cleaner motor. The magnitude of the vacuum was regulated by adjusting a variable leak into the box through the use of a bleed-off valve. The desired vacuum could be achieved within 5 to 10 sec. after activation of the motor and maintained at a steady magnitude for an indefinite period of time. The level of the vacuum was continuously measured by a standard mercury manometer connected to the inside of the box.

* From the Internal Medicine Department, Aerospace Medical Sciences Division, USAF School of Aerospace Medicine, Brooks AFB, Texas.

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Vol. 16, Oct. 1965

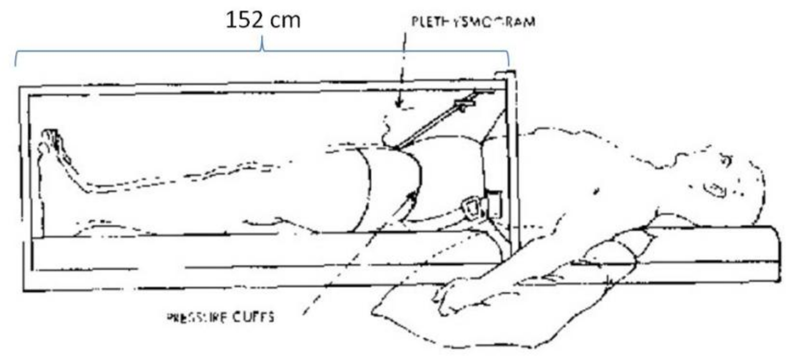

FIG. 1. Side view of negative pressure device shows the rubber seal around the waist. The pressure cuffs and plethysmogram were used only when blood volume measurements were made in the legs.

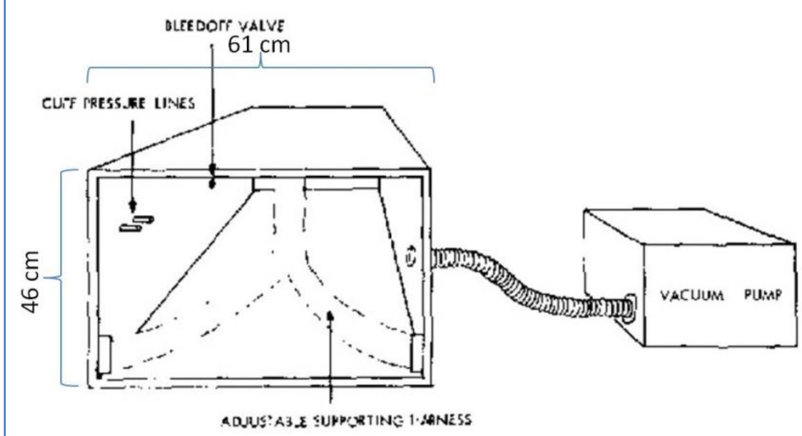

FIG. 2. End view of negative pressure device with front panel and rubber seal removed shows supporting harness and negative pressure source.

Progress of LBNP

Date	Location	Event	Author	Notes
1550 BCE	Egypt	Cupping		
1000 BCE	China			
400 BCE	Greece		Hippocrates	
1964	Brooks AFB	LBNP	D Graveline	Original developer; conceived with E Wood (inspired by O Gazenko)
1965 1966	UCSF	LBNP	A Greenfield, G Plassaras E Brown	Abstract Paper
1965	Brooks AFB	LBNP	P Stevens & L Lamb	Paper

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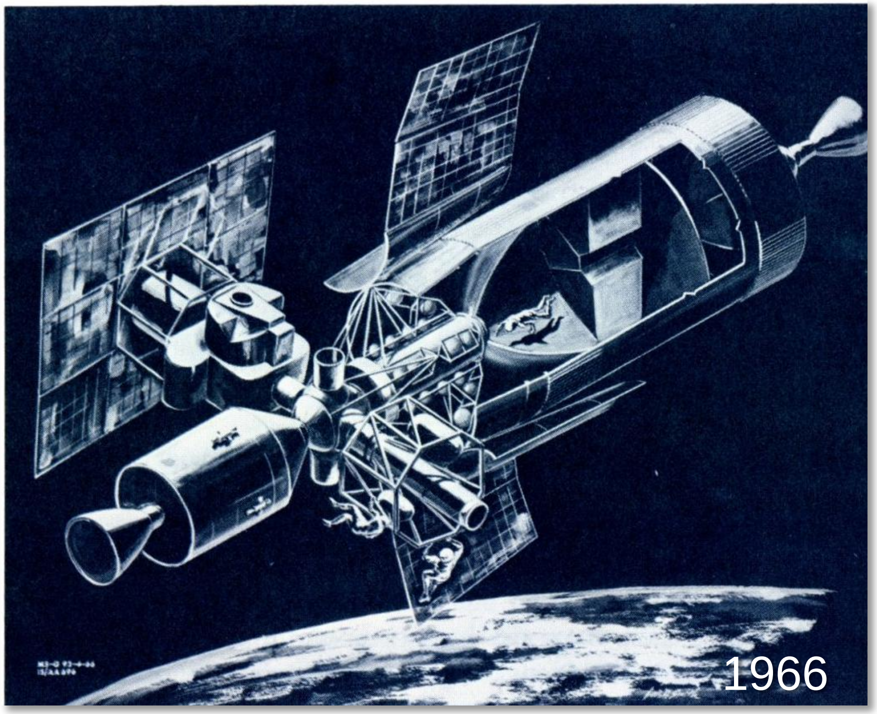
1965	Brooks AFB	LBNP	P Stevens & L Lamb	Paper
1966	Brooks AFB	In-flight LBNP		For MOL, Apollo (1967)
1970	IBMP, Moscow	In-flight LBNP	O Gazenko	For Salyut (1971)
1970	NASA, Houston	In-flight LBNP	G Hoffler	For AAP, Skylab (1973)

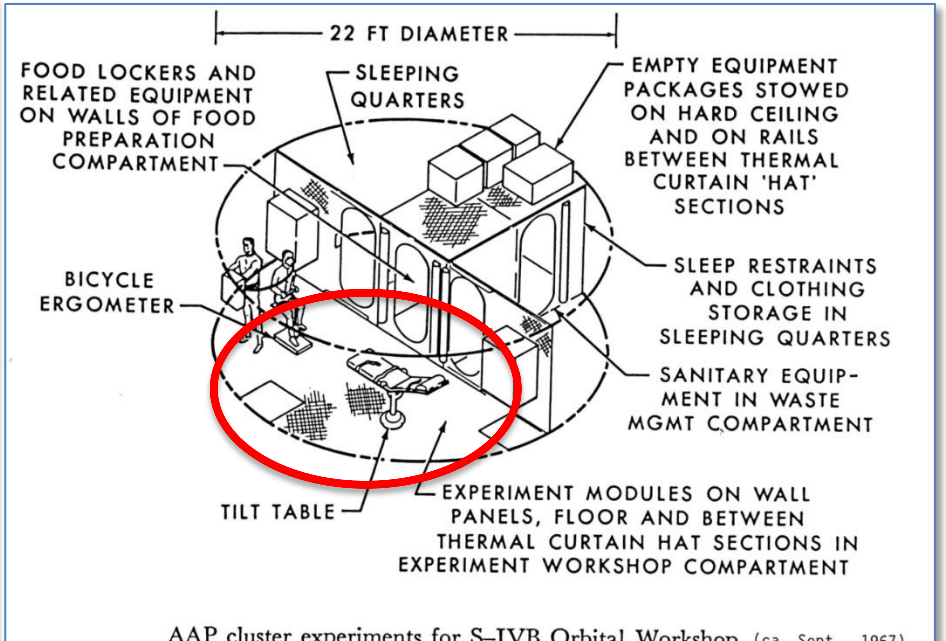
Nomenclature

- "Exposure of the Body Below the Iliac Crests to Sub-atmospheric Pressure"
- Lower Body Negative Pressure (LBNP)
  - No such thing as "negative" pressure
- Lower Body Decompression
  - Counterpart to lower body compression garments
- Lower Body Suction

Spaceflight application

Early applicability, but implementation slightly inappropriate…


1966



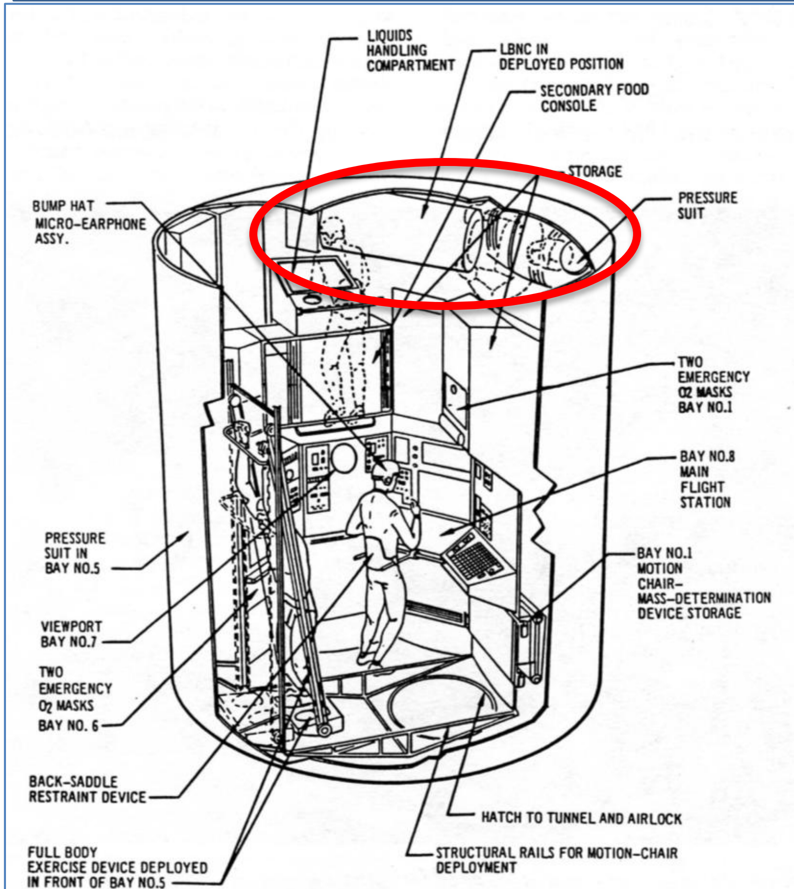
AAP cluster experiments for S–IVB Orbital Workshop. (ca. Sept., 1967)
From: Skylab: A Chronology, R.W. Newkirk and I.D. Ertel, Washington, D.C.: NASA Scientific and Technical Information Office, 1977.

