COMPARTMENT SYNDROMES
INTRODUCTION

“Increasing pressure within a closed anatomic space”

- Rise in Pressure…Reaches a Critical Level…Collapse of Microcirculation

- Can Involve all parts of human body

- e.g. Cranial Cavity, Abdominal Cavity, Thoracic Cavity & Extremities
ABDOMINAL COMPARTMENT SYNDROME
WHAT IS INTRA-ABDOMINAL PRESSURE?

“Intra-abdominal pressure (IAP) is the steady-state pressure concealed within the abdominal cavity.”

Normal IAP approx. 5-7 mmHg.

- Elevated IAP is a common finding in the ICU
- IAP increases and decreases with respiration
- IAP is directly affected by:
  1. Solid organ or hollow viscera volume
  2. Space occupying lesions
     - Ascites, blood, fluid, tumors
  3. Conditions that limit expansion of the abdominal wall
     - Burn eschars, third-space edema
WHAT IS ABDOMINAL PERFUSION PRESSURE?

• "Abdominal perfusion pressure (APP) = mean arterial pressure (MAP) minus intra-abdominal pressure (IAP) = MAP - IAP."

- The critical IAP that leads to organ failure varies by patient
- A single threshold IAP cannot be globally applied to all patients
- Analogous to cerebral perfusion pressure, APP assesses not only the severity of IAP, but also the relative adequacy of abdominal blood flow
- APP is superior to IAP, arterial pH, base deficit, and arterial lactate in predicting organ failure and patient outcome
- Failure to maintain APP > 60 mmHg by day 3 predicts survival
HOW SHOULD IAP BE MEASURED?

- "IAP should be expressed in mmHg and measured at end-expiration in the complete supine position after ensuring that abdominal muscle contractions are absent and with the transducer zeroed at the level of the midaxillary line."

- Physical exam is inaccurate in predicting IAP
  - Sensitivity 40-61%
  - Positive predictive value 45-76%
Intra-vesicular or “bladder” pressure measurement represents a safe, rapid, and cost-effective method for monitoring IAP. Bladder pressure measurements can be performed in any ICU using commonly available equipment.

- The recommended instillation volume has been decreased.
  - Larger volumes of saline can lead to falsely elevated IAP measurements.

The reference standard for intermittent IAP measurement is via the bladder with a maximal instillation volume of 25ml sterile saline.
WHAT IS INTRA-ABDOMINAL HYPERTENSION?

- “IAH is defined by a sustained or repeated pathological elevation in IAP $\geq 12$mmHg.”

<table>
<thead>
<tr>
<th>Grade</th>
<th>Bladder pressure (mmHg)</th>
<th>Indication of surgical decompression</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>12-15</td>
<td>No evidence of ACS</td>
</tr>
<tr>
<td>II</td>
<td>16-20</td>
<td>Noninvasive interventions</td>
</tr>
<tr>
<td>III</td>
<td>21-25</td>
<td>Decompression strongly indicated</td>
</tr>
<tr>
<td>IV</td>
<td>$&gt;25$</td>
<td>Immediate Decompression</td>
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ABDOMINAL COMPARTMENT SYNDROME

• “ACS is defined as a sustained IAP > 20mmHg (with or without an APP < 60mmHg) that is associated with new organ dysfunction/failure.”

ACS = IAH + organ dysfunction

The most common organ dysfunction / failure(s) are:
- Metabolic acidosis despite resuscitation
- Oliguria despite volume repletion
- Elevated peak airway pressures
- Hypercarbia refractory to increased ventilation
- Hypoxemia refractory to oxygen and PEEP
- Intracranial hypertension
Abdominal Compartment Syndrome (ACS)

- **Primary ACS**: condition associated with injury or disease in the abdomino-pelvic region that frequently requires early surgical intervention.
Secondary ACS: refers to conditions that do not originate from the abdomino-pelvic region

Sepsis / Capillary Leak

Burns

Massive Resuscitation
The Pathophysiology of IAH

1. VASCULAR COMPRESSION
   - ↑RVP
   - ↓IVC
   - Flow
   - Cardiac compression

2. DIAPHRAGMATIC ELEVATION
   - Cardiac contraction
   - ↑Intrathoracic pressure
   - ↓Cardiac preload
   - ↓Cardiac contractility
   - ↑Systemic afterload

