CHAPTER 22

Women's Health Issues in Aerospace Medicine

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My ambition is to have this wonderful gift produce practical results for the future of commercial flying and for the women who may want to fly tomorrow's planes.

—*Amelia Earhart*

This chapter is primarily concerned with the current state of women's health as related to aerospace medicine. Although much has been conjectured and written about the training and working of women in the aerospace environment, this chapter addresses the evidence provided in the current state of the literature. Women have made and are making significant contributions across the aerospace spectrum from commercial to military to space flight. As women meet these challenges, the flight surgeon must be aware of issues unique and pertinent to women's overall health and well-being. Except for possibly the latter stages of pregnancy, women have no restrictions or significant limitations in flight performance. The health care professional can be confident about addressing particular women's health issues as noted in this chapter in standard manner resulting in sustained high performance by women in all aspects of flight or for women participating only as passengers.

Women's involvement in aviation begins with its earliest days that continues currently both in air and space travel. Currently in the United States, women comprise 6% of all Federal Aviation Administration (FAA) pilots with number totaling 36,584 (1). Within the United States military, women make up roughly 6% of all fixed and rotary wing pilots (1). Thirty-two percent of National Aeronautics and Space Administration (NASA) employees are women with approximately 18% serving in scientific or engineering roles. Of the 91 current active astronauts, 18% or 20% are women and of the 15 international astronauts, 2 are women (2). Reviewing FAA data, the number of women in all classes decreased over the last 25 years but this is offset by the remarkable 13-fold increase in the first (air transport pilot) and second class (commercial) female pilot population. Women are represented in all aviation support roles from mechanic to flight engineer, but only constitute a majority in the flight attendant category at 80% (1).

Contributions or firsts for women occurred in every decade since the start of powered flight in 1903 by the Wright brothers and continues through today. The following is a brief overview of the few notable contributions and achievements by women in the aerospace field.

1910—Raymond De Laroche of France is the first woman in the world to receive a pilot license.

1911—Harriet Quimby is the first American woman to earn a pilot certification and fly across the English Channel.

1921—Bessie Coleman is the first African American, man or woman, to receive a pilot license.

1932—Amelia Earhart of the United States is the first woman to cross the Atlantic Ocean solo in an aircraft.

1934—Helen Richey, an American, is the first woman hired as a pilot for a United States Commercial Airline.

1942—Mary Van Segue of the United States is certified as the first female Air Traffic Controller.

1942—The United States Women's Air Force Service Pilots (WASPs) led by Jackie Cochran are the first American women to pilot U.S. military aircraft.

1953—Jacqueline Cochran is the first woman to break the sound barrier done in a Boeing North American F86 Sabre jet.

1963—Valentina Tereshkova of the United Soviet Socialist Republic is a cosmonaut and the first woman in space aboard the Vostok 6.

1973—Emily Warne, an American, is hired as the first female air transport pilot for a modern, jet-equipped scheduled airline, Frontier Airlines.

FIGURE 22-1 Portrait of Sally Ride, first American woman in space as part of the STS 7 shuttle mission. Courtesy of NASA.

1974—Barbara Raines becomes the first woman pilot for the U.S. military.

1983—Sally Ride is the first American woman in space as part of the STS 7 shuttle mission (Figure 22-1).

1986—Jenna Yeager copilots the Voyager credited with the first around the world, nonstop, nonrefueled flight.

1993—U.S. Department of Defense, through Secretary of Defense, Les Aspin, opens combat aviation to women.

1999—Lt. Col. Eileen Collins of the United States Air Force (USAF) is the first woman to serve as a space shuttle commander. She previously piloted two Space Transportation System (STS) missions (Figure 22-2).

2007—Astronaut Sunita Williams aboard the International Space Station set a record for the number of space walks and total time in space walks for a woman at four walks totaling 29 hours 17 minutes.

FIGURE 22-2 Lt. Col. Eileen Collins of the United States Air Force, the first woman to serve as a space shuttle commander. Courtesy of NASA.

PREGNANCY IN AVIATION

Policy

Standardized policies regarding routine national and international commercial travel of pregnant passengers are nonexistent (3). Civil air company policies, however, do take into account the length of the pregnancy. The more advanced the gestation, the more likely rupture of membranes, labor, or delivery will occur. Predictors for many pregnancy-related events are not always readily evident. Fifty percent of the pregnancies that result in preterm delivery have no identifiable risk factors (4). What are the implications? Diversion for even a commuter flight can be expected to take 30 to 45 minutes depending on meteorologic conditions and air traffic. Responding commercial airlines in a survey by Breahtnach et al. reported that only 70% trained aircrew in delivery and fewer than 30% had a full delivery kit (3). Therefore, a conservative approach with some flexibility is generally employed. Many airline medical departments allow pregnant travelers to fly at their discretion to 36 weeks estimated gestational age for domestic flights and 35 weeks for international, or specifically, transcontinental or transoceanic flights (5). Exceeding airline restrictions generally requires a medical provider statement verifying that labor is not imminent and no underlying complications exist.