1967

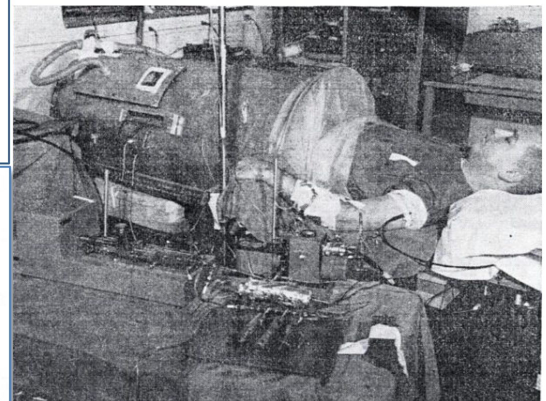
…possibly just a placeholder.

US in-flight LBNP capability—MOL (USAF)

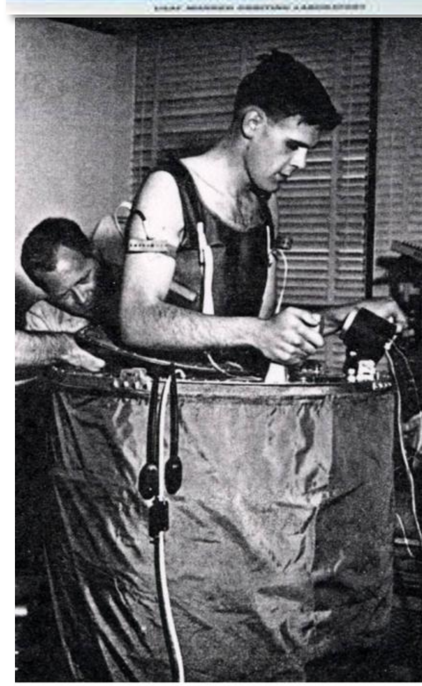
Initiated Dec. 1963 Authorized Aug. 1965 Cancelled June 1969	Planned: 5 missions, 2 pilots, 30 days



McDonnell-Douglas, 1968



NASA photograph S-66-7370

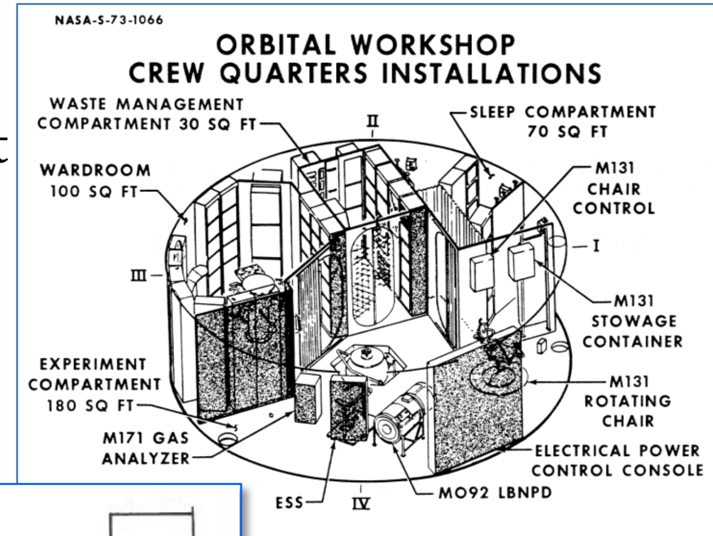


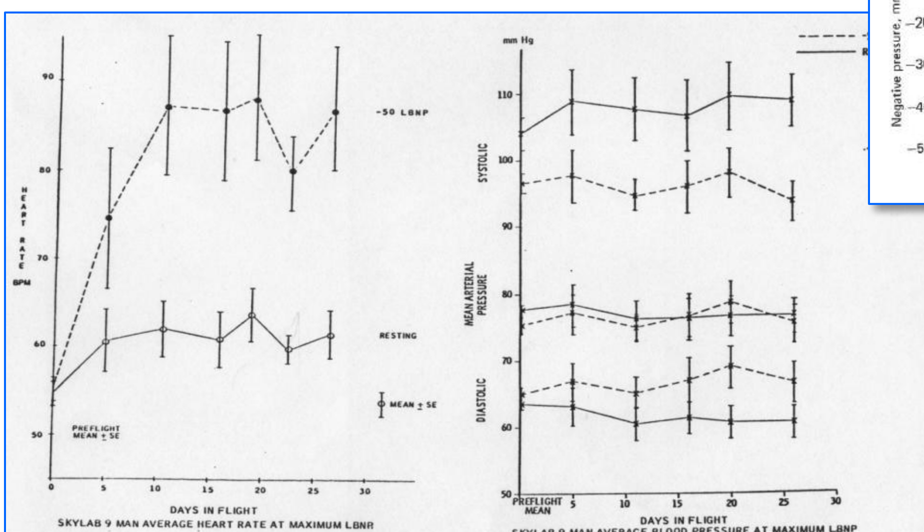
NASA photograph S-66-33890

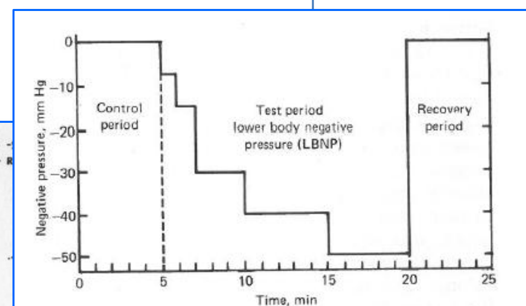
US in-flight LBNP capability—Skylab

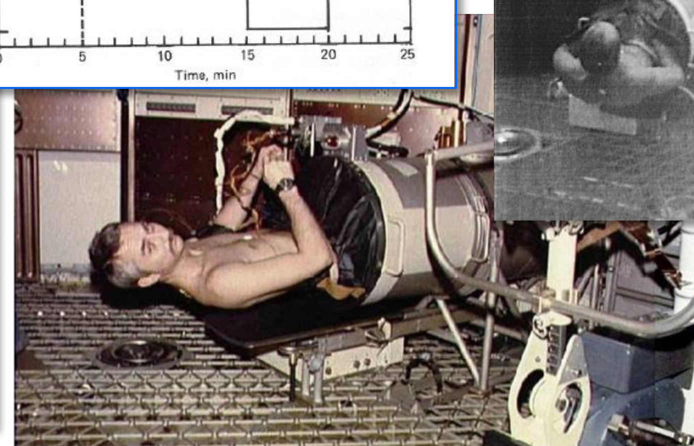
Skylab (1973-1974)

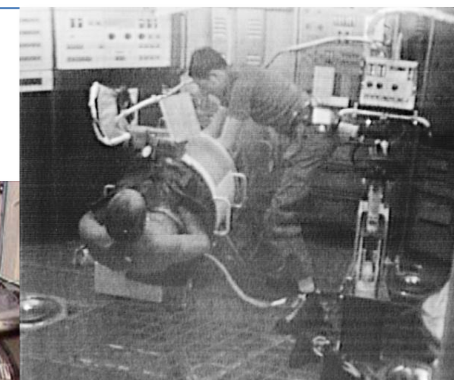
- ~4-day intervals
- Greater stress in-flight than pre-flight
- Loss of OI < 4-6 days
- Predicted early post-flight OI







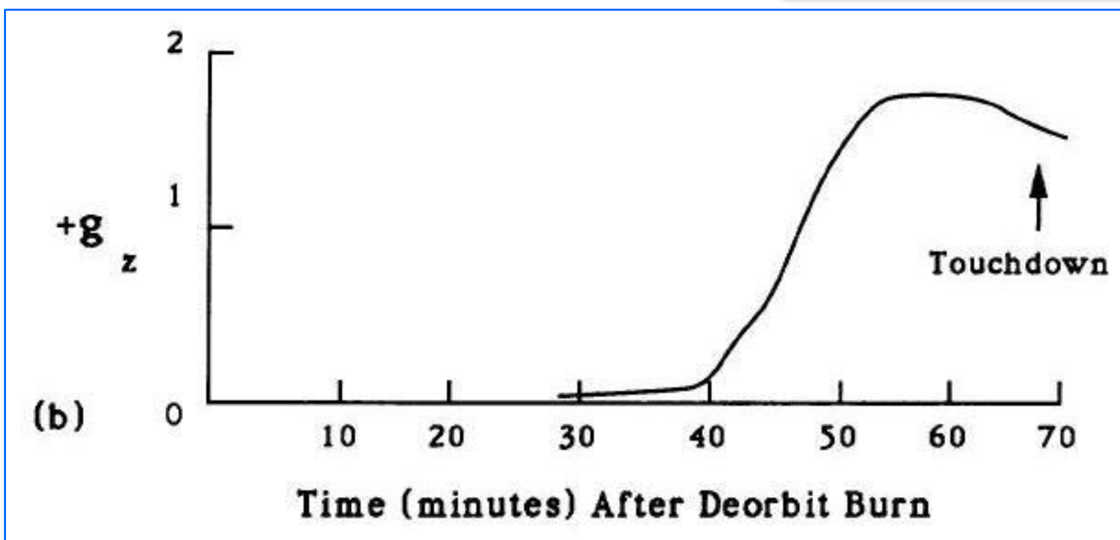




Orthostatic stress and spaceflight redux

Space Shuttle Orbiter

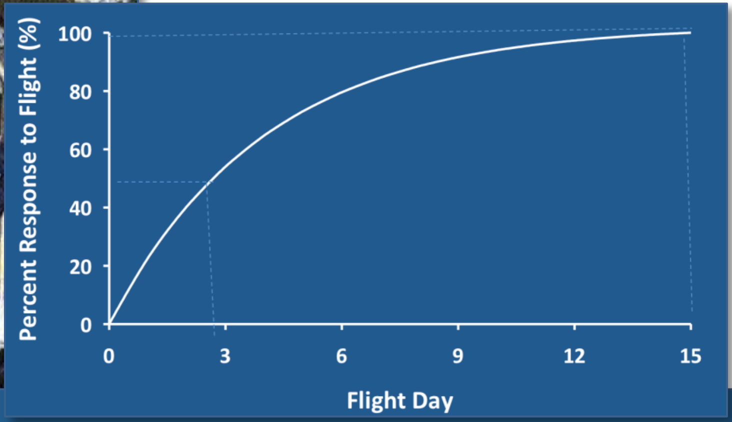
- Approved 1972
- All crewmembers seated upright during re-entry, landing
  - Piloting required
  - $>1\ G_z$ for up to 10 min.
  - After up to 10+ days in weightlessness

