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Non-coronary cardiac surgery and percutaneous cardiology procedures in aircrew

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ABSTRACT

This manuscript focuses on the broad aviation medicine considerations that are required to optimally manage aircrew following non-coronary surgery or percutaneous cardiology interventions (both pilots and non-pilot aviation professionals). Aircrew may have pathology identified earlier than non-aircrew due to occupational cardiovascular screening and while aircrew should be treated using international guidelines, if several interventional approaches exist, surgeons/interventional cardiologists should consider which alternative is most appropriate for the aircrew role being undertaken; liaison with the aircrew medical examiner is strongly recommended prior to intervention to fully understand this. This is especially important in aircrew of high-performance aircraft or in aircrew who undertake aerobatics. Many postoperative aircrew can return to restricted flying duties, although aircrew should normally not return to flying for a minimum period of 6 months to allow for appropriate postoperative recuperation and assessment of cardiac function and electrophysiology.

INTRODUCTION

Aircrew work in a demanding environment that requires individuals to tolerate high cognitive demand and potential physiological stress factors including noise, vibration, hypoxia, hypobaria and potentially sustained ($+G_z$) acceleration.[1] The latter is especially true for recreational aerobatic pilots and military aircrew. It has been known for decades that this environment represents a unique challenge to the cardiovascular system[2] and impairment from cardiovascular symptoms may cause distraction or sudden incapacitation that may jeopardise flight and mission safety.[3] Of particular concern are thromboembolic events and rhythm disturbances due to their potential for sudden incapacitation.[i ii]

Cardiovascular disease accounts for almost 50% of all pilot licenses declined or withdrawn for medical reasons. As retirement age for commercial pilots has increased (up to the age of 65 years) in many airlines, cardiovascular disease has gained increasing importance, with increasing numbers of aircrew having undergone cardiovascular intervention or surgery. Risk assessment in aviation cardiology is a challenging but evolving field,[4] however currently most licensing authorities have an accepted risk threshold of a 1% annual risk of sudden incapacitation for dual pilot commercial operations. This is known as the '1% safety rule'.[5]

This manuscript focuses on the general principles for aircrew treated with intervention or surgery for valvular heart disease, diseases involving the aorta and congenital heart disease. Specific details with regards to cardiac surgical interventions (including coronary revascularisation) for pilots have recently been published and offer more technical detail for the cardiovascular surgeon.[6]

SPECIAL CONSIDERATIONS FOR CARDIOTHORACIC SURGICAL AND CARDIOLOGICAL INTERVENTIONS IN AIRCREW

Aircrew are often asymptomatic when pathology is detected (as disease may be picked up as part of routine periodic medical examinations (PME), the frequency of which is determined by the licensing agency, and is often dependent on age and aircrew role) and they may be referred for consideration of surgery earlier than usual civilian referrals. This is often a proactive decision to ensure that the risk of cardiac chamber dilation or dysfunction, and associated arrhythmia is minimised. Special considerations are required, particularly in pilot aircrew, or those operating in high-performance aircraft, with regards to the choice of procedure and prosthetic materials to optimise coronary and valvular flow profiles. As a general principle, as with non-aircrew, the most appropriate, evidence-based clinical intervention or

[i]Evidence-based cardiovascular risk assessment in aircrew poses significant challenges in the aviation environment as data to support decision-making at the low level of tolerable risk in aviation are rarely available from the published literature. As a result, there are discrepancies between aviation authority's recommendations in different countries and even between licensing organisations within single countries. The NATO HFM-251 Occupational Cardiology in Military Aircrew working group is constituted of full-time aviation medicine and aviation cardiology experts who advise both their military and civil aviation organisations including, but not limited to, the Federal Aviation Administration (FAA), Civil Aviation Authority (CAA), European Aviation Safety Agency (EASA) and NASA. The recommendations of this group are as a result of a 3-year working group that considered best clinical cardiovascular practice guidelines within the context of aviation medicine and risk principles. This work was conducted independently of existing national and transnational regulators, both military and civilian, but considered all available policies, in an attempt to determine best evidence-based practice in this field. The recommendations presented in this document, and associated manuscripts, are based on expert consensus opinion of the NATO group. This body of work has been produced to develop the evidence base for military aviation cardiology and to continue to update the relevant civilian aviation cardiology advice following the 1998 European Cardiology Society aviation cardiology meeting.

surgery should be the prime consideration. However, if a course of action is likely to compromise an individual's return to aircrew duties, the surgeon or cardiologist should be willing to offer alternative options, which may differ from usual practice, but must still be clinically appropriate.(see table 1) Aircrew should be actively involved in such considerations and made aware of the additional risks that might be associated with these alternative courses of action. However, so long as an informed decision is agreed between the surgeon and the individual, informed consent is maintained.