3. DIRECT ORGAN COMPRESSION
   - ↑PV pressure
   - ↓Renal Vascular Resistance
   - ↑Renal Failure
   - ABDOMINAL WALL ISCHAEMIA/OEDEMA
   - RESPIRATORY FAILURE
   - ↑Splanchnic Vascular Resistance
   - ↑ICP
   - ↑Splanchnic Ischaemia
## CLINICAL MANIFESTATIONS

<table>
<thead>
<tr>
<th>CENTRAL NERVOUS SYSTEM</th>
<th>GASTROINTESTINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑ Intracranial pressure</td>
<td>↓ Celiac blood flow</td>
</tr>
<tr>
<td>↓ Cerebral perfusion pressure</td>
<td>↓ SMA blood flow</td>
</tr>
</tbody>
</table>

### CARDIAC

- Hypovolemia
- ↓ Cardiac output
- ↓ Venous return
- ↑ PCWP and CVP
- ↑ SVR

### PULMONARY

- ↑ Intrathoracic pressure
- ↑ Airway pressures
- ↓ Compliance
- ↓ PaO2  ↑ PaCO2
- ↑ Shunt fraction
- ↑ Vd/Vt

### RENAL

- ↓ Urinary output
- ↓ Renal blood flow
- ↓ GFR

### HEPATIC

- ↓ Portal blood flow
- ↓ Mitochondrial function
- ↓ Lactate clearance

### ABDOMINAL WALL

- ↓ Compliance
- ↓ Rectus sheath blood flow
Identification of Patients at Risk

Large volume fluid resuscitation (> 3.5 L / 24 hrs)
Damage Control Laparotomy
Acidosis
Hypothermia
Coagulopathy / Massive Transfusion Protocols
Pulmonary, renal, hepatic dysfunction
Ileus
Abdominal surgery / primary fascial closure

*If two or more risk factors for IAH / ACS are present, a baseline IAP measurement should be obtained*
1. Sedation & Analgesia

- Pain, agitation, ventilator dyssynchrony, and accessory muscle use during breathing may all lead to increased abdominal muscle tone.
- Sedation and analgesia can reduce muscle tone and decrease IAP to less detrimental levels.
- While such therapy would appear prudent, no prospective trials have been performed evaluating the benefits and risks of sedation and analgesia in IAH/ACS.
Grade I & II IAH: Medical Management (Cont..)

2. Neuromuscular blockade (NMB) may be considered in selected patients with mild to moderate IAH while other interventions are performed to reduce IAP (Grade 2C)

- Diminished abdominal wall compliance due to pain, tight abdominal closures, and third-space fluid can increase IAP to detrimental levels
- The potential beneficial effects of NMB in reducing abdominal muscle tone must be balanced against the risks of prolonged paralysis
- NMB is unlikely to be an effective therapy for patients with severe IAH or the patient who has already progressed to ACS
3. Gastric/Rectal Suctioning & Prokinetic Agents

- **Both air and fluid within the hollow viscera can raise IAP and lead to IAH / ACS**
- **Nasogastric and/or rectal drainage, enemas, and even endoscopic decompression can reduce IAP**
- **Prokinetic motility agents such as erythromycin, metoclopramide, or neostigmine can aid in evacuating the intraluminal contents and decreasing the size of the viscera**
- **Insufficient evidence is currently available to confirm the benefit of such therapies in IAH/ACS**
4. Fluid Resuscitation

*Fluid resuscitation volume should be carefully monitored to avoid over-resuscitation in patients at risk for IAH/ACS (Grade 1B)*

**Hypertonic crystalloid and colloid-based resuscitation should be considered in patients with IAH to decrease the progression to secondary ACS (Grade 1C)**

- Excessive fluid resuscitation is an independent predictor of IAH/ACS and should be avoided
- The use of goal-directed hemodynamic monitoring should be considered to achieve appropriate fluid resuscitation
5. **Therapeutic Paracentesis**