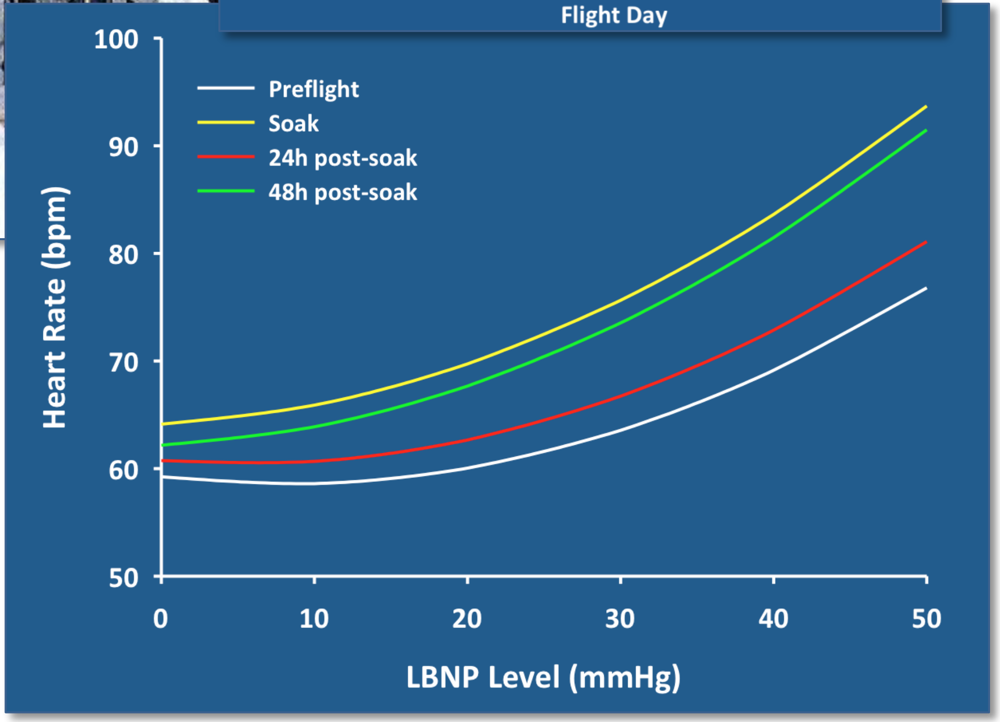


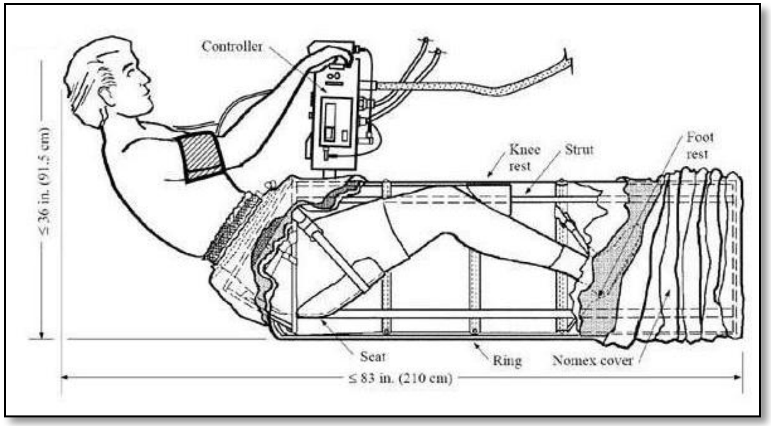
US in-flight LBNP capability: Space Shuttle

Year	Mission	Research	Orthostatic Intolerance			Application
			Monitoring	Countermeasure		
				Eval.	Demo.	
1990	STS-32		X	X		Extended Duration Orbiter Medical Project (EDOMP): 15-30-day missions under consideration
1991	STS-43		X	X		
	STS-44		X	X	X	
1992	STS-50 USML-1		X	X		
	STS-47 SL-J		X	X		
	STS-52		X	X X		
1994	STS-58 (SLS-2)		X	X		
	STS-64		X		X	
	STS-65 IML-2		X		X	
1995	STS-71 SL-Mir		X			Mir, 3 months
1998	STS-90 Neurolab	X				Neural CV control

US in-flight LBNP capability: Space Shuttle







Early notional concept: Airlock LBNP

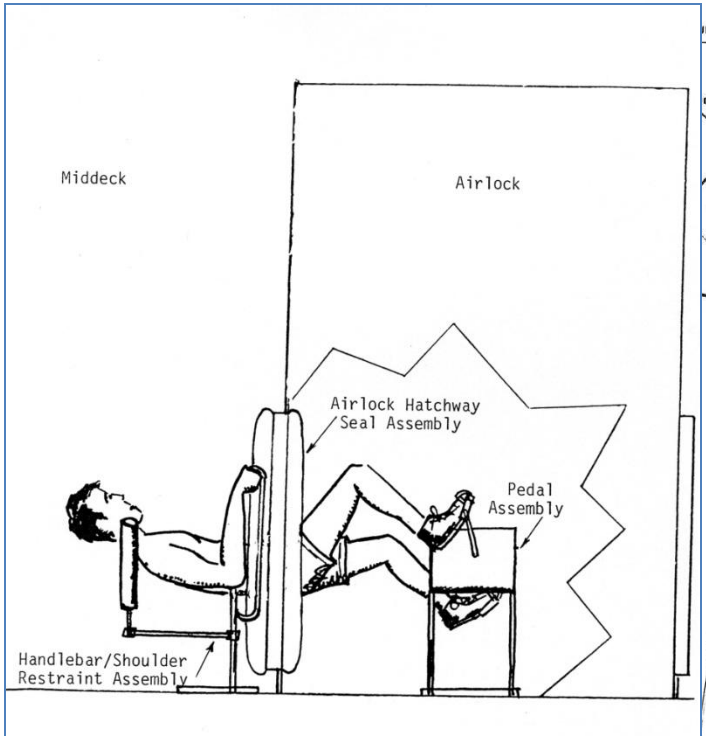
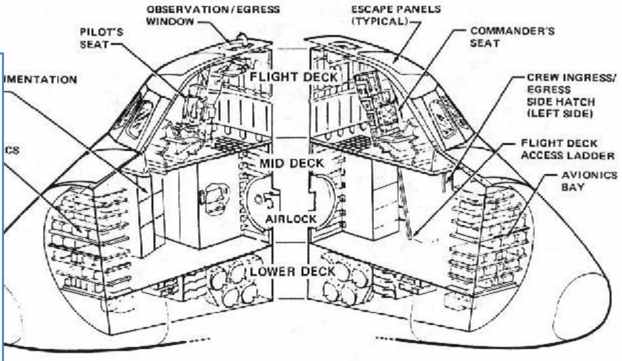
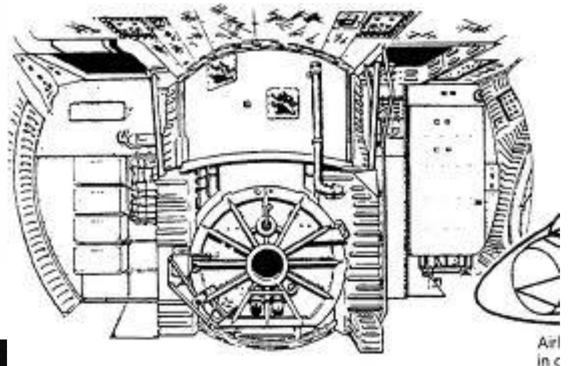
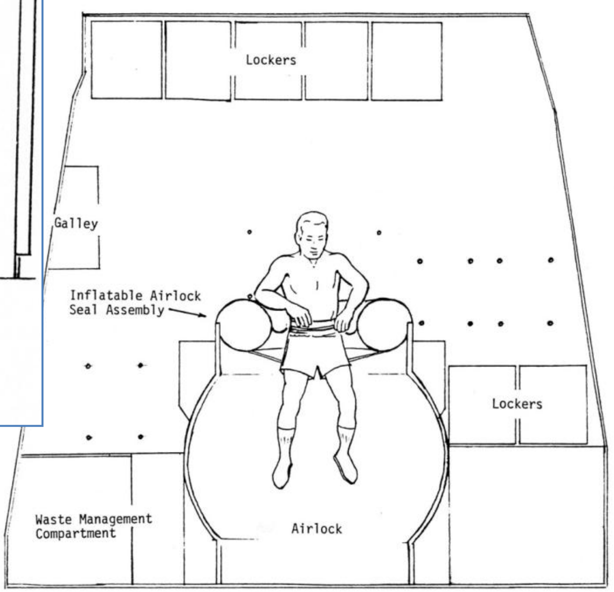


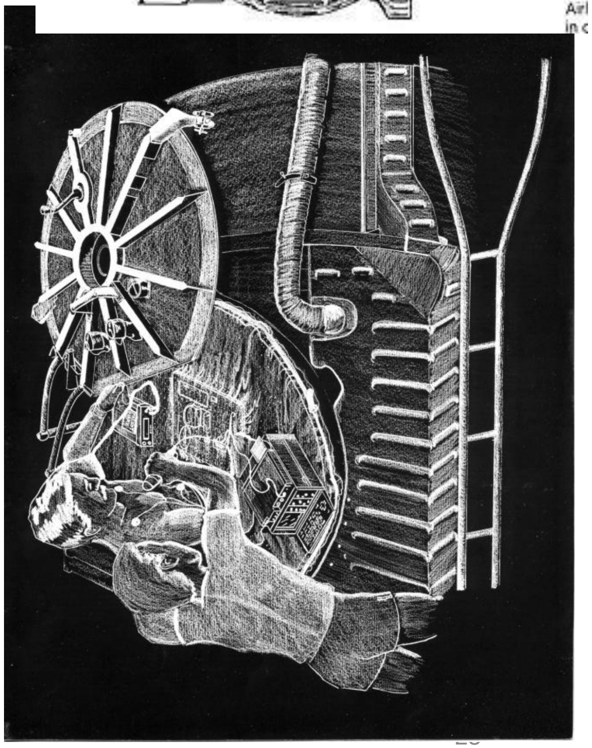
Figure 7. Inflight bicycle exercise during LBNP in Orbiter airlock.