It is essential that the cardiovascular surgeon and/or cardiologist liaise with the pilot's aeromedical examiner (AME), and/or licensing authority, early to ensure a complete understanding of the implications of different surgical or interventional options, and the need for specific postprocedure investigations to assess their patient's return to flying.

Postsurgery, both clinical and occupationally oriented assessments are required to assess fitness for aircrew duties. There are usually several essential preconditions that must be met prior to consideration of returning aircrew to duties following a cardiovascular surgery or intervention. For pilot aircrew, and those operating in high-performance aircraft, these include a normal cardiac output (ejection fraction (EF) >50% on echocardiography), normal myocardial perfusion and acceptable transvalvular gradient profiles that allow maintenance of optimal cerebral and coronary perfusion, even under exceptional physiological strain. Depending on the aircraft platform flown and an individual's occupational role, it is often possible for these aircrew to return to flying after cardiovascular intervention or surgical procedures, however, often with occupational restrictions. For non-pilot aircrew and those flying, or controlling aircraft, in less physiologically demanding environments, near normal values may be allowable, as long as the risk of distraction and incapacitation is within acceptable limits to the employing/licensing authorities.

Table 1 Surgical considerations in aircrew

Special surgical considerations may be required for pilot aircrew or those operating in high-performance aircraft, with regards to the choice of procedure and prosthetic materials. Early liaison between the surgeon and AME/licensing authority is strongly recommended	Strongly recommended
Aircrew should be made aware of any additional risks that might be associated with occupationally nuanced decisions. As long as an informed decision is agreed between the surgeon and the individual, informed consent is maintained	Strongly recommended
Aircrew operating in high-performance aircraft require a normal cardiac output, normal myocardial perfusion and acceptable valvular gradients prior to consideration of return to flying duties	Strongly recommended
Aircrew in less physiologically demanding environments, near normal values may be allowable, as long as the risk of distraction and incapacitation is within acceptable limits to the employing/licensing authorities	Recommended
Pilots are likely to be unfit for single-seat high-performance flying. In exceptional cases with appropriate follow-up, return to restricted flight duties might be considered	Consider

AME, aeromedical examiner.

VALVE SURGERY

Good transvalvular flow and acceptable left ventricular ejection fraction (LVEF) are usually mandatory to operate effectively in the aviation environment. Aircrew flying high-performance aircraft must be able to maintain cardiac output even under high preload conditions (with sustained acceleration (+G_z)), and any chronotropic or inotropic deficit secondary to valvular disease is usually poorly tolerated.[7] In addition to the direct effect of valvular heart disease, additional factors affecting suitability for flying duties include the risk of LV impairment, increased arrhythmia risk and the potential need for anticoagulation. In military aviation, anticoagulation is often disqualifying, however, many civil regulations have become less strict in recent years, despite controversy regarding both bleeding and thrombosis risk.[6 8] Antiplatelet agents, such as aspirin and clopidogrel, are usually acceptable for flying duties.

AORTIC VALVE

As with coronary intervention, considerations regarding valve surgery may differ in aircrew compared with the non-flying population.[9 10] Aircrew may present earlier with mild-to-moderate disease, as this may be detected at routine PME, and the surgeon should strongly consider liaising with the appropriate aviation medicine specialist and/or licensing authority prior to the determination of the most appropriate procedure.

In the aircrew population, aortic valve surgery is usually secondary to bicuspid aortic valve degeneration, both for regurgitation and stenosis. In aortic disease, specific decisions may need to be taken with regards to the choice of prosthetic material to optimise transvalvular flow as well as coronary perfusion and to avoid the need for lifelong anticoagulation if possible. In contrast to usual practice, tissue valves may be preferred, even in young aircrew, because of their optimal transvalvular flow and because they appear to provide superior coronary perfusion.[11–15] However, to ensure appropriate informed consent, this decision must include a detailed discussion with regards to the potentially reduced longevity of tissue valves, compared with mechanical valves, and the increased risk of reoperation for redo valve surgery.