Women with complicated pregnancies may encounter other risks with air travel. Absolute contraindications to air travel include ruptured membranes, bleeding during pregnancy, diagnosed ectopic pregnancy, and severe preeclampsia. First trimester bleeding can represent an undiagnosed ectopic pregnancy or threatened/incomplete abortion. Fifteen to 20% of clinically recognized pregnancies end in spontaneous abortion. Second and third trimester bleeding can represent labor, incompetent cervix, abruption, or placenta previa (6). Pregnancies complicated by multiple gestations, a history of preterm labor (PTL), or existing uterine irritability are predisposed to early delivery. Severe anemia affects oxygen delivery to the placenta and should be corrected before flight or minimally necessitates in-flight oxygen supplementation. Oxygen therapy should also be supplied for conditions that potentially compromise placental reserve such as intrauterine growth restriction, postmaturity, and preeclampsia.

The risk with air travel in pregnancy may be minimal in comparison to the environmental risk, such as endemic malaria, that may be encountered in the ultimate destination. The best policy is to consider all aspects of the proposed journey including lodging, activities, food, and medical support, and to mitigate risk that each of these elements poses by establishing sound prenatal care. Pretravel prenatal care typically includes ultrasonography, assessment of immune status to various infections, the need for immunization, malaria prophylaxis, and creation of a prenatal record. Ultrasonography facilitates more precise dating of the pregnancy and helps confirm suspected multifetal gestation and ectopic pregnancy. Non contraindicated immunizations can be administered. Typically, live viral vaccinations such as mumps, rubella, oral polio, varicella, and yellow fever are avoided in pregnancy. Prescriptive medications, including malaria chemoprophylaxis and other stand-by therapies such as antiemetics and antidiarrheals should be considered (7). The prenatal record should be carried together with the passport, visa, and immunization records.

Pregnant aircrew have distinct responsibilities and required activities in the performance of their flight duties. The changing balance, flexibility, mobility, and body habitus in pregnancy become evident in the second trimester and may interfere with the ability to safely pilot or assist passengers during an emergent egress. Therefore, commercial aircrew is generally restricted from duties after 28 weeks or completion of the second trimester (8). Although pregnancy is not disqualifying in general aviation, the aircrew must be made aware of the impact flying has on the third trimester such as cockpit ergonomics and placental reserve. Placental maturation continues throughout pregnancy. Maturation beyond 34 to 36 weeks is affiliated with several processes including microcalcification deposition that affect oxygen delivery to the fetus and ultimately lower fetal respiratory reserve. This lowered reserve may not pose a problem in the uncomplicated pregnancy in an oxygen tension encountered at 8,000 ft (the commercial cabin), but may become problematic for the nonacclimated fetus in an oxygen tension encountered at 14,000 ft (general aviation, nonpressurized cabin).

Women who fly high-performance military aircraft or are engaged in aerial aerobatics will experience high levels of accelerative force (G force). Egress through an ejection seat will result in higher accelerative force. These forces can be sudden, unexpected, and violent and may pose an unacceptable maternal or fetal risk in the gravid aviator. Resultant outcomes would be dependent on gestational age. Significant first trimester insults are likely limited to a fetal loss with no immediate bleeding and would not result in any additional maternal morbidity beyond the nongravid female. Therefore, the gravid female aviator would be just as successful piloting the aircraft or surviving the egress. Significant second or third trimester exposure poses the additional risk of uterine rupture. Twenty percent of cardiac output flows to the uterus by 30 weeks. Therefore, rupture of the uterus or placental abruption would likely result in both fetal loss and profound maternal morbidity or mortality. In this scenario, it is unlikely that she would be able to pilot the aircraft (aircraft loss) or survive the ejection. There are no available studies that address these issues, and pregnant aviators should seek counsel from both their obstetrician and their flight surgeon to determine the point in the pregnancy where temporary grounding would be appropriate. Informed consent must be universally applied to performance aircraft or platforms with ejection seats.

Physiology Impacts in Flight

The unique physiology of pregnancy is impacted by the flight environment (Table 22-1). In general, these considerations apply to the gravid aircrew/frequent flyer or the infrequent traveler. Aeromedical providers must have familiarity with system-specific maternal physiologic changes of pregnancy as well as fetal physiology in order to perform appropriate consultation and policy promulgation for the gravid female or provide aeromedical evacuation (AE) *en route* care for the pregnant (or newly postpartum) patient. As an example, an asymptomatic 31-year-old passenger at 30 weeks gestation with focal findings of a systolic ejection murmur with an S_3 gallop and lower dependent edema is likely normal and cleared to schedule her commuter flight as opposed to same findings and suspicion of heart failure in a nongravid female of the same age.