Charles, unpublished, 1985









Early notional concept: Airlock LBNP

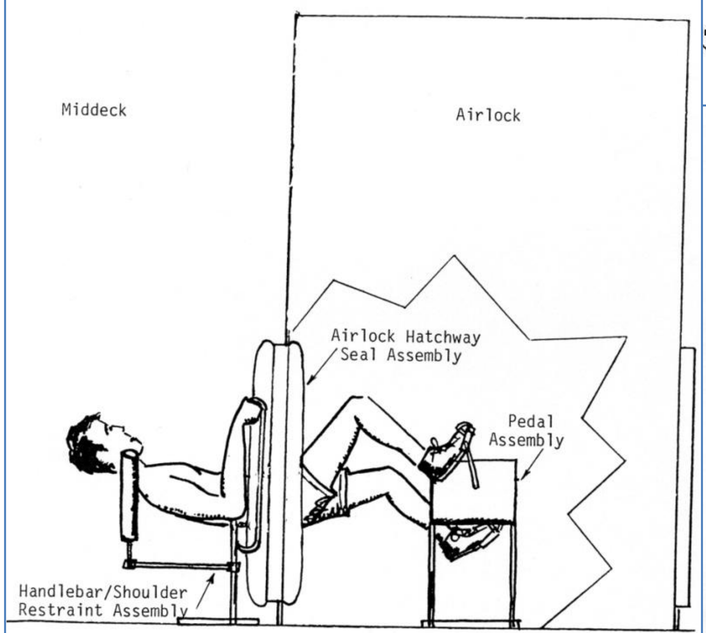
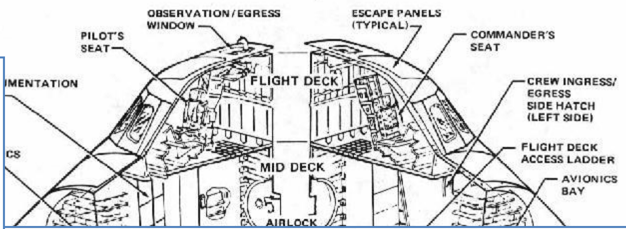


Figure 7. Inflight bicycle exercise during LBNP in Orbiter airlock.

Charles, unpublished, 1985



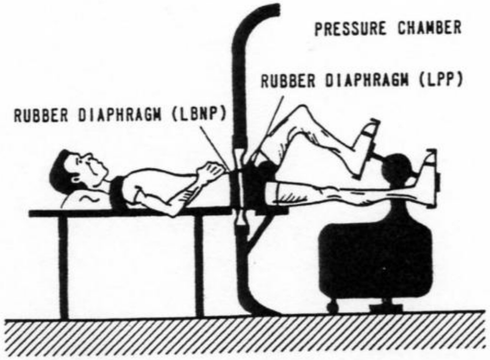
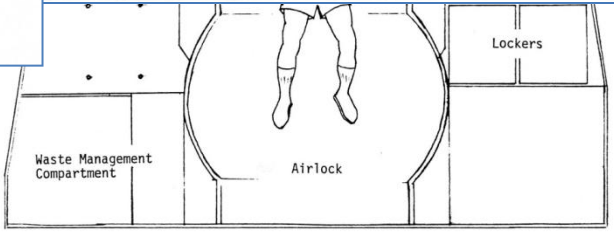
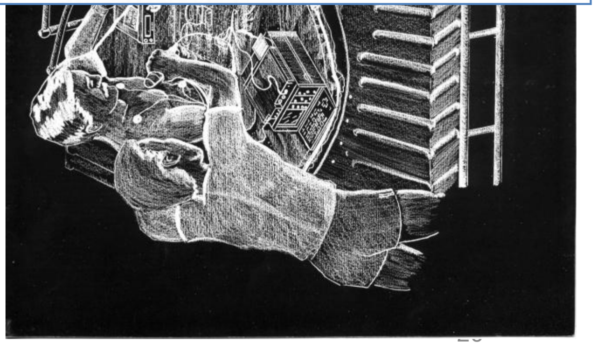


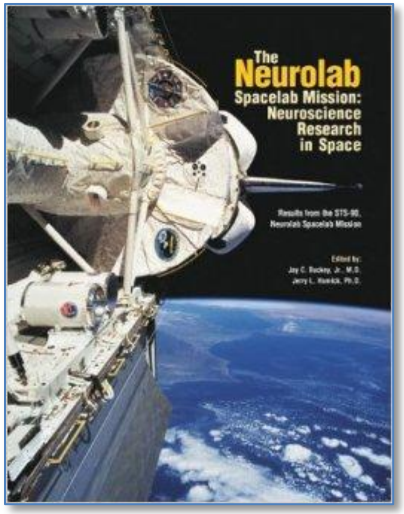
Fig. 1. Schematic illustration of the experimental set-up enabling the subject to perform supine cycle ergometry during exposure to LBNP and LPP.

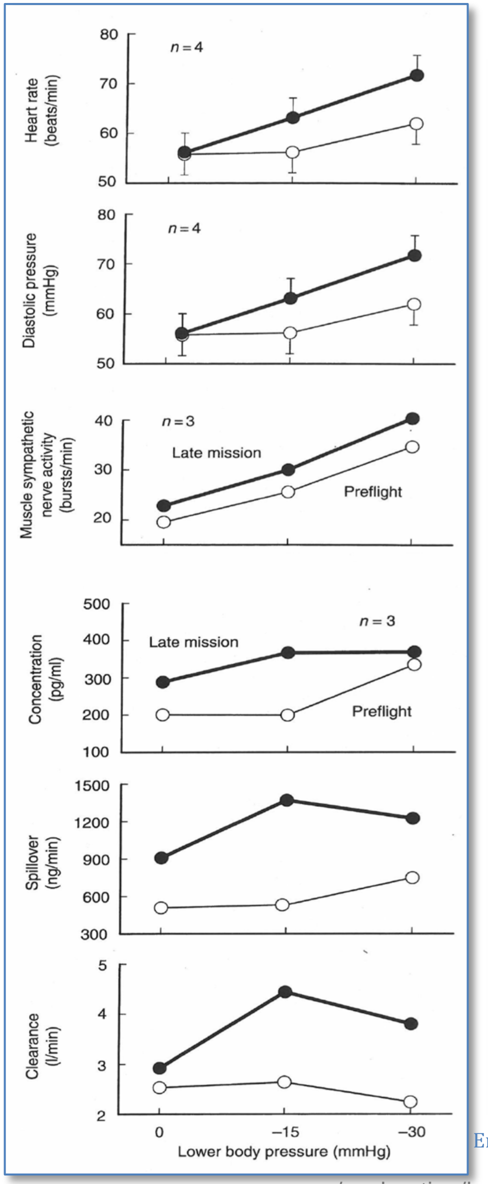
Ola Eiken, Acta Physiol Scand v131 suppl 566, 1987



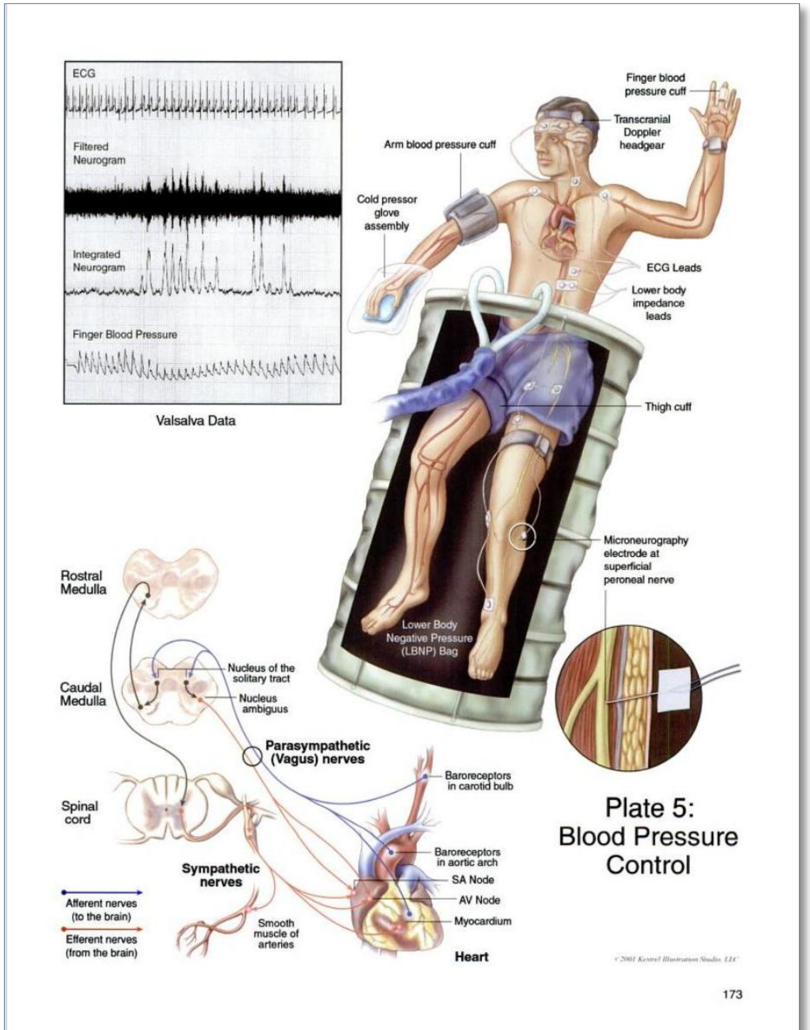


US in-flight LBNP capability: Neurolab





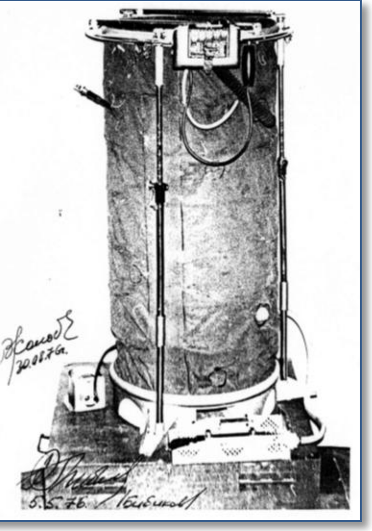
Ertl *et al.*, 2003



Buckey and Homick, 2003

Soviet, Russian in-flight LBNP capability

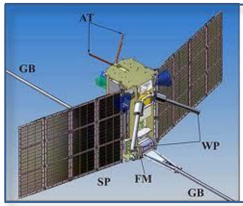
BETEP (Veter)
Salyut, 1971



Chibis
Salyut 4 (1975-1977)
Salyut 5 (1976-1977)
Salyut 6 (1977-1981)
Salyut 7 (1982-1986)
Mir (1986-1999)
ISS (2000-2012)