Aortic valvotomy is not compatible with aircrew duties as it is a palliative procedure with variable outcomes and mainly performed for symptomatic relief for those who are unfit for surgery.[8] Transcatheter aortic valve implantation (TAVI) is generally reserved for patients not suitable for surgical aortic valve replacement because of comorbidities and is therefore currently usually not compatible with a return to professional aircrew duties. As this field evolves, however, and potentially younger patients, including aircrew, are considered for TAVI procedures, this is likely to require further consideration with a review of the evidence to support occupational aviation recommendations.

Further detail on surgical considerations have recently been published[6] and requirements for follow-up after aortic valve surgery are listed in table 2.

[ii]Aircrew are defined somewhat differently in civil and military aviation. NATO and ICAO delegates the definition of aircrew to national authorities. In the civilian sector aircrew are often categorised as flight crew (pilots)/technical crew members and cabin crew, with separate regulation for air traffic controllers. The military define aircrew more broadly as 'persons having duties concerned with the flying or operation of the air system, or with passengers or cargo when in flight'. From a risk perspective, professional (commercial) pilots have a higher attributable risk than private pilots and non-pilot aircrew. Controllers are considered to have an attributable risk equivalent to professional pilots. From a cardiovascular perspective, aircrew whose flying role includes repetitive exposure to high-acceleration forces (G_z) comprise a subgroup who, due to the unique physiological stressors of this flight environment, often require specific aeromedical recommendations. A more detailed description of aircrew is available in table 1 of the accompanying introductory paper on aviation cardiology (Nicol ED, *et al*. *Heart* 2018;**105**:s3–s8. doi:10.1136/heartjnl-2018-313019).

Table 2 Follow-up requirements after aortic valve surgery.

Prosthetic valve function	ΔP_{mean} at rest <20 mm Hg
Transvalvular flow pattern and in LVOT	Laminar
Dimensions of sinus portion and aorta	<4.5 cm and <4.0 cm, respectively*
Other heart valves	No pathologies
Dimensions of the heart chambers	LVEDD <5.6 cm*
LV wall thickness, free wall and septum	<1.3 cm*
LV ejection fraction	≥50%†
No rhythm disturbances	48-hour Holter recording

Adapted from Syburra 2018.[6]
*Cardiac and aortic dimensions, and LV wall thickness may vary according to the body surface area and level of fitness, respectively.
†On echocardiography.
LV, left ventricular; LVEDD, left ventricular end-diastolic diameter.; LVOT, left ventricular outflow tract.

MITRAL VALVE

In aircrew, mitral valve repair is predominantly indicated for mitral valve regurgitation with associated left atrial enlargement. Mitral valve repair is often compatible with a return to flying duties, provided postoperative investigations reveal satisfactory LV function without systolic or diastolic dilation, and there is no more than minor mitral regurgitation postoperatively.[8] When undertaking mitral valve repair in aircrew, it is recommended that the surgeon should consider left atrial appendage (LAA) exclusion to minimise the likelihood of thromboembolic disease, particularly in those with associated atrial arrhythmia. Mitral valve replacement for any indication including mitral stenosis is usually a disqualifying procedure due to the enhanced risk of thromboembolic complications and arrhythmias.[16 17]

PULMONARY AND TRICUSPID VALVES

Pulmonary and tricuspid valve procedures are unusual in the aircrew population and usually linked to significant underlying pathologies that would preclude aircrew duties. A summary of recommendations for valve disease can be found in table 3.

Table 3 Valve disease

For pilot aircrew and those working in high-performance aircraft who require aortic valve replacement, specific decisions may need to be taken with regards to the choice of prosthetic material to optimise transvalvular flow as well as coronary perfusion and to avoid the need for lifelong anticoagulation if possible	Recommended
Mitral valve repair is often compatible with a return to flying duties, provided postoperative investigations reveal satisfactory LV function without systolic or diastolic dilation, and there is no more than minor mitral regurgitation postoperatively and no evidence of aeromedically significant arrhythmia	Recommended
LAA exclusion is recommended in aircrew undergoing mitral valve repair to minimise likelihood of thromboembolic disease, particularly in those with associated atrial arrhythmia	Recommended
Aortic valvotomy and TAVI are not recommended in aircrew	Not recommended
Mitral valve replacement is usually incompatible with a return to aircrew duties	Not recommended

LAA, left atrial appendage; LV, left ventricular; TAVI, transcatheter aortic valve implantation.

