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To fly as a pilot after cardiac surgery

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Summary

Aircrew are responsible for safe and reliable aircraft operations. Cardiovascular disease accounts for 50% of all pilot licences declined or withdrawn for medical reasons in Western Europe and is the most common cases of sudden incapacitation in flight. Aircrew retirement age is increasing (up to age 65) in a growing number of airlines and the burden of subclinical, but potentially significant, coronary atherosclerosis is unknown in qualified pilots above age 40. Safety considerations are paramount in aviation medicine, and the most dreaded cardiovascular complications are thromboembolic events and rhythm disturbances due to their potential for sudden incapacitation. In aviation, the current consensus risk threshold for an acceptable level of controlled risk of acute incapacitation is 1% (for dual pilot commercial operations), a percentage calculated using engineering principles to ensure the incidence of a fatal air accident is no greater than 1 per 10^7 h of flying. This is known as the '1% safety rule'. To fly as a pilot after cardiac surgery is possible; however, special attention to perioperative planning is mandatory. Choice of procedure is crucial for license renewal. Licensing restrictions are likely to apply and the postoperative follow-up requires a tight scheduling. The cardiac surgeon should always liaise and communicate with the pilot's aviation medicine examiner prior to and following cardiac surgery.

Keywords: Pilot • Cardiac surgery • Licensing regulations • Guidelines

INTRODUCTION

The medical regulatory process for aircrew

The determination of an individual's ability to fly after a surgical procedure falls under the field of aviation medicine and different restrictions apply to aircrew (pilots, navigators, air traffic controllers and other professionals who operate in the aviation environment) and passengers. The assessment of aircrew requires specific aviation medicine training and certification from both the national and the supranational aviation agencies [e.g. Civil Aviation Authority (CAA) in the UK, Federal Aviation Administration (FAA) in the USA and European Aviation Safety Agency (EASA) for the European Continent]. A licensed aeromedical examiner (AME) is the primary medical person who assesses aircrew [1–3], albeit nowadays the UK CAA enables general practitioners to assess (non-commercial) light aircraft pilots [4]. The AME, as a general aviation medicine specialist is also a valuable resource who may assist surgeons, both when determining the most appropriate surgical management of aircrew and when determining the postoperative timescale for patients to fly as both passengers and aircrew. Professional pilots hold Class I licenses, recreational pilots Class II, with differing medical standards required to be met to be eligible. In the civil environment restrictions on licenses include Operation Multicrew License (OML) for Class I or Operational Safety License (OSL) for Class II, mandating a second pilot qualified on type to be present, and able to take control, in the event of acute incapacitation. In aviation, the current consensus risk threshold is known as the '1% safety rule' (Fig. 1) [1, 3]. Military aircrew clearance is usually significantly more restrictive than that for civil regulations.

The aviation environment

The flight deck is a unique and demanding working environment, especially in military aviation and aerobatics. In addition to the high inherent cognitive demand placed on aircrew (and particularly pilots), one must also consider additional factors that may degrade physical performance such as acceleration forces in both civil and military high-performance flight and mission pressure, enemy threat and sleep deprivation in the military environment. Acceleration (or Gz) is a gravitational force that, in flight, is usually applied to the vertical axis of the body. If it is experienced from head to foot (positive Gz), it is termed +Gz. Additional positive Gz is experienced when a pilot pulls out of a dive or pulls into an inside loop [5]. The high +Gz environment is an exceptional physiological parameter that places a significant physiological cardiovascular burden on the heart and that requires thoughtful consideration in all stages of surgical management.

The average duration of a flight is 1 hour, and the health of the pilot totals 10% of the operational risk. The current accident rate in air transportation with fatal outcome is about 0.1 per million flying hours. In a two-man operation aircraft, the risk of a double sudden incapacitation for the aircraft is less than 1 per 10^{12} flying hours. In the worst-case scenario, a pilot presenting a yearly 1% risk of sudden incapacitation will jeopardize one of one million flights. While only 10% of the flight is considered critical (takeoff and landing), it endangers one aircraft in 10 million flights. Assuming that only 1% of the handovers in a dual cockpit fails, only one fatal event will result from medical cause in one billion flights.

Figure 1: Calculation of the 1% safety rule, from [1, 3].

