MILITARY FIREFIGHTER EXPOSURE TO PERFLUOROALKYL SUBSTANCES (PFAS) AND ADVERSE REPRODUCTIVE OUTCOMES

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Department of Environmental Health
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<tbody>
<tr>
<td>1</td>
<td>Define perfluoroalkyl substances (PFAS), describe common sources and routes of exposure, and understand why PFAS are used in firefighting foam</td>
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<td>2</td>
<td>Briefly explain the toxicological and human literature on PFAS exposure and male and female reproductive health</td>
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<td>3</td>
<td>Identify the clinical implications of PFAS exposure in a couple attempting conception at Wright-Patterson Air Force Base</td>
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<td>4</td>
<td>Discuss the public health implications of PFAS exposure in reproductive aged couples</td>
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PART-1
UNDERSTANDING PERFLUOROALKYL SUBSTANCES
Per- and polyfluoroalkyl substances (PFAS) are a large class of synthetic chemicals.

- Widely used to make products heat, oil, stain, and water resistant
- In production since 1950s
- Previously known as perfluorinated chemicals (PFCs)
- Hundreds of different PFAS exist
- Perfluorooctyl sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are the two most well-known and well-studied
What are some of the features of PFAS?

- All PFAS contain carbon (C) and fluorine (F) atoms
- C-F bonds: strongest covalent bonds in organic chemistry
- Properties (and name) change based on the length of the carbon chain in the PFAS molecule
- PFOA is referred to as C8 because there are 8 carbon atoms in the chain
- Highly resistant: thermal and chemical stability

PFOA, also known as C8, has 8 carbons.
PFAS Uses

Non stick cookware (e.g., Teflon pans)

Water and/or stain resistant carpet, textiles, and clothing (e.g., Scotch guard)

Paper and cardboard food packaging (e.g., pizza boxes, cooking paper)

Aqueous Film Forming Foam (AFFF) Fire Fighting Foam
PFAS Uses
PFAS Uses

PFAS BRAND NAMES

- Teflon
- Scotchguard
- Stainmaster
- Stainsafe
- Silverstone
- Polartec
- Texapore
- Gore-Tex

PFAS WORDS to AVOID

- "nonstick"
- "water-repellent"
- "weather-protective"
- "stain-resistant"
- "fluoro" or "perfluoro"
Chemicals in Your Popcorn?

What do a pizza box, a polar bear and you have in common?

All carry a kind of industrial toxicant called poly- and perfluoroalkyl substances, or PFAS, that do two things: They make life convenient, and
- Drinking contaminated water: private wells and municipal systems
- Ingesting contaminated food: food packaging; bioaccumulation of meat and fish; produce grown in contaminated soil and water
- Hand-to-mouth transfer from surfaces/products: migrate from PFAS consumer goods
- Inhalation of air and dust: house dust; workplace air exposure
- Dermal absorption: contact with textiles, clothing, sofa seating, other
✓ Drinking water can be a source of exposure in communities where these chemicals have contaminated water supplies

✓ Contamination: localized, usually associated with a specific facility

- Parkersburg, West Virginia
- Oil refineries, airfields or other locations used for firefighting
PFAS Accumulation and Elimination in Humans

- Bind to protein molecules in serum upon absorption
- Bioaccumulate but not in fatty tissue
- Renal clearance: influenced by GFR, eliminated in urine
- Shorter chain PFAS faster clearance than long chain PFAS
- Variability in accumulation and elimination by sex
- Detected in: serum, seminal fluid, amniotic fluid, cord blood, breast milk, liver tissue
- Efficient placental transfer
✓ Unique physical and chemical properties make them highly persistent in our environment and in our bodies

✓ Elimination half-life in humans: 2.3 to 8.5 years

<table>
<thead>
<tr>
<th>PFAS</th>
<th>HALF LIFE</th>
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<tbody>
<tr>
<td>Perfluorooctanoic acid (PFOA)</td>
<td>3.8 years</td>
</tr>
<tr>
<td>Perfluorooctanesulfonate (PFOS)</td>
<td>5.4 years</td>
</tr>
<tr>
<td>Perfluorohexane sulfonic acid (PFHxS)</td>
<td>8.5 years</td>
</tr>
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</table>
Why are PFAS used in Firefighting Foam?