POSTOPERATIVE MANAGEMENT

After any valve surgery, aircrew usually must wait for at least 6 months until returning to flying to allow for complete surgical recovery and to minimise the risk of arrhythmia. For pilot aircrew, normal valvular and ventricular functions are usually mandatory, with a normal stress ECG and echocardiogram. For non-pilot aircrew, mild residual LV dysfunction may be acceptable if the risk of arrhythmia is acceptable and no additional consequences of the aviation environment are expected. Pilot aircrew may need to be restricted to multipilot and low-performance aircraft with $+G_z$ limitations. Non-pilot aircrew may be considered for unrestricted aircrew duties, dependent on role, and whether they are deemed flight or mission critical. After the first follow-up examination after 6 months, most licensing authorities require annual follow-up with echocardiography, with additional investigations such as Holter monitoring and stress ECG at periodic intervals table 4.

Table 4 Postoperative management

Aircrew should not return to flying duties for at least 6 months postvalve surgery	Strongly recommended
For pilot aircrew, normal valvular and ventricular function is usually mandatory, with a normal stress ECG and echocardiogram	Strongly recommended
For non-pilot aircrew mild residual LV dysfunction may be acceptable if the risk of arrhythmia is low	Strongly recommended
After the first follow-up examination at 6 months, annual follow-up with echocardiography, Holter monitoring and exercise ECG is recommended	Recommended

LV, left ventricular.

AORTIC SURGERY

Mild aortic dilatation is common in aircrew, and assessment of aortic dimensions must consider body surface area. Aircrew applicants with thoracic aortic dilatation each time may be accepted for aircrew duties, if mild and they undergo regular follow-up. In non-syndromic patients, indications for surgery include an ascending aorta diameter of >5.5 cm or an annual increase in dilatation at a rate >0.5 cm per year. If there is concomitant bicuspid aortic valve disease or a connective tissue disorder is diagnosed, earlier intervention may be indicated[6 18 19] (table 2). Congenital connective tissue disorders such as Marfan's syndrome, Ehlers-Danlos or Loeys-Dietz syndrome are usually incompatible with aircrew duties, not only because of their cardiac manifestations, but also the systemic disorders associated with these conditions. Mild forms, presenting late, in already experienced aircrew, may be acceptable for restricted flying duties, if mild and without systemic manifestations.

Early liaison with surgical colleagues is recommended for all aircrew with aortic dimensions approaching 5 cm, especially those who fly in high-performance aircraft (see the online supplementary figure 1). As with non-aircrew, exclusion of significant coronary artery disease is recommended presurgery.[20] The effect of sustained acceleration (high $+G_z$) on aortic dilatation is not known. After surgery for a thoracic aortic aneurysm, aircrew may be able to return to restricted (non-high performance) flying duties.

Aortic dissection is incompatible with aircrew duties, even if successfully repaired. A summary of recommendations for aortic disease can be found in table 5.

Table 5 Aortic surgery

Early liaison with surgical colleagues is recommended for all aircrew with aortic dimensions approaching 5 cm, especially those who fly in high-performance aircraft.	Strongly recommended
Aircrew applicants with thoracic aortic dilatation may be accepted for aircrew duties if dilation is mild and they undergo regular follow-up	Recommended
After thoracic aortic surgery, aircrew may be able to return to non-high-performance flying duties with appropriate follow-up	Recommended

CONGENITAL HEART DISEASE

The most frequent congenital heart defects seen in aircrew requiring surgical consideration are bicuspid aortic valve disease with significant stenosis or regurgitation, haemodynamically significant atrial and ventricular septal defects, and Patent Foramen Ovale (PFO) associated with stroke.[21] Interventions for congenital heart diseases in aircrew are covered in detail in the accompanying congenital paper.[21]

CONCLUSION

A return to flying duties following cardiothoracic surgery or intervention is possible for aircrew, although often in a restricted capacity and after an appropriate observation period, usually no less than 6 months postoperatively. The choice of the procedure and prosthetic material are often critical for returning to flying duties. Postintervention, a detailed documentation of all procedures is mandatory for the aviation authorities. It is essential that there is close liaison between the cardiothoracic surgeon, cardiologist and aviation specialist with the patient, prior to and following cardiac surgery. The surgeon and the interventional cardiologist should make themselves aware of the professional ramifications of any proposed procedure on their patient's future flying career.

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