_Percutaneous catheter decompression should be considered in patients with intraperitoneal fluid, abscess, or blood who demonstrate symptomatic IAH or ACS (Grade 2C)_

- **Paracentesis** represents a less invasive method for treating IAH/ACS due to free fluid, ascites, air, abscess, or blood
- **Percutaneous catheter insertion** under ultrasound guidance allows ongoing drainage of intraperitoneal fluid and may help avoid the need for open abdominal decompression in selected patients with secondary ACS
Decompressive Laparotomy

- Abdomen is decompressed, Abdominal fluid evacuated.

- Leave abdominal fascia and skin open, with protective material to contain water & protein losses & prevent evisceration.

- Definitive closure, when patient has recovered from acute inflammatory phase ~ 5-7 days post-insult
Grade III & IV IAH / ACS: Surgical Mx (cont..)

1. Primary fascial closure (70-80% of cases) is the ultimate goal

Vac-Assisted Temporary Abdominal Closure

Absorbable Mesh placement – Vicryl vs Dexon

Wittmann Patch

Fascial Medialization (Lateral Releasing Incisions vs Component Separation)

2. Abdominal Wall Hernia
Skin Coverage – Skin flaps vs STSG
“Poor Man’s Vac Pack Dressing”

Thin plastic sheet, a sterile towel, closed suction drains, and a large adherent operative drape. This dressing system permits increases in intra-abdominal volume, without a dramatic elevation in IAP.
INTRA-ABDOMINAL WOUND VAC DRESSING
EXTREMITY COMPARTMENT SYNDROME
Extremity Compartment Syndrome

- Elevated tissue pressure within a closed fascial space of the extremity
- Reduces tissue perfusion – ischemia
- Results in cell death – necrosis
History

- Volkmann 1881
- Richard von Volkmann published an article in which he described the condition of irreversible contractures of the flexor muscles of the hand to ischemic processes occurring in the forearm.
- Application of restrictive dressing to an injured limb.
History

- Hildebrand 1906
- First used the term Volkmann ischemic contracture to describe the final result of any untreated compartment syndrome, and was the first to suggest that elevated tissue pressure may be related to ischemic contracture.
History

- Murphy 1914
- First to suggest that fasciotomy might prevent the contracture
Volkmann’s Ischemic Contracture
Etiologies

- Fractures (50% of Cases)
- Crushing Injuries
- Prolonged Ischemia/Reperfusion
  - Embolus/Thrombosis with thrombolysis/embolectomy
  - Repair of Arterial Injury
- Extravascular forearm infusions
- Lloyd Davies positioning
- Pneumatic Torniquet
- Burn Eschar
- Snakebites
The most common cause incidence of accompanying compartment syndrome of 9.1%

The incidence is directly proportional to the degree of injury to soft tissue and bone

occurred most often in association with a comminuted, grade–III open injury to a pedestrian

Blick et al JBJS 1986
## Incidence

<table>
<thead>
<tr>
<th>Type of Fx</th>
<th>% of ACS</th>
<th>Incidence all ages</th>
<th>Incidence &lt;35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibial diaphysis</td>
<td>36%</td>
<td>4.3%</td>
<td>5.9%</td>
</tr>
<tr>
<td>Distal radius</td>
<td>9.8%</td>
<td>0.25%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Forearm diaphysis</td>
<td>7.9%</td>
<td>3.1%</td>
<td>3.2%</td>
</tr>
</tbody>
</table>

McQueen et al; JBJS Br 2000
Blunt Trauma

- 2nd most common cause
- About 23% of CS
- 25% due to direct blow

McQueen et al; JBJS Br 2000
Compartment Syndrome
Tissue Survival

- Muscle
  - 3–4 hours – reversible changes
  - 6 hours – variable damage
  - 8 hours – irreversible changes

- Nerve
  - 2 hours – looses nerve conduction
  - 4 hours – neuropraxia
  - 8 hours – irreversible changes
DIAGNOSIS

- Alert Patient – Physical Examination
- Patients with Neurologic Compromise – Invasive techniques

- Physical Exam Findings:
  - Compartment Firm and Painful
  - Pain, out of proportion to the degree of injury
  - Pain, exacerbated by passive stretching of involved muscle group
  - Paresthesias
Clinical Evaluation

“Pain and the aggravation of pain by passive stretching of the muscles in the compartment in question are the most sensitive (and generally the only) clinical finding before the onset of ischemic dysfunction in the nerves and muscles.”