- Chemical diversity in types of PFAS → multifunctional uses
- Resist degradation and oxidation → they don’t break down
- Thermal stability primarily attributed to the strength of the C-F bond in the fluoroalkyl tail
- HIGHLY resistant to heat degradation even at extreme temperatures
- Some PFAS decompose and mineralize at temperatures >1000°C
Ubiquitous PFAS Exposure

✓ Widespread use of PFAS chemicals over the last 60+ years and their long elimination half lives have resulted in ubiquitous general population exposure

✓ Concern regarding the persistence, bioaccumulation, and possible ecological and human health effects of long-chain PFAS led to manufacturers developing replacement short-chain PFAS chemistries

✓ Replacement chemistry: Short-chain alternatives

✓ Regrettable substitution
# National Health and Nutrition Examination Survey (NHANES)

<table>
<thead>
<tr>
<th>PFAS Analytes*</th>
<th>Women 2007-2008 Concentration (μg/l)</th>
<th>PERCENTILE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GM***</td>
<td>50th</td>
</tr>
<tr>
<td>PFOS</td>
<td>10.7</td>
<td>10.8</td>
</tr>
<tr>
<td>PFOA</td>
<td>3.56</td>
<td>3.70</td>
</tr>
<tr>
<td>PFNA</td>
<td>1.33</td>
<td>1.30</td>
</tr>
<tr>
<td>PFHxS</td>
<td>1.46</td>
<td>1.40</td>
</tr>
<tr>
<td>PFDA</td>
<td>0.27</td>
<td>0.30</td>
</tr>
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</table>

*PFOS, perfluorooctane sulfonate; PFOA, perfluorooctanoate; PFNA, perfluorononanoate; PFHxS, perfluorohexane sulfonate; PFDA, perfluorodecanoate; **Limit of detection (LOD) 0.1 for all analytes except PFHxS (0.2); ***GM, Geometric Mean
Which of the following products do not contain PFAS?

A. Non-Stick Cookware
B. Stain-Repellant Upholstery
C. Cellophane Wrap
D. Certain fire fighting foams
E. Wooden dishware
PART-2
PFAS AND REPRODUCTIVE HEALTH
Potential Reproductive Health Effects

RODENT ANIMAL MODELS

- Reduced testosterone levels
- Reduced birth weight and gestational length
- Increased pregnancy loss and neonatal mortality
- Birth Defects: Ventricular Septal Defect, cleft palate
- Delays in postnatal growth

Potential Reproductive Health Effects

HUMAN: FERTILITY AND PREGNANCY OUTCOMES

➢ Possible association with longer time to pregnancy, reduced fecundity, and increased risk of pregnancy loss
➢ Increased risk of pregnancy induced hypertension and pre-eclampsia
➢ Higher PFOS exposure may be associated with morphologically abnormal sperm and possible infertility
➢ Perturbation of spermatic epigenetic processes
➢ No studies have examined the role of paternal PFAS exposure on pregnancy loss and other birth outcomes

Fei 2009, Soubry 2014
HUMAN: BIRTH OUTCOMES

- Decreased birth weight
- Small for gestational age
- Preterm birth

Lauritzen, 2017. Sagiv, 2017
Which of the following is a potential reproductive health effect of PFAS exposure?

a) Decreased Antral Follicle Count
b) Macrosomia (Large Infant)
c) Still Birth
d) Abnormal Sperm Shape
PART-3

CLINICAL IMPLICATIONS OF PFAS EXPOSURE IN COUPLES ATTEMPTING CONCEPTION
36-year-old nulliparous female TSgt and 38-year-old male TSgt are referred for an infertility work up.

They are both Air Force service members, and have worked in the Civil Engineering Squadron as fire fighters, since their enlistment at the ages 18 and 20, respectively.

They have tried unsuccessfully for two years to conceive.
There has been much discussion over the last two years within their squadron, regarding the Air Force’s uses of PFOA and PFOS.

Ground water at Wright Patterson Air Force Base in Dayton, OH has been contaminated.

The couple wonders if this, and similar exposures over the last 15 years has lead to their infertility problems.
Live Fire Training Exercise
<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
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<tbody>
<tr>
<td>FSH</td>
<td>15 IU/L</td>
</tr>
<tr>
<td>LH</td>
<td>10 IU/L</td>
</tr>
<tr>
<td>AMH</td>
<td>2 ng/ml</td>
</tr>
<tr>
<td>Prolactin</td>
<td>20 ng/dl</td>
</tr>
<tr>
<td>Progesterone</td>
<td>0.9 ng/ml</td>
</tr>
<tr>
<td>AFC</td>
<td>5 (Left), 4 (Right)</td>
</tr>
<tr>
<td>TSH, T4, TPO-Antibodies</td>
<td>2.8 mIU/L, 6 ug/dl, Antibody-negative</td>
</tr>
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Clinical Studies, Female

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFOA</td>
<td>7 ug/ml (NHANES, 2009: ref mean 3.56)</td>
</tr>
<tr>
<td>PFOS</td>
<td>23 ug/ml (NHANES, 2009: ref mean 10.7)</td>
</tr>
<tr>
<td>Hysterosalpingograph</td>
<td>Within Normal Limits</td>
</tr>
<tr>
<td>Transvaginal U/S</td>
<td>Uterus and ovaries have a normal appearance</td>
</tr>
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### Clinical Studies, Male