Fetal

Monitoring of maternal and fetal physiologic reactions during commercial flights demonstrate moderate, but significant maternal cardiopulmonary changes, including a transcutaneous P_{O_2} drop of 25% at maximum cabin altitude (7,855 ft), but no concomitant fetal tachycardia, bradycardia, or loss of variability (9). Therefore, this cabin altitude, corresponding to a maternal Pa_{O_2} of 64 mm Hg and an oxygen saturation of 90%, introduces a maternal hypoxia that does not appear to acutely affect the normal fetus. For periods up to 30 minutes, animal models have demonstrated that during a sudden decompression at 15,000 ft, maternal arterial P_{O_2} drops to 46 mm Hg (O_2 saturation 82%) without any suspected fetal hypoxic degeneration of the brain or heart. This relative fetal tolerance to hypoxia exists because the fetal oxygen supply to critical organs is maintained through a combination of physiologic advantages of the fetal circulation and fetal compensatory mechanisms such as redistribution of blood flow to vital organs (shunting) and decreased oxygen consumption (10).

There are three physiologic advantages of the fetal circulation in matters of oxygen-carrying capacity and dissociation. First, the fetal circulation carries more hemoglobin (gm/dL) than the adult. Second, the fetal hemoglobin (HbF) oxygen dissociation curve is shifted to the left of adult hemoglobin (HbA), and thereby allows 20% to 30% increased oxygen-carrying capacity in the fetus. Lastly, the Bohr effect has a positive influence on gaseous oxygen transfer on the hemochorial circulation. Fetal blood, derived from the umbilical blood flow, enters the fetal placenta carrying large amounts of carbon dioxide that rapidly diffuses into the intervillous spaces of the maternal placenta. Local loss of carbon dioxide makes the fetal blood more alkaline and shifts the oxygen dissociation curve left and upward. The opposite occurs with maternal carbon dioxide gain. As a result, the oxygen-binding capacity of fetal blood is raised while maternal blood is lowered, thereby allowing for enhanced oxygen transfer. The Bohr effect operates in one direction for maternal blood and in the other for fetal blood (11).

Maternal

The air travel impacts on the gastrointestinal physiologic changes of pregnancy are occasionally manifested by abdominal pain and nausea/vomiting. Intestinal gas expansion, occurring at altitude, can cause bloating and

TABLE 22-1

[a]The Potential Maternal Aeromedical Impacts of the Flight Environment on the Gravid Female

Organ System	*Physiologic Change of Pregnancy*	*Flight Environmental Threat*	*Potential Maternal Aeromedical Impact (s)*
Cardiovascular	Decreased systemic vascular resistance and increased venous capacitance	Prolonged immobility	Vasovagal response, syncope
Respiratory	Increased tidal volume, decreased total lung capacity, and decreased residual volume yielding physiologic dyspnea of pregnancy	Decreased cabin P_{AO_2}	Worsening dyspnea
Hematologic	Increased plasma volume yielding nasopharyngeal edema (compounded by nasopharyngeal hyperplasia)	Ambient pressure changes	Barosinusitis, baro-otitis, syncope
	Increased clotting factors and fibrinogen, uterine compression of the vena cava (venous stasis)	Prolonged immobility	Thromboembolic phenomenon
Gastrointestinal	Delayed gastric emptying, nausea vomiting of pregnancy	Motion (air sickness)	Nausea/vomiting
	Slowed GI motility, mild distension	Ambient pressure changes	Abdominal distension, colic
Musculoskeletal	Altered lumbar curvature, gravid uterine impingement, joint laxity	Prolonged immobility, aircraft vibration, poor cockpit ergonomics	Low back pain, pelvic pain
	Changing center of gravity	Turbulence	Altered balance and increasing risk of traumatic fall

[a]See also Chapter 8.

colicky abdominal discomfort or pain that is compounded by abdominal crowding from the pregnancy. Therefore, gas-producing foods should be avoided a few days before the flight. Nausea of early pregnancy may be compounded by air travel. Therefore, physicians should consider prescribing antiemetics for these women (8).

The enlarging, gravid uterus alters the center of gravity and lends to a more unsteady gait. Loss of balance and lack of coordination increases the risk of falls. Ligamentous laxity and vascular engorgement increase the risk of injury. Third-trimester abdominal trauma may cause a placental abruption. Because air turbulence cannot always be predicted, the seat belt should be worn at all times when seated. The belt should be fastened low near the pubic symphysis or on the upper thighs in order to reduce the potential injury to abdominal contents. Cabin ambulation in the third trimester should be done with caution (8).

Most data confer a weak association between air travel and venous thromboembolic phenomenon (12). Pregnancy-altered clotting factors, thrombophlebitis, and dependent venous stasis, attributed to volume expansion and obstruction of the vena cava from uterine compression, increase the risk of thromboembolic phenomenon in flight. These pregnancy-related changes begin late first trimester and persist to 6 weeks postpartum. This risk may be potentiated by being immobile in cramped seats for long periods of time. Loose-fitting clothing should accompany periodic leg stretching and hourly ambulation (when possible) in flight. Gravid women with a prior thromboembolic event or additional factors that predispose them to venous thrombosis should consult their physician regarding anticoagulation with low molecular weight heparin. The efficacy of acetylsalicylic acid in preventing deep vein thrombosis (DVT) is conflicting (5). Support stockings, frequent movement, loose clothing, and adequate hydration may diminish DVT risk (6).