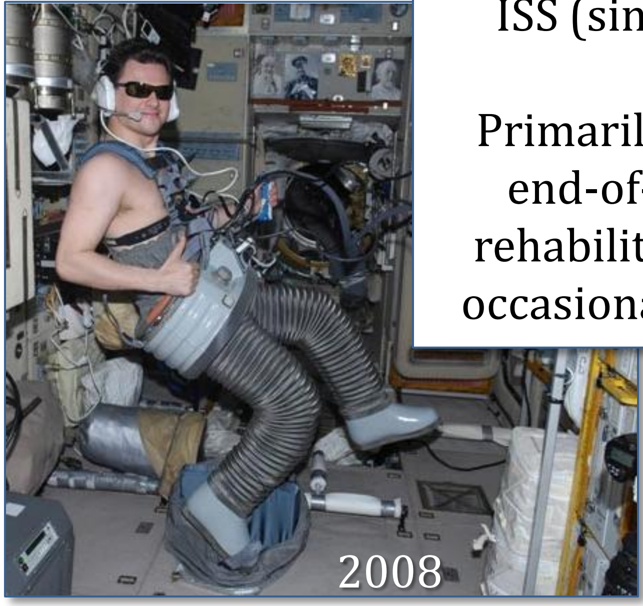
Chibis-M
ISS (since 2012)

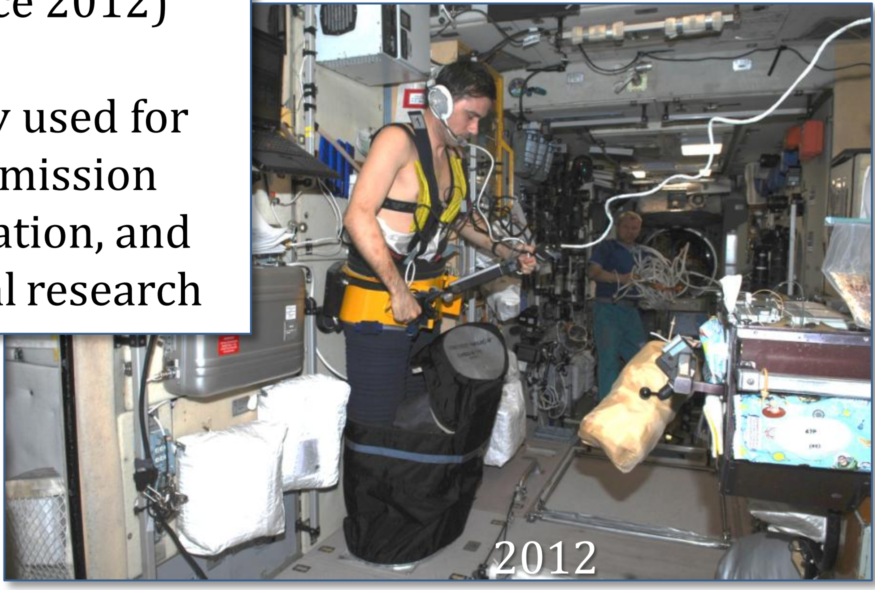
Primarily used for end-of-mission rehabilitation, and occasional research



Chibis-M microsatellite
Nov. 2011
Progress M-13M

Chibis (lapwing)





Chinese in-flight LBNP capability

Development of Self-generating Lower Body Negative Pressure Device. YANG Chang-bin, SUN Xi-qing, WANG Yong-chun, YAO Yong-jie, WU Bao-min. Space Medicine & Medical Engineering, 2003, 16(4): 281 ~ 283

Abstract: Objective To develop a kind of self-generating lower body negative pressure device. **Method** The device consists of a flexible bellows, reinforced by several steel rings and sealed by gasproof adhesive plaster. An adjustable valve, a one-way flap valve, shoulder straps and handles are incorporated on the top of the bellows. The user's lower body was contained in the bellows. As the user's legs were extended, the bellows was elongated and the air pressure in it decreased. **Result** Negative pressures of −58, −46, −38 and −26 mmHg respectively was created with the adjustable inlet valve completely closed, one-quarter open, half open, or fully open. **Conclusion** This self-generating lower body negative pressure device combines exercise and LBNP into one thing and is safe and easy to use. It might be used in preventing cardiovascular deconditioning during spaceflight or for anti-G training of pilots.

Key words: lower body negative pressure; aerospace medicine; devices; design

Address reprint requests to: YANG Chang-bin. Department of Aerospace Medicine, The Fourth Military Medical University, Xi'an 710032, China

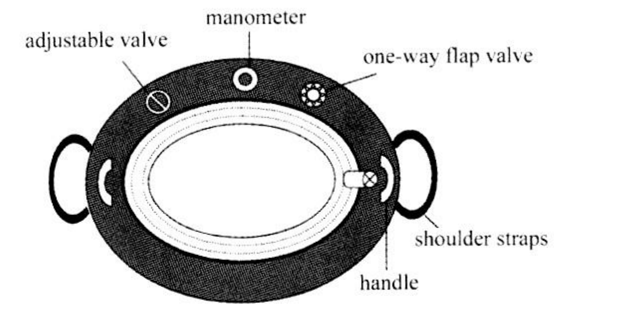


图 2　自行下体负压训练器俯视图

Fig. 2　Top view of self-generating lower body negative pressure device

From Watenpaugh, et al.,1999

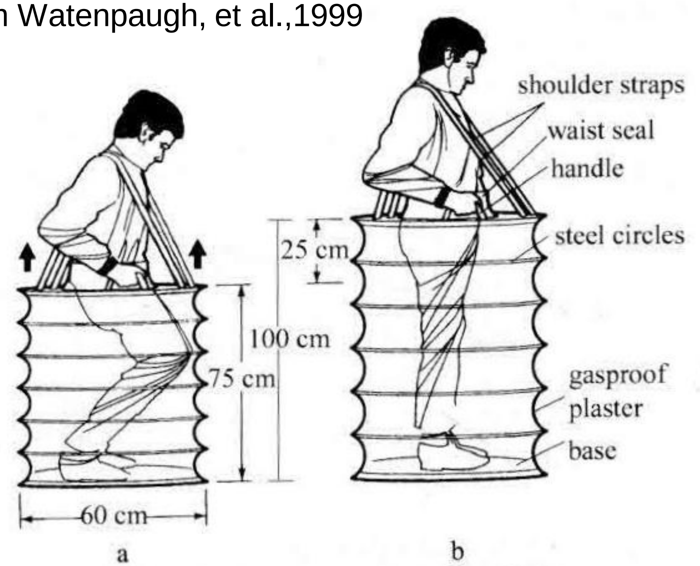
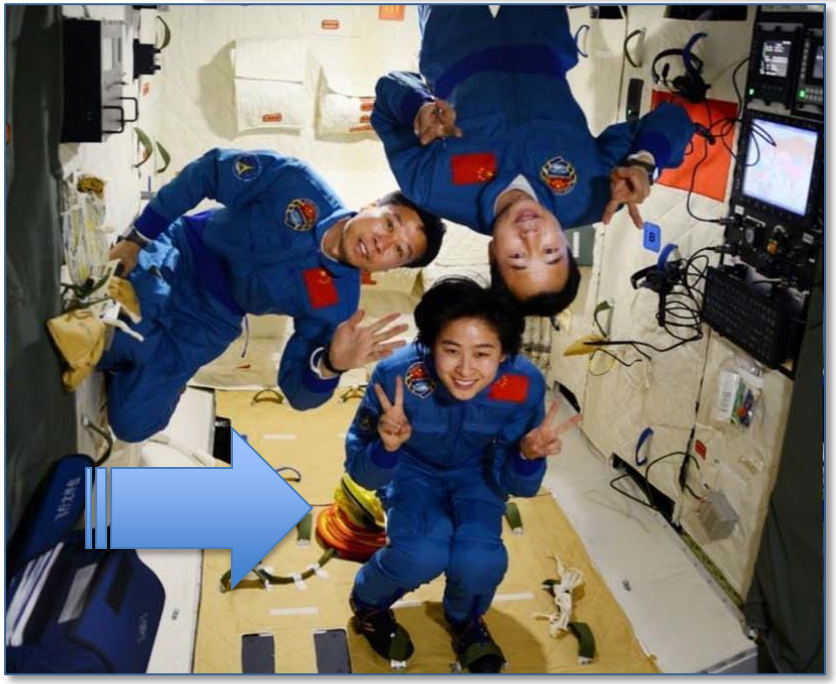
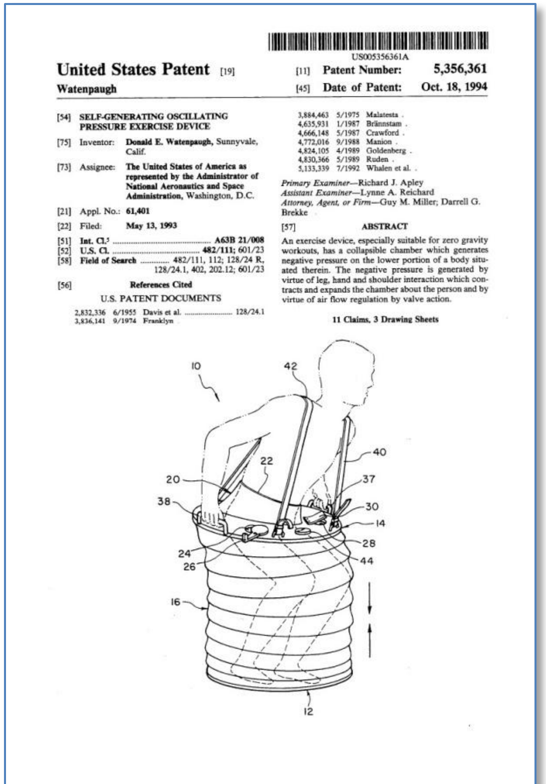


图 1　自行下体负压训练器示意图

Fig. 1　Schematic show of self-generating lower body negative pressure device



Imitation ? Flattery! (Plus spaceflight!)