Whitesides AAOS 1996
Compartment Syndrome
Pressure Measurements

- Suspected compartment syndrome
- Equivocal or unreliable exam
- Clinical adjunct
- Contraindication
  - Clinically evident compartment syndrome
Compartment Syndrome Pressure Measurements

- Stryker device
  - Side port needle

- Catheter
  - Side Ported Needle
  - Slit catheter
Stryker Stic System

- Easy to use

Unique design with unique benefits

- Side ported, non-coring needle for tissue fluid pressure equilibration
- Diaphragm chamber maintains sterile fluid pathway
- One way valve prevents backflow of fluid
- Automatic zero balance button eliminates manual zeroing adjustments
- Digital display (with low battery indicator) to quantify pressure reading
- Pre-filled syringe for rapid, convenient utilization

(Not actual size)
Compartment Syndrome
Pressure Measurements

- Simple Needle
  - 18 gauge
  - Least accurate
  - Usually gives falsely higher reading

- Slit Catheter and Side ported needle
  - No significant difference
  - More accurate

Moed et al. JBJS 1993
Compartment Syndrome
Pressure Measurements

- Measurements must be made in all compartments
- Anterior and deep posterior are usually highest
- Measurement made within 5 cm of fx
- Marginal readings must be followed with repeat physical exam and repeat compartment pressure measurement

Heckman, Whitesides JBJS 1994
Threshold for fasciotomy

- McQueen, Court-Brown JBJS Br 1996
- 116 pts with tibial diaphyseal fx had continuous monitoring of anterior compartment pressure for 24 hours
  - 53 pts had ICP over 30 mmHg
  - 30 pts had ICP over 40 mmHg
  - 4 pts had ICP over 50 mmHg
- Only 3 had \( \text{delta pr(DBP–ICP)} \) of < 30, they had fasciotomy
- None of the patients had any sequelae of the compartment syndrome
- Decompression should be performed if the differential pressure level drops to under 30 mmHg
Compartment Syndrome
Indications for Fasciotomy

- Unequivocal clinical findings
- Differential Pressure (DBP–CP) < 30 mmHg
- Rising tissue pressure

Prophylactic Fasciotomy
- > 4–6 hrs of total limb ischemia
- Arterial Injury with Venous Injury
- Crush Injury
- Electrical Injury
Fasciotomy: Medial Leg

Gastroc-soleus

Flexor digitorum longus
Fasciotomy: Lateral Leg

- Intermuscular septum
- Superficial peroneal nerve
Thigh Fasciotomy

- Release of 3 separate compartments
  - **Quadriceps Compartment** is entered through an anterolateral incision on thigh.
  - **Hamstring Compartment** is decompressed by posterior division of anteromuscular septum.
  - **Adductor compartment** is entered through a third incision medially along the length of this compartment.
Compartment Syndrome
Thigh

- Lateral to release anterior and posterior compartments
- May require medial incision for adductor compartment
Volar Compartment is decompressed with an incision along volar aspect of forearm.

- Carpel tunnel Release.

- Measure Dorsal compartment pressures, and if it remains elevated, perform a dorsal fasciotomy, by an incision on the back of the forearm from wrist to lateral condyle.
Forearm Fasciotomy

- Volar–Henry approach
  - Include a carpal tunnel release
- Release lacertus fibrosus and fascia
- Protect median nerve, brachial artery and tendons after release
Forearm Fasciotomy

- Protect median nerve, brachial artery and tendons after release
- Consider dorsal release
Secondary / Split-thickness skin graft.

Techniques that apply gradual tension:
Standard staples applied at both the wound margins, and vessel loops placed in a shoe-string type fashion. Tightened progressively.