Aeromedical Evacuation of the Obstetric Patient

Perinatal regionalization, emphasized strongly beginning in the 1990s, has been associated with improved outcome for very low birth weight infants and for women with complications requiring intensive services. This phenomenon involves stabilization of the mother, intrauterine transfer, and the optimum delivery at a medical center that has the volume to sustain costly technology and specialized personnel (13). Generally, the best and most efficient fetal transport mechanism, delivering oxygen and nutrition to the fetus, remains the gravid mother. Clinical circumstances may dictate it is safer to transport medical personnel to the patient than transport an unstable patient in an unstable environment. General contraindications to maternal air transport include maternal instability, a rapidly deteriorating fetus, imminent delivery, lack of experienced (*en route*) medical attendants, and hazardous flight conditions (meteorologic). This assessment of transport versus local care is best left to the accepting or aeromedically validating perinatal team. As with all medical evacuation, arrangements for transfer should be made before the transport. Standing agreements with referral hospitals should be established to provide sufficient guidance for transport and provide communication consistency (14).

The transport team should be familiar with the aviation environment and skilled in perinatal care that includes the ability to perform a vaginal delivery. When possible, the evacuating platform should be suited to support equipment that may be needed during transport. Standard equipment includes a delivery kit, uterotonics, oxygen, intravenous fluids, an infant warmer, and maternal and fetal stabilization equipment. Pharmacologic agents such as tocolytics, oxytocin, calcium gluconate (magnesium toxicity), antihypertensives, and antiemetics are useful while handling the more common complications during transport (Table 22-2). Preflight assessment and preparation typically include a cervical check [except in suspected placenta previa or preterm premature rupture of membranes (PPROM) without labor] and intravenous access and adequate airway, if indicated. Transport in a left lateral recumbent position displaces the gravid uterus off the vena cava and thereby increases maternal venous return and subsequent cardiac output and uterine perfusion. Advanced cardiac life support considerations are the same as for the nongravid female. The fetal heart rate can be assessed with a handheld Doppler with digital display (14). Oxygen supplementation should be used liberally as it improves fetal cerebral cortical oxygen tension (15). Planning the AE, including the decision to use fixed wing or rotary aircraft, depends on a myriad of factors including available assets, meteorologic conditions, geography/terrain, airfield support, landing areas, and the distance to the nearest appropriate medical facility (14).

TABLE 22-2

Diagnosis and In-flight Complications of Aeromedevac Transport of Obstetric Patients

Diagnosis (in %)		*Complications (in %)*	
Preterm labor (PTL)	33.0	Nausea/vomiting	15.0
Preterm premature rupture of membranes (PPROM)	21.3	Increased contractions	7.0
Pregnancy-induced hypertension	21.3	Other[a]	3.0
PTL and PPROM	7.5		
Other	8.8		

[a]Other included hypertension, hypotension, and decreased maternal respiratory drive. (From O'Brien DJ, Hooker EA, Hignite J, et al. Long-distance fixed wing transport of obstetrical patients. *South Med J* 2004;9:816–818.)

Most AE transports will occur for fetal purposes and fall in three categories or a combination of PTL, PPROM, and pregnancy-induced hypertension(PIH)/preeclampsia (Table 22-2).

In patients who present with PTL or PPROM, tocolytic therapy is frequently employed before or during air transport. The goal of this therapy is to prevent in-flight delivery and allow time for administration of corticosteroids (promote fetal lung maturity) and group B streptococcus prophylaxis (prevent meningitis and other potential infections). These three measures have been shown to reduce perinatal morbidity and mortality attributed to prematurity (4).

Severe maternal hypertension or PIH can be complicated by pulmonary edema, eclampsia, and fetal compromise. *En route* care for eclampsia includes blood pressure control, maternal seizure control and suppression, injury prevention, oxygenation, and minimizing the risk of aspiration. Use of magnesium for seizure control must be closely monitored because it can diminish the maternal respiratory drive in high doses and cause apnea (14).

Outcomes

The preponderance of existing evidence, albeit limited, indicates that the commercial aircraft is not deleterious to pregnancy. This sentiment is shared by 93% of obstetricians in the United Kingdom (16). As discussed, the oxygen levels at normal operating altitudes in pressurized aircraft are adequate for the normal fetus in flight. Pregnancy outcomes for chronic exposure to altitude by way of the aircraft do not significantly deviate from the norm (17,18). Similarly, data examining spontaneous pregnancy loss in flight attendants indicates that there is no difference in miscarriage rate from the general population (19,20).

COSMIC RADIATION AND IMPACT ON PREGNANCY AND FEMALE HEALTH

Except for the occasional solar particle event, cosmic radiation exposures for the infrequent traveler are minimal and are unlikely to influence pregnancy outcomes such as spontaneous abortion, growth restriction, congenital malformations, mental retardation, and childhood malignancy induction (21). However, exposure for the frequent gravid traveler or aircrew must be weighed, and in certain cases, controlled. Cumulative fetal exposure less than 20 mSv should not result in harm (22). It is prudent to apply a buffer to this value. Therefore, organizations and/or medical providers should communicate risk and implement administrative controls such as modifying work schedules or choosing alternative means of transportation in order to ensure that the cumulative conceptus dose does not exceed 1 mSv (International Commission on Radiological Protection) (23). Depending on the controlling regulatory body, risk communication and control implementation may be either advisable or regulatory in nature (21) (see also Chapter 8).