United States Patent [19]

Watenpaugh

[11] Patent Number: 5,356,361

[45] Date of Patent: Oct. 18, 1994

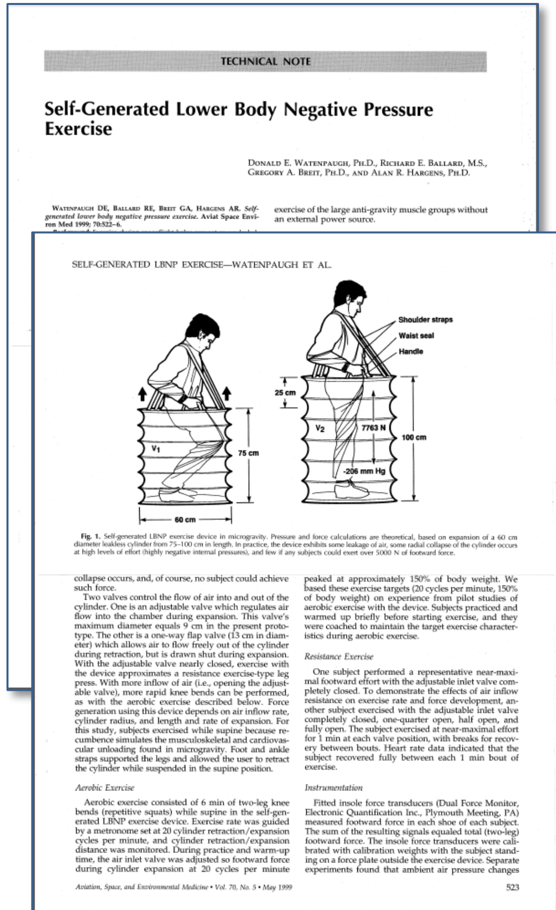
[54] SELF-GENERATING OSCILLATING PRESSURE EXERCISE DEVICE

[75] Inventor: Donald E. Watenpaugh, Sunnyvale, Calif.

[57] ABSTRACT

11 Claims, 3 Drawing Sheets

Watenpaugh patent, 1994


TECHNICAL NOTE

Self-Generated Lower Body Negative Pressure Exercise

Donald E. Watenpaugh, Ph.D., Richard E. Ballard, M.S., Gregory A. Breit, Ph.D., and Alan R. Hargens, Ph.D.

SELF-GENERATED LBNP EXERCISE—WATENPAUGH ET AL.

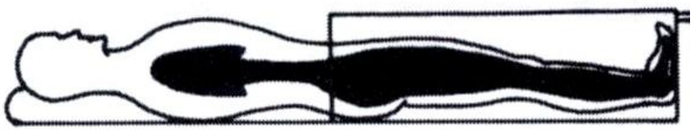
Watenpaugh, Hargens *et al.*, 1999


自行下体负压训练器的研制

Yang *et al.*,2003

LBNP ≠ LBNP (even in weightlessness)

ΔP load



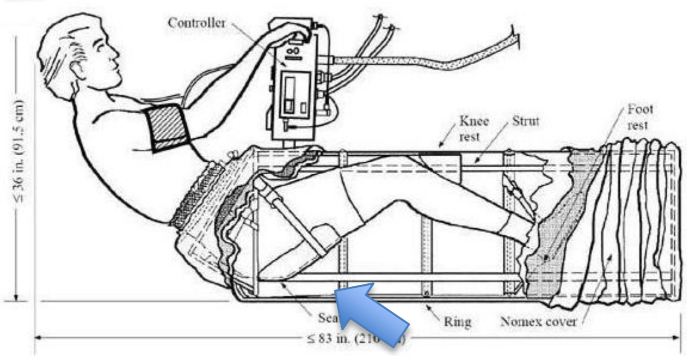
FGRF

ΔP load on feet

- Skeletal muscle involvement
- Muscle pump activation
- Counteracts fluid sequestration

versus

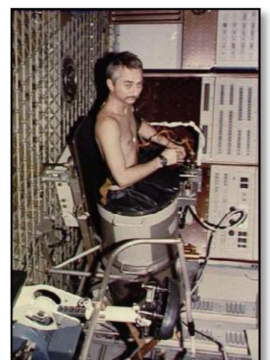
ΔP load



"FGRF"

ΔP load on buttocks or crotch

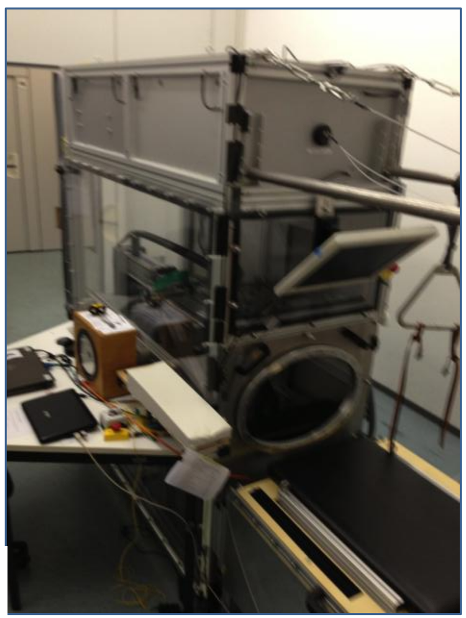
- No leg skeletal muscle involvement
- No muscle pump activation



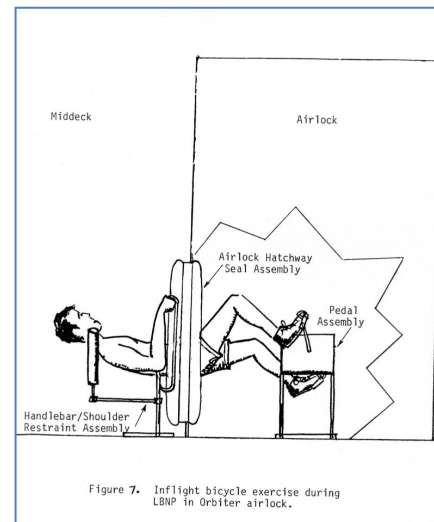
LBNP combined with exercise

Cooper & Ord, 1968

Wattenpaugh *et al*., 1999
Self-generated LBNP (no pumps, no internal exercise device)

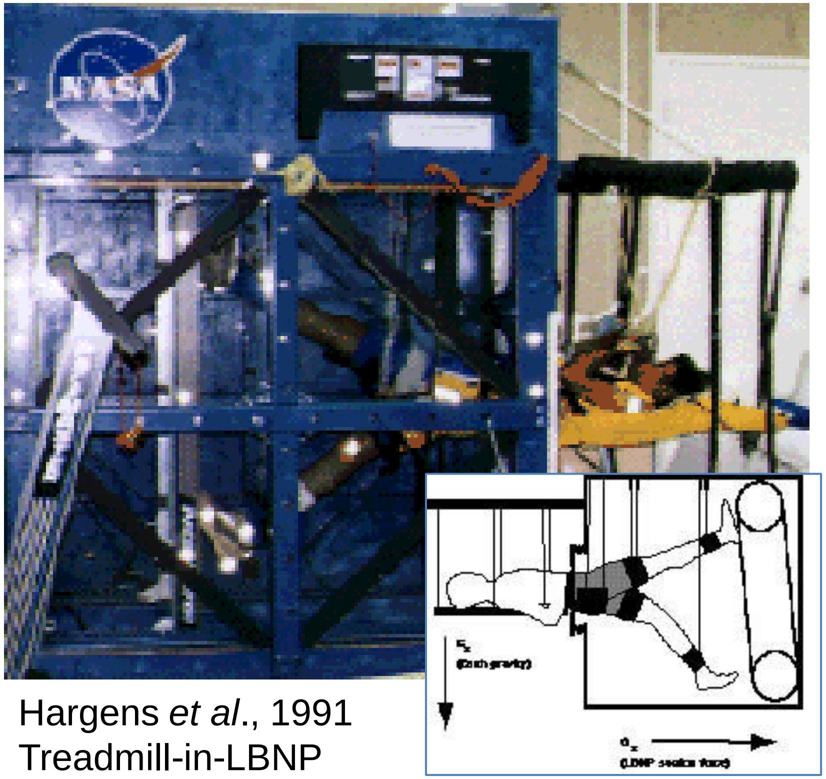


DLR, 2013

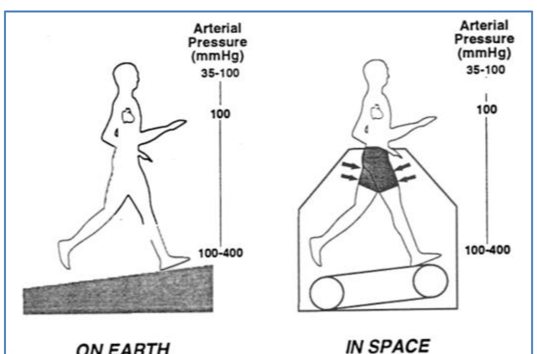


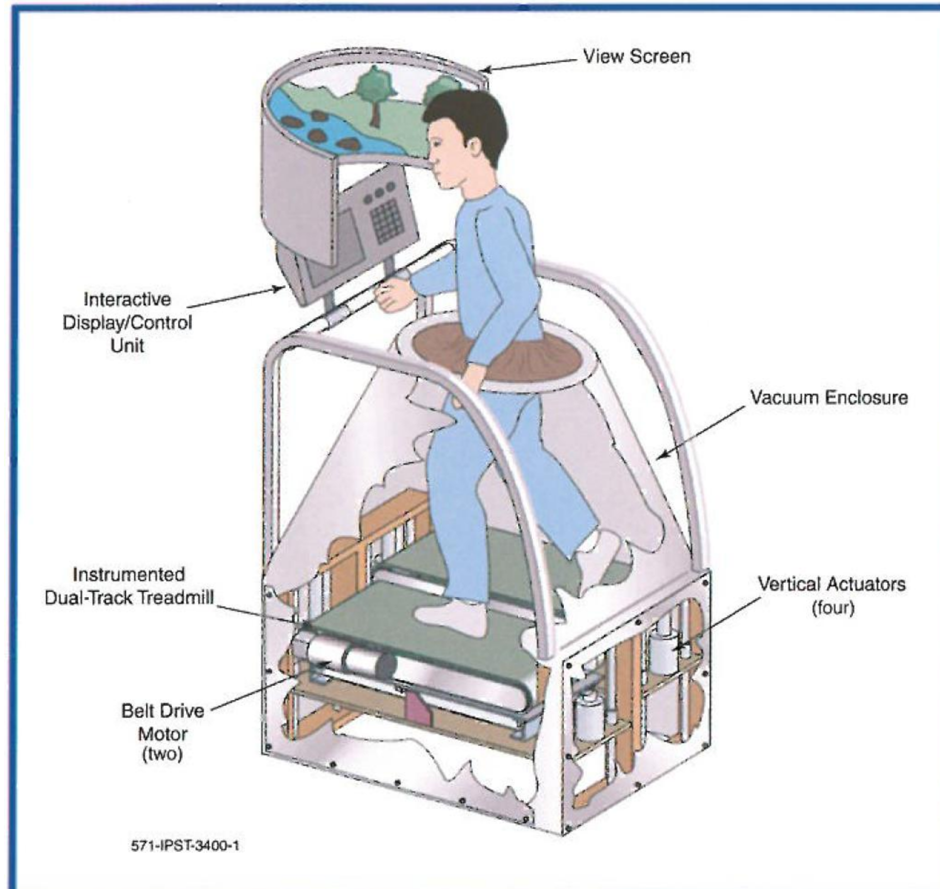
Charles, 1985 (unpublished)

LBNP combined with exercise



Hargens *et al*., 1991
Treadmill-in-LBNP
(requires pump, exercise device)





The proposed treadmill will have split, moveable tracks, and each foot will be moving independently—forwards, backwards, or up and down—on its own belt.