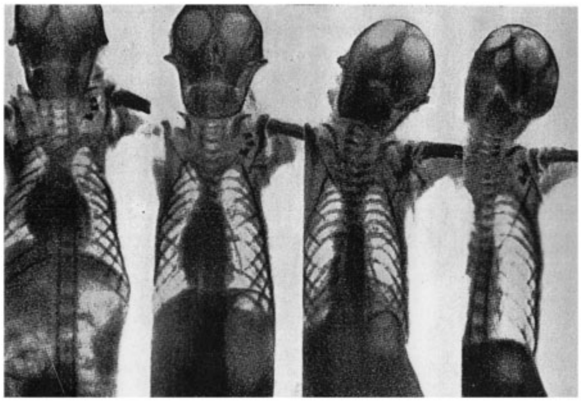

Figure 2: Monkey in centrifuge: chest X-rays of a chimpanzee undergoing centrifuge testing at + 1Gz, +2Gz, +4Gz and +6Gz. Mediastinal elongation with topographic changes [30].

To perform competently in this unique environment requires high cardiac output, optimal coronary flow profiles and best transvalvular gradient profiles. In military aviation and aerobatics, +Gz-loads represent an exceptional physiological strain on the cardiovascular system to maintain vital cerebral, coronary and myocardial perfusion under unusual attitudes (Fig. 2). As an example, we know that aortic valve bioprostheses display different flow characteristics and gradient slope curves under low- and high-flow conditions [6, 7], and it is this type of data that is critical in the management of aircrew who present for cardiac surgery.

Cardiothoracic surgical considerations in pilots

It is possible to return to flying as a pilot after cardiac surgery; however, special attention to perioperative planning is essential; choice of procedure (e.g. full revascularization) and prosthetic material (e.g. stentless or haemodynamically improved stented bioprostheses) are often critical in the determination of license renewal. Restrictions on pilot licenses are likely to apply following surgery and postoperative follow-up usually requires intensive additional investigations at specific time points. The cardiac surgeon should always liaise with the pilot's AME prior to the operation and understand the ramifications of different courses of action, and the need for certain clinical investigations to allow the AME to determine their suitability to return to their flying career or recreation.

As a general principle, the authors recommend that the most appropriate, evidence-based, surgical intervention should always be offered, ensuring that the pilot is aware of the ramifications of this suggestion to their professional role. If unacceptable to the pilot, however, the surgeon should be willing to offer aircrew alternative options (that may differ from usual practice). These should still be clinically appropriate but allow these professionals the opportunity to continue with their professional careers (even if limited). Pilots should be aware of the additional risks that might be associated with these alternative courses of action, but as long as an informed decision is agreed between the surgeon and pilot, informed consent is maintained.

Confirming flight licensing after cardiac surgery is a challenge for both the cardiac surgeon and the AME. Only the AME is authorized to determine the flight status of pilots [3]. In Europe, EASA releases the medical regulations for flight crew licensing in a specific document, the Part-MED [8, 9]. In contrast to the surgical and cardiological guidelines, aviation authorities update their regulations at a slower pace, as they need to be synchronized with a multitude of legislation in individual countries. These standards represent the legal framework with which AMEs and surgeons have to comply. Although the European Society of Cardiology (ESC)/European Association for Cardio-Thoracic Surgery (EACTS)/American Heart Association (AHA) [10, 11] guidelines and recommendations are usually familiar to all surgeons, the Part-MED represents a further legally binding series of regulations that the surgeon should be cognisant with when operating on professional aircrew.

For pilots undergoing cardiac surgery, there are many limitations related to both the surgical intervention and to the post-surgical therapeutic options. Anticoagulation remains a disqualifying condition for most commercial pilots, and partial revascularization would often also lead to a loss of flight license in many countries. High +Gz loads induce mediastinal shifts (Fig. 2), potentially impacting on graft flows and prosthetic valve function. As no randomized studies exist in this field due to the small, often younger, specialist cohort, the AMEs and surgeons have to rely on understanding of the physics of the aviation environment, cardiovascular physiology in this environment and a good dose of common sense.

METHODS

Study design

To underpin this review, we performed a focused systematic review of current aeronautical and related surgical literature. We screened the Medline database with the keywords (English language only) 'aortic–aorta–valve–coronary artery–bypass grafting–surgery–pilot–air crew–licensing' and established a threshold time cut-off including the publication year 1993 for literature review and 2008 for Flight Crew Licensing Regulations. We reviewed the latest EASA and International Civil Aviation Organization (ICAO) flight crew licensing regulations as well as the previous releases from the Joint Aviation Authority (JAA). We additionally reviewed airline's current operation procedures. Where applicable, we added selected aspects of our respective Air Forces' Operating Manuals (English, German and French languages).

Specific aspects of flight crew licensing literature

Contemporaneous literature, especially peered reviewed, is scarce in aviation medicine. Most of the information is to be found in manuals from the respective national authorities (such as UK Civil Aviation Authority and US Federal Aviation