Several studies have looked for an excess of radiation-induced cancer, specifically melanoma and breast, in female aircrew. A recent meta-analysis has indicated a slight, significant excess of breast cancer incidence reflected in the cumulative relative risk (RRc) of 1.41 (1.22–1.62) ($p < 0.0001$) and of malignant melanoma RRc 2.13 (1.58–2.88) ($p < 0.0001$) in female flight attendants, but no significant excess of cancer incidence when considering all types (24). However, attributing causation to the effects of ionizing radiation is difficult because a myriad of other exposures such as second-hand smoke, reproductive factors, organic pesticides applied in aircraft, delayed childbearing, differential breast feeding rates, and lifestyle may act as confounders or covariates (see also Chapter 8).

GYNECOLOGIC ISSUES AND FLIGHT IMPACT

Gynecologic disorders rarely cause sudden incapacitation in flight. Treatment efficacy should index onset and duration of pain relief pertinent symptoms, and functionality outcomes including qualitative work performance and absenteeism. Medications with significant side effects (especially central nervous system) should not be used during performance of aviation duties. A period of temporary grounding may be appropriate when new medications are initiated.

Dysmenorrhea

Dysmenorrhea is pain with menstruation and can be separated into primary and secondary forms. Primary dysmenorrhea, prevalent in 40% to 50% of young women and accounting for 15% of missed workdays in this cohort, is affiliated with the ovulatory cycle and generally occurs in the absence of other gynecologic pathology; whereas, secondary dysmenorrhea often occurs in the presence of gynecologic conditions such as endometriosis, adenomyosis, uterine leiomyomata, pelvic inflammatory disease, and cervical stenosis. Dysmenorrhea is characterized as spasmodic pelvic cramps beginning shortly before menses and lasting 2 to 3 days. It is usually a time-predictable and time-limited condition that can be factored in flight planning. It may be accompanied by lower back pain, vomiting, headache, dizziness, and diarrhea that can be distracting in flight.

Management of dysmenorrhea is supportive, pharmacologic, and/or surgical. Empiric medicines will satisfactorily relieve pain in 80% to 90% of women (25). Nonmedical responders, deemed after 3 to 6 months of treatment failure, will generally undergo imaging and/or laparoscopy for evaluation of secondary etiologies.

Premenstrual Syndrome

Premenstrual symptoms affect 85% of menstruating women. Severe symptoms occur in 5% to 10% of women and can cause impairment. Although serotonergic dysregulation is currently the most plausible etiology, the exact etiology of premenstrual syndrome (PMS) is not completely understood (26). Recent, stricter criteria for the diagnosis of PMS have been established by the American Psychiatric Association (APA) and comprise the following essential elements (27):

1. Affective and somatic symptoms of PMS
2. Symptoms relegated to the luteal phase
3. Impairment of daily functioning
4. Absence of other maladies that could account for the symptoms

Affective symptoms such as depression, irritability, anxiety, confusion, and somatic symptoms such as headache, bloating, and breast tenderness can decrease concentration and cause inattention, indecisiveness, and fatigue, all of which are incompatible with aviation duties. The diagnosis should be established by a prospective diary of symptoms correlated with the menstrual cycle and fulfilling the APA elements. A symptom-free interval must exist. Long-standing therapies including oral contraceptive pills (OCPs), aerobic exercise, supportive counseling, and dietary modification have demonstrated varying success and should be tailored to the individual patient's symptoms. Recently, selective serotonin reuptake inhibitors have been shown to be effective (26).

Abnormal Gynecologic Bleeding

Abnormal gynecologic bleeding (nonpregnant) may be anovulatory or ovulatory in women of the reproductive years. Should anemia occur, it may cause fatigue manifested by decreased performance, compromise adaptation at lower oxygen tensions, and reduce G tolerance. Abnormal uterine bleeding in the menopausal woman that occurs in the absence of hormone replacement therapy is clinically concerning and warrants a thorough evaluation for malignancy.

Anovulatory bleeding is common at the extremes of reproductive age and results from a lack of consistent ovulation and progesterone production that cause maturation of the endometrium. Conception failure results in progesterone withdrawal and a time predictable menses. Other causes of anovulatory bleeding include thyroid disease, obesity, stress, exercise, polycystic ovarian syndrome, and weight loss. Anovulatory bleeding generally responds to contraceptive (OCP) suppression, cyclic progestin treatment, or clinical improvement of identified medical conditions.

Ovulatory bleeding is usually caused by structural abnormalities including leiomyomata, adenomyosis, endometrial/cervical polyps, and malignancy or medical conditions such as gynecologic infection or blood dyscrasia. Infections are diagnosed by physical examination or endometrial aspirate and treated with antimicrobials. Typically, structural lesions are identified by a combination of imaging and surgical diagnostics, including ultrasonography, saline infusion sonography, and hysteroscopy. As with anovulatory bleeding, most structural lesions, except malignancy, polyps, and submucous fibroids, may be given a trial of 3 to 6 months of medical therapy. Medical nonresponders are generally treated surgically (28).