GRC, 2002

Seated LBNP

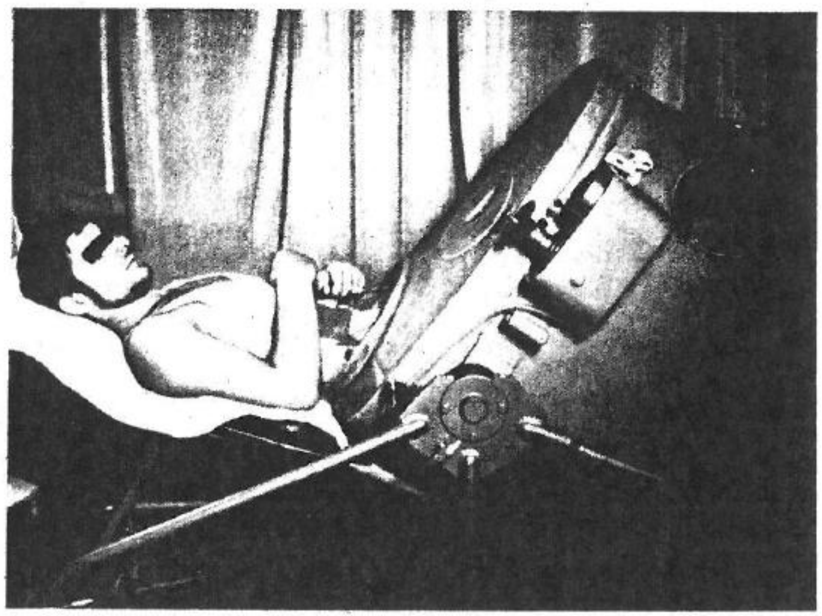


Fig. 2. Seat with vacuum container

UPRIGHT SEATED LBNP BOX—LATEGOLA & TRENT

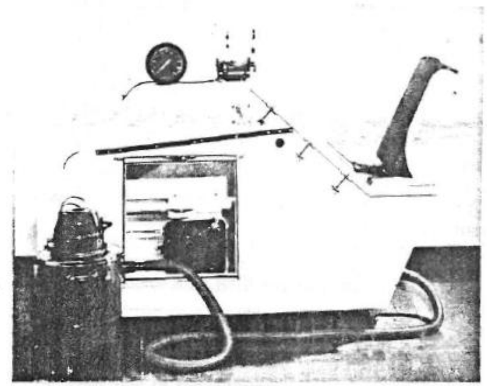


Fig. 1. Side view of the upright seated LBNP box.

the empty volume of the supine LBNP box (5). The back and floor consist of 2.5-cm thick plywood, and the sides, front, top, hatch cover, and seat-cushion support consist of 1.9-cm thick plywood. Internal cross braces of lumber were located at anticipated points of maximum stress. The external metal brace seen in Fig. 1 is a redundant reinforcement. The box is mounted on four 10.2-cm casters for easy mobility. Although this box is routinely used at a negative pressure of −40 torr, it has withstood a test pressure of −120 torr.

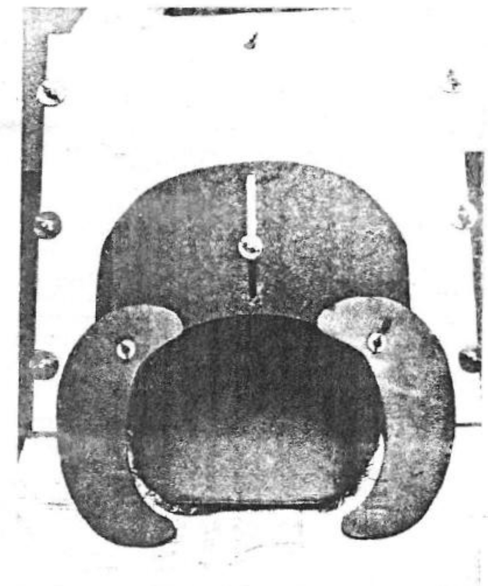


Fig. 3. External view of the hatch cover and its three adjustable waist-contoured slats.

Pestov & Asyamolov, 1972

Lategola & Trent, 1979

Design of an electronically controlled lower-body positive and negative compound pressure range chamber for use with a sitting posture

Keita ISHIBASHI, Ph. D.; Masaki OTAKA; Hisao YOSHIDA; Koichi IWANAGA, Ph. D.

Department of Design Science, Graduate School of Engineering, CHIBA UNIVERSITY
1-33, Yayoi, Inage, Chiba, 263-8522, Japan

CHIBA UNIVERSITY

Lower body negative pressure (LBNP) is used as a perturbation to the cardiovascular system[1]. While various designs of LBNP devices have been introduced, most of the researchers designed these devices to apply LBNP to a subject in the supine position[2, 3]. One of the advantages of the supine position for LBNP is that a wide range of the negative pressure load can be set in this position compared to the sitting position, in which the relative gravitational blood shift has already occurred. However, it is difficult to impose additional mental work on a subject in the supine position, and it may not be possible to evaluate the task performance appropriately[4]. When both positive and negative pressure is available, a sufficient range of pressure load values will be also available in the sitting position. We designed an electronically controlled lower body positive and negative compound range pressure (LBPNP) chamber for use with a sitting posture.

The LBPNP chamber is a cubic structure made of plywood on a stainless steel frame (Table 1). A neoprene skirt for air-tight sealing fits around the subject's iliac crest (Fig. 1). An electronically controlled pressure control system for LBNP is used with this chamber. The main components of the system are an electronically controlled blower and a differential pressure gauge which measures the compound pressure range (Table 2). A proportional-integral-derivative (PID) control is used for the pressure control with a PC installed with an AD/DA converter. The controllable range of the pressure gauge of the LBPNP is from −70 mmHg to +70.00 mmHg with a 12-bit DA controller.

Although marginal leakage from the air-tight seal during positive pressure caused a 1.3 mmHg offset during the 20 mmHg LBPP condition, the LBPNP chamber was used successfully to test the positive and negative compound pressure ranges in a subject (Fig. 2). We observed large transient physiological responses to mild LBNP (−20 mmHg), LBPP (+20 mmHg), and LBPNP conditions (from −20 mmHg to +20 mmHg with a 30-sec period of sinusoidal pattern).

We thus found that the LBPNP chamber for use with the sitting position can be used to simultaneously assess the orthostatic tolerance and task performance of a subject.

REFERENES

1) Goswani N. et al., Aviat Space Environ Med, 79(5), 2008
2) Verghese C, Prasad A, Aviat Space Environ Med, 64, 1993
3) Ishibashi K. et al., J Physiol Anthropol, 31:30, 2012
4) Iwanaga K. et al., Abs. book of 11th ICPA, 2013

ACKNOWLEDGMENTS

This research was supported in part by a JSPS KAKENHI Grant Number 24247045 and a Grand-in-Aid from Chiba University.

CONTACT INFORMATION

Keita Ishibashi, Ph.D., ishibasi@faculty.chiba-u.jp

Table 1. Main components of the LBPNP chamber.

Frame:	stainless steel square tube, 50mm x 50mm, t = 2 mm 850mm × 650mm × 600mm, Shinko co., ltd.
Panel:	plywood, t = 21 mm
Clamps:	steel (S45C) clamps, QLRE100, Imao corp.
Window:	polymethyl methacrylate (PMMA) plate, t = 25mm
Sealing skirts:	neoprene kyak skirt, KAKR002, Sandiline
Release valve:	stainless ball valve, φ50mm x 1, φ25mm x 1
Cut-off valve:	stainless ball valve, φ25mm x 2
Flange:	stainless flange, φ50mm x 1, φ25mm x 6
Sealer:	silicone sealant, 8051N, Cemedine co.,ltd.

Table 2. Main components of the control system.

Speed control blower:	VASF 1.50/1; Gebr Becker
Differential pressure transmitter:	PU-10kPa; Halstrup-Walcher
Digital manometer:	AD-1000; Halstrup-Walcher
DC power supply:	AD-8723D, A&D Co., Ltd.
Isolation transformer:	CDF1-1000, Toa denshi Co.,Ltd.
AD converter:	AD16-16U(PCI)EH, CONTEC Co., Ltd.
DA converter:	MaP1990DAD, Nihonsanteku Co., Ltd.
Control computer:	MT7900, Epson Direct Corp.
OS: Windows XP, Microsoft	
Programming language: Visual Basic 6.0, Microsoft	
Dynamic Link Library: SBL2100, Nihonsanteku Co., Ltd.	

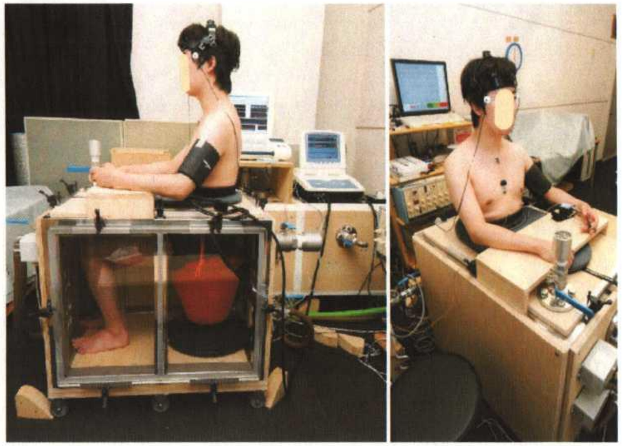


Figure 1. Experimental set-up with instrumented subject.