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testosterone</td>
<td>700 ng/dl</td>
</tr>
<tr>
<td>FSH</td>
<td>3 mIU/mL</td>
</tr>
<tr>
<td>PFOA</td>
<td>6 ug/l (NHANES, 2009: ref mean 4.47)</td>
</tr>
<tr>
<td>PFOS</td>
<td>28 ug/l (NHANES, 2009: ref mean 23.2)</td>
</tr>
</tbody>
</table>
Is the semen analysis normal?

- Yes
- No

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>2.2 ml</td>
</tr>
<tr>
<td>Appearance</td>
<td>normal</td>
</tr>
<tr>
<td>Morphology</td>
<td></td>
</tr>
<tr>
<td>- 23% normal</td>
<td></td>
</tr>
<tr>
<td>- 72% head defect</td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td></td>
</tr>
<tr>
<td>- 30 million/ml</td>
<td></td>
</tr>
<tr>
<td>Motility</td>
<td></td>
</tr>
<tr>
<td>- Rapid Progression, 27%</td>
<td></td>
</tr>
<tr>
<td>- Immotile, 30%</td>
<td></td>
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</tbody>
</table>
Abnormally-Motile Sperm

**SEMEN ANALYSIS**

**NORMAL RESULTS**

**ABNORMAL RESULTS**

**MOTILITY**
- <40%

**MORPHOLOGY**
- >4%

**CONCENTRATION**
- <15 million/ml
The couple eventually conceives...

**HOW WILL THEIR EXPOSURE TO PFAS AFFECT THE PREGNANCY?**

a) There is no need to monitor blood pressure more often during the pregnancy

b) Health effects of PFAS are not specific, and can be caused by other factors

c) There is an association with PFAS and pre-eclampsia

d) Pregnancy induced hypertension occurs in many pregnancies and the specific etiology is often not known
PART-4
UNDERSTANDING PUBLIC HEALTH IMPLICATIONS OF PFAS EXPOSURE IN REPRODUCTIVE AGED COUPLES
AFFF Mechanism of Action

AFFF HAS BEEN USED BY THE AIR FORCE SINCE THE 1970s

FOAM AGENT AT WORK

oxygen
aqueous film or polymeric membrane
foam blanket
fuel

Diagram showing the mechanism of action of AFFF.
OH EPA Director shut down two wells in Area A of Wright Patt and required monthly testing of other wells to detect potential contamination

Levels exceeded the new EPA lifetime exposure standard of 70 parts per trillion
The Air Force awarded a $6.2 million contract to ICL Performance Products in August 2015 for 418,000 gallons of Phos-Chek 3 percent.

Phos-Chek 3 percent was marketed as an environmentally responsible foam; it is a 6 carbon chain AFFF developed under the EPA's Stewardship Program.

Delivery of the product began in August 2016, and all foam in fire stations was replaced by 2017.

Regrettable substitution.
✓ The Air Force was also awarded a contract to retrofit all aircraft rescue and firefighting vehicles (>800) with a mobile foam test system
✓ Fire vehicle operational checks and required annual foam tests will be performed without discharging AFFF into the environment
✓ Retrofitting will be complete in 2018
✓ Viable strategy
Public Health Implications: Reducing Exposure

THE AIR FORCE DISCONTINUED REGULAR FOAM DISCHARGE TESTS IN JULY 2015
Public Health Implications: Reducing Exposure

✓ The Air Force has restricted AFFF for emergency use only.
✓ When AFFF is used, Air Force hazardous materials teams will treat the response scene as a hazardous site, and remove/destroy foam residue before contamination can occur

➢ Training exercises performed in double lined pits to prevent soil and groundwater contamination
➢ Tanks and ponds to collect burn pit effluent
➢ Incineration disposal facilities
✓ Viable strategy
Public Health Implications: Reduce Water Contamination

✓ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
  ➢ Assess, Inspect, Investigate, Clean-up

✓ If lifetime EPA limit is exceeded due to the Air Force mission, the Air Force will provide alternative drinking water sources
  ➢ Bottled water
  ➢ Water filtration systems
  ➢ Connecting private wells to public drinking water supplies
PFAS/PFOA exposure was believed to contribute to this couples’ infertility

Air Force initiatives may decrease future occupational exposures

Infertility affects 15% of couples

Male factor infertility is diagnosed in 20-30% of couples seeking treatment

Understanding how environmental chemicals like PFAS increases the risk of infertility and pregnancy loss is a research gap and public health goal