Endometriosis

Endometriosis is a pervasive, symptomatically complex disease of reproductive ages that may be defined as the presence of endometrial gland-like tissue and stroma at an extrauterine site and can range from subclinical foci (found on incidental laparoscopy) to severe infiltrating diseases involving the bowel, bladder, and ureters. A rare association with spontaneous pneumothorax exists (29). Endometriosis occurs in 15% of asymptomatic women presenting for laparoscopic surgery for tubal ligation, 40% of women with chronic pelvic pain, and 60% of women with dysmenorrhea, 5% to 50% of women with infertility problems, and 20% of women hospitalized for pelvic pain (30). The definitive pathophysiology of the disease process remains uncertain; however, the direct surgical visualization confirmed by histologic examination remains the gold standard for diagnosis. Symptom presentation varies and can include dysmenorrhea, pelvic pain, and low back pain that can be distracting in flight.

Diverse opinions exist regarding the optimal therapy for endometriosis. Most strategies involve an initial trial of ovarian suppression and symptom amelioration with OCP followed by gonadotropin-releasing hormone (GnRH) agonists for OCP failures. GnRH agonists can lead to menopausal symptoms including hot flashes and mood alterations and may affect flight certification. Low-dose estrogen add-back can be used, if needed. If no clinical improvement ensues, then surgical treatment is generally performed or the diagnosis reconsidered (31).

IMPACT OF ANTHROPOMETRICS ACCOMMODATION AND BIOMECHANICS FOR WOMEN IN AIRCRAFT

In general, the key to aircraft operation is strength measure rather than cockpit fit. Lower body strength between men and women is comparable, but experimentally differences exist in upper body strength. This distinction may blur in the current modern fixed and rotary wing aircraft where stick and rudder control are of lesser importance for piloting. Most studies looking at these differences focused on these stick and rudder skills in older airframes. A critical element of these studies was handling hydraulic failure that arguably in the present day aircraft is no longer a factor in control. From a size perspective, the 50th percentile female correlates to the 5th percentile male. Challenges in cockpit fit and access to controls as well as suitable fit of personal protective equipment exist. Women on average are shorter and weigh less than men. The average female height in America is 64 inches. In addition, women have a shorter arm length compared to men of the same height. All of these parameters can affect cockpit fit and potentially aircrew performance.

Schender et al. conducted a series of small subject number studies looking at the small stature female, defined as a female at the 5th U.S. percentile weighing 120 lb or less (32). They assessed dynamic strength capabilities of these subjects in the performance of flight profile tasks, the ability to successfully eject, and the capability to support helmets with added devices under acceleration stresses (32,33). Operational flight simulations for aerial combat maneuvers, emergency procedures, and standard fighter flight were used to evaluate upper body muscle endurance. Although with only a small number of subjects, the authors concluded that women of small stature had strength comparable to men in dynamic activities such as lifting, pulling, or pushing and no decline in ability throughout the exercises. However due to the smaller moment created by the arm about the shoulder, a disadvantage could occur in flexion, abduction, or rotation tasks. A 1981 study assessing strength of men versus women for aircraft control operations concluded that men and women had similar leg strength but women demonstrated lesser arm strength (34). Both this study and a 1973 FAA Civil Aeromedical Institute report on control force limits for aircraft of that time demonstrated that these limits defined as the required temporary and prolonged application of force to the controls for aileron, elevator, and rudder control were set too high for many female and for some male aviators (34,35). Physical training programs do demonstrate increases in female capabilities to handle these flight tasks.

A critical strength measure in the aerospace environment is the ability to exhibit sustained muscle endurance especially in high-G maneuvers. Women are capable of pull force requirements for static and dynamic ejection sequences and can safely initiate these sequences (33). The cervical stresses of added head weight particularly in the high-G environment were limiting for the women tested with regard to mask/mask-hose placement, and the ability to read lower cockpit displays and locate targets. In +4 to −4 G_z, all of the subjects experienced an impaired ability to move their heads and limitations in visual range due to the mechanics of the helmet assembly and not due to visual compromise (33). The sex differences in strength are due to differences between men and women in muscle size as estimated by lean body weight or limb cross-sectional dimensions. Women, just as men, possess a wide variety of strength characteristics.