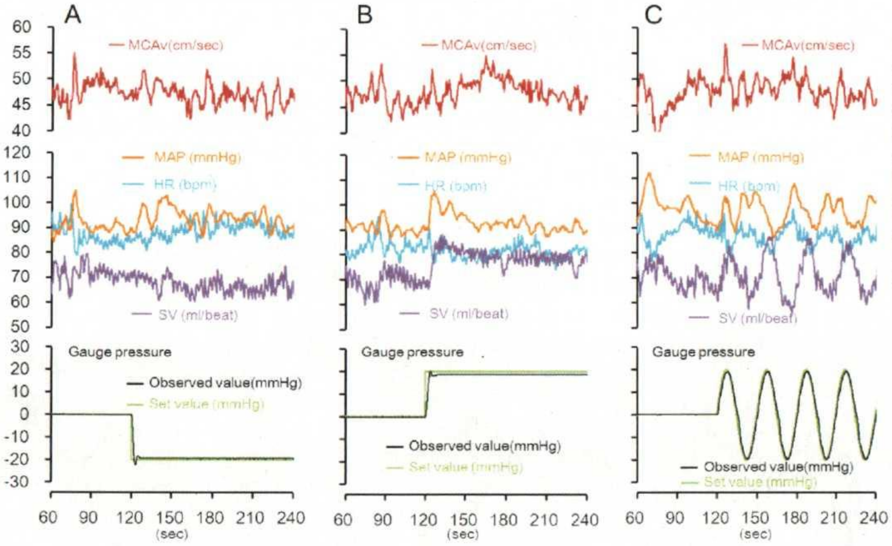


Figure 2. Traces of middle cerebral arterial blood flow velocity (MCAv), mean arterial pressure (MAP), heart rate (HR), stroke volume (SV), and gauge pressure of LBNP (−20 mmHg; panel A), LBPP (+20 mmHg; panel B), and LBPNP conditions (from −20 mmHg to +20 mmHg with a 30-sec period of sinusoidal pattern; panel C).

Disclosure Information
85th Annual Scientific Meeting
Keita Ishibashi
I have no financial relationships to disclose.
I will not discuss off-label use and/or investigational use in my presentation

Immersion LBNP

Series III: seated in a chair. In this case the hydrostatic pressure corresponded to the height of the column of blood in a sitting position.

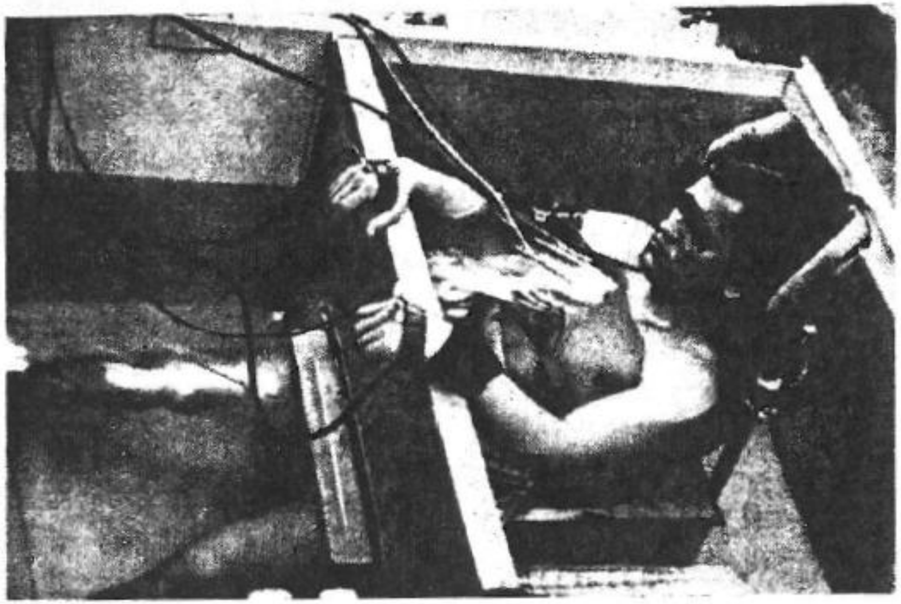


Fig. 1. General appearance of immersion bath ensuring pressure drop on the lower part of the human body

Series IV: immersion in a sitting position in an immersion bath divided by a tight partition which made it possible to reduce the compensating counterpressure of the immersion medium on the lower part of the body (Fig. 1). Since the remaining experimental conditions (water temperature, position, breathing at negative pressure, suspended state of the body and extremities) in this case corresponded to the conditions in the first series, the principal difference was a carefully measured decrease (by 24 mm Hg) in external pressure on the lower (beginning with the waist) part of the body.

Pestov & Asyamolov, 1972

LBNP plus Head-up Tilt

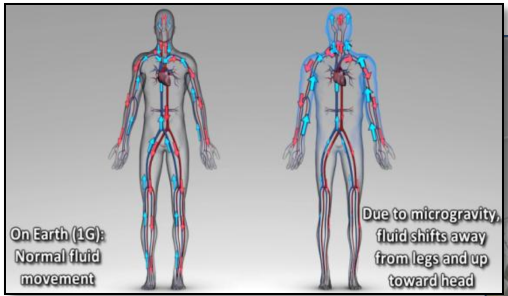
“AustroMars” Helmut Hinghoffer-Szalkay, Graz, Austria

DLR, Köln, 2013

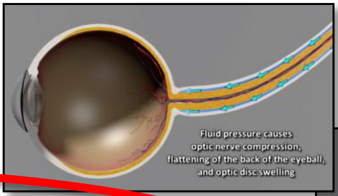
Application to VIIP: Fluid shifts

PIs: Michael Stenger, Alan Hargens, Scott Dulchavsky, Valery Bogomolov

- Fluid compartmentalization measures:
  - Total Body Water (D_2O)
  - Extracellular Fluid (NaBr)
  - Intracellular Fluid (Calculated)
  - Plasma Volume (CO rebreathing)
  - Interstitial Fluid Volume (Calculated)



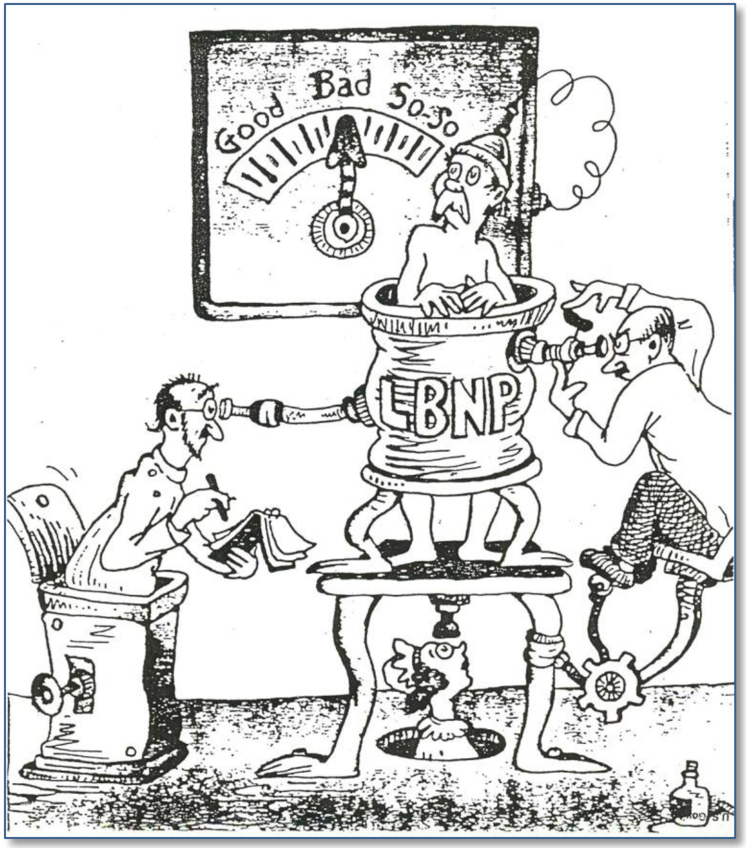
- Imaging measures:
  - Head & Neck ultrasound (Carotid, jugular, vertebral, cerebral)
  - Ocular ultrasound (Ophthalmic, retinal, ONSD)
  - Ocular Structure (OCT)
  - Cardiovascular and portal vein ultrasound
  - Tissue thickness of calcaneous, tibia, forehead and eyelid
  - Magnetic Resonance Imaging (upright, supine, HDT) for vascular and ventricular dimensions, CSF production and flow, and ICP estimation
- Other physiological measures:
  - Intracranial Pressure (CCFP/DPOAE)
  - Intraocular Pressure (Tonopen/Icare)
  - Blood Pressure / Heart Rate / TPR
- Preflight/Inflight/Postflight
- With and without fluid shift manipulation (HDT/HUT/LBNP) and breathing maneuvers



Application to VIIP

Conclusion

- LBNP is applicable to investigations of gravity-dependent physiological mechanisms in weightlessness
- LBNP has demonstrated value as a gravity-surrogate or gravity-replacement for in-flight rehabilitation
  - Cost-benefit calculation
    - Significant cost
- LBNP has flexibility to meet clinical and scientific requirements



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ASMA 2014 Abstract

- Program ID number: 080
- Title: STANDING WITHOUT GRAVITY: THE USE OF LOWER BODY NEGATIVE PRESSURE FOR RESEARCH AND RECONDITIONING IN SPACEFLIGHT
- Insight into VIIP (Visual Impairment Intracranial Pressure), May 12, 2014 02:00 PM Indigo E

- J.B. Charles, M.R. Campbell, M.B. Stenger, S.M.C. Lee
- Weightlessness during spaceflight causes cephalad redistribution of intravascular and extravascular fluid, provoking cardiovascular and autonomic nervous system adaptations. The resulting functional state is appropriate for weightlessness but can result in orthostatic hypotension and intolerance during and after return to a persistent acceleration or gravitational environment. Lower body negative pressure (LBNP) applies subambient air pressure to the legs and lower abdomen inside a volume sealed at the waist, and decompression by 40-50 mmHg reverses the spaceflight-induced cephalad shift. LBNP has been used both to test the state of cardiovascular system during spaceflight and as a countermeasure by all space-faring nations.
- Two configurations have thus far been used in spaceflight since the first LBNP flew on the first Soviet Salyut station in 1971. The Soviet and Russian configuration, used in four Salyut stations, the Mir space station and the Russian segment of the International Space Station, has no saddle to support the body so during decompression the feet press against the bottom of the collapsible chamber which shortens and applies force against the feet proportional to the decompression level. Thus, activation of the skeletal musculature partially counteracts vascular and venous pooling in the enclosed body segments, stimulating the orthostatic compensatory mechanisms as they would be standing on Earth. In the American configuration, used aboard Skylab and the Space Shuttle, a saddle supported the astronaut so the feet did not contact the bottom of the chamber, and vascular engorgement was not countered by muscular contraction. This minimized skeletal muscle involvement, unmasked vascular compensatory mechanisms for research purposes, and allowed measurements of changes in leg volume and muscle sympathetic nerve activity. Both variants have demonstrated research and therapeutic value in appropriately designed protocols.
- LBNP continues to be used for research and countermeasures on ISS, and future versions may explore the value of exercise during LBNP as an integrated countermeasure. This paper will review the history and development of LBNP for spaceflight research and therapeutic purposes.
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