MIXED GENDER CREW DYNAMICS

This section addresses mixed gender crew dynamics. Societal acceptance of women in all aviation roles has evolved and on occasion been aided by governmental mandates. The timeline at the start of this chapter lists some of the milestones for women in aviation. WASPs performed significant support aviation services during World War II such as towing targets, ferrying aircraft, and serving as instructor pilots among other duties. Their integration into true military aviation service to the nation took some time longer. In 1979, a legislative act gave the WASPs, well-deserved, veteran status. In the 1970s, the Navy and then Army (1973), followed by the Air Force (1976) began training women for military aviation operations. A survey study conducted by the Naval Aeromedical Research Institute in 1977 focused on the attitudes of male aviation trainees toward women in naval aviation training (36). In this study, a modified Attitude toward Women Scale (AWS) developed by Spence and Helmreich was used to determine male attitudes in naval aviation trainees versus a "control" of male college students at a Texas University (36). The instrument included 55 statements with an additional 20 questions added by naval psychologists to address specific military situations (36). The naval aviation trainees were willing to accept women as their peers and this was felt to be critical with the initiation of an all-volunteer military force. Interestingly, the authors postulated that the senior leadership who command units and formulate aeromedical and training policy should also be polled, but no report of this survey is available. The college students were less accepting of women as peers as per the AWS. In 1993, then Defense Secretary Les Aspin signed the authorization for women to enter the fields of combat aviation. In 1997, the USAF researchers conducted a semistructured clinical interview to assess female USAF pilots and their personal health, families, squadron relationships, and career stressors. Of the 114 pilots interviewed, 64 men and 50 women, an analysis of the data provided showed considerable progress in acceptance of women and their integration into military units (37). Working relationships among men and women were not characterized by gender distinctions but rather by commonality of experience, shared risks, and exposures. A key factor that is still true now is the need for adequate clinical resources to address women's health needs in order to maintain the aeromedical readiness of units. This includes having the appropriate equipment, training, and laboratory support to conduct gynecologic examinations in a discrete and comfortable manner. The overwhelming majority of men and women desired to fly in combat mainly to meet their responsibilities and training as a pilot, and even more overwhelmingly at 97% and 98%, respectively, men and women felt comfortable flying with both genders (37). Women still listed sexual discrimination as the number one stressor, but men listed greater family stress than women. With several current combat arenas now, it would be interesting to repeat this study among the services to assess the impact of extended, multiple deployments and significant combat missions with regard to crew dynamics and gender relations. In addition, the prospect of mixed gender crews in a return to the moon or extended duration Mars mission should prompt further study in this area.

OTHER GENDER-RELATED ISSUES

G Tolerance

Factors other than strength are more important for operations in present day high-performance aircraft. Endurance is more important in sustaining G_z tolerance in high-performance tasks, and Gillingham conducted the classic work on gender and G_z tolerance effects (38). In standard G_z profiles with both gradual and rapid onset, there was no difference between the sexes in relaxed or straining G tolerance. In addition, no significant difference was detected in G_z tolerance with regard to menstruation. Women had no breast-related symptoms but two episodes of urinary incontinence were reported. This finding of "G parity" has been borne out in multiple studies. In F-16 flight simulation studies using more than 30 performance measures, women were able to execute on par with men (39). However, physiologic differences with regard to adaptation to G_z stress among women and men exist. Women tend to lack adaptation with no increases in cardiac contractility or baroreceptor sensitivity resulting in greater effort with more strain versus men to sustain G_z loads (39). Further studies with similar results demonstrating a lack of difference in acceleration tolerance among genders suggest that for cockpit and aircraft design and development, requirements need not be modified for women (40). G_z tolerance decreases in the microgravity environment among both men and women. Both require countermeasures to mitigate the decrement caused by long exposures to the microgravity environment. Waters et al. has demonstrated that women have increased post–spaceflight orthostatic hypotension. This is predicted by low vascular resistance (41). Women need to employ these techniques and can satisfactorily participate in long-term space missions (42).

Urinary incontinence in the face of acceleration became an issue with Gillingham's report of two cases in his study (38). Anonymous surveys of women in regular military flying duties revealed a reported rate of incontinence similar to the general population and no effect on execution of duties in flying high-performance aircraft (43). Testing with a brief centrifuge exposure shows no significant predisposition to urine leakage and no negative effects of pelvic surgery or parity. These studies have shown that urinary incontinence is not limiting in aviation training or mission execution.

Hypoxia and Thermoregulation

In these areas, exhaustive studies featuring large and significant numbers of female subjects are lacking. Assessing the response to acute hypoxia of trained and sedentary women at varying altitudes using bicycle ergometer testing revealed that, similar to men, trained women experience a larger performance drop in maximal oxygen consumption, V_{O_2}, at altitudes of 1,000, 2,500 and 4,500 m (44). V_{O_2} is the maximal oxygen consumption generally expressed as an absolute rate of liters of oxygen per minute and reflecting an individual's aerobic capacity. Woman mountaineers tested at varying altitudes versus sea level both acutely and after longer-term exposure have similar responses to men. These include similar increases in heart rate and decreases in aerobic power ($V_{O_{2max}}$) (45,46).

Use of oral contraceptives for more than a month does affect peak exercise capacity with time to peak exercise, peak power, and V_{O_2} all moderately decreased (47). The phases of the menstrual cycle in and of itself did not have any effect on peak exercise effort among those studied.

Although differences in body mass, size, and composition exist between men and women, women have a greater density of heat-activated sweat glands. Men and women experience quantitative differences in sweating with women experiencing delayed and less-intense sweating as a means of thermoregulation. A baseline increase in body core temperature during the luteal phase of the menstrual cycle is attributed to the effects of progesterone. Female response to cold is impacted by smaller lean body mass and greater body fat content. However, no true differences in thermoregulation between men and women exist except for those associated with actual physical capacity and that of body size and composition (48).

Motion Sickness

Several studies, using both retrospective questionnaires as well as questionnaires combined with dynamic testing, report that women report both more symptoms and more intense motion sickness symptoms than men. Provocation studies have utilized tools such as optokinetic rotating drums, pseudo-Coriolis stimulation, and body rotation in a rotating chair about the yaw axis (49,50). Provocation studies provide data showing no significant difference between men and women in severity of symptoms and no physiologically measurable differences. In general questionnaires before provocation testing, women report more episodes of motion sickness (49). On the basis of societal norms, the thought is that it is more acceptable for women to report their symptoms and similarly that men underreport due to nonacceptance. The pseudo-Coriolis effects using a rotating drum with and without head motion revealed no changes in vection between men and women, but women did report more symptoms (50). Assessing both gender and ethnicity revealed comparisons to only one ethnic group making results difficult to generalize, but noting with the use of body rotation women reported more symptoms than men (51). Testing with a motion sickness questionnaire and static spatial ability tasks demonstrated that women reported higher scores on a motion sickness questionnaire and were less accurate on the tasks (52). Women may tend to report more symptoms or episodes of motion sickness, but in provocation testing there is no significant difference between men and women.

Motion sickness may vary with the hormonal and physiologic changes associated with the menstrual cycle. One small series indicated, after dynamic testing in a rotating chair and cabin assembly, that day 5 of the menstrual cycle is the point for maximal motion sickness susceptibility with a decrease in days 12 to 19, to a minimum at day 26 (53). Day 1 is defined as the first day of menstruation. With Coriolis-induced motion sickness and Doppler calf and forearm blood flow measurements, along with a subjective symptom scale, the physiologic and psychophysical measures showed no difference across the phases of the menstrual cycle (54). What are the implications of these findings? First, that motion sickness susceptibility is individualized, and although symptoms may occur, an individual's capacity to continue to function is variable—whether male or female. Second, with regard to motion sickness, there are no limitations in female activity and capability due to menstrual phases.

Decompression Sickness

Currently, rigorous study indicates that both men and women are equally susceptible to decompression sickness (DCS). While DCS could be affected by hormonal changes associated with the menstrual cycle, menopause, or use of OCPs, the literature lacks studies to support these prior claims. A study by Webb et al. studied 961 decompression exposures among 291 subjects (55). The length of profiles used ranged from 1.5 to 8 hours of exposure in 25 separate profiles of varying altitudes, duration, and activity in order to bring about symptoms. Among the 197 men and 94 women, there was no significant difference in altitude DCS risk.

Voice Communication

Female speech with its different acoustic features from males may be compromised by voice communication systems designed for male voice patterns. A study testing military aircraft cockpits in the 95 to 115 dB range demonstrated that the interpretation of female speech was lower than that for males for all experimental conditions (56). Further analysis indicated that although differences existed, these were only significant at the highest levels of cockpit noise. The difference detected at the highest levels was also impacted by the design of the communication system based on male speech spectrum, and the spectra of the cockpit noise. Use of active noise reduction technology would overcome these differences and perhaps help both genders in clear voice communication. The limited research to date indicates that there is acceptable voice communication and understanding for both genders during normal cruise operations (56).

CONCLUSION

This chapter gives the current state of literature on women's health issues and women functioning in the aviation environment. Women have and continue to contribute in all aspects of aviation. Their specific health care needs that differ from men in no way limit their ability to be continued participants and contributors.

In regard to pregnancy, the airline passenger must be assessed and assisted with planning for all aspects of travel, which include transport, food, lodging, activities, and medical support throughout an entire trip. Analysis of each phase and risk mitigation combined with appropriate prenatal care will go far in eliminating in-flight complications. Aircrew have different demands from passengers and must be more restricted in terms of duty performance during some phases of pregnancy due to environmental hazards such as G_z forces, rapid egress, altitude, among others. Policies regarding pregnancy in military aviation may benefit from standardization. Commercial space flight operators must consider the impact of pregnancy and potential hazards during training and space flight.

Gynecologic disorders such as dysmenorrhea, PMS, abnormal gynecologic bleeding, and endometriosis rarely cause sudden in-flight incapacitation and can initially be addressed by the flight surgeon. In most cases, only temporary periods of grounding will be required for treatment and flight safety.

Women, not surprisingly, vary in body size, strength, composition, and capability just as men do. In general, women have the muscular endurance and strength to accomplish required flight tasks, and targeted physical training increases these capabilities. Studies of G tolerance, hypoxia, thermoregulation, motion sickness, and DCS imply no significant difference between genders, and thereby similar susceptibility and impact of these on both men and women in flight. New and modern airframes include design features that require less input force from operators. Anthropometric issues will remain and continued research and measurements will continue to be valuable for proper design accommodations.

Social acceptance of women across the aviation spectrum increased over the last century and continues to do so. The extended space flight missions and current combat exposures offer new opportunities to study and optimize the work of mixed gender crews.

Although some research has been devoted to this area to quantitatively and empirically address the particular physiologic differences between men and women that have aerospace impact, much more must be done especially as the prospect of a return to the moon, Mars exploration, and commercial space flight loom on the horizon. Women have much more to contribute in the aerospace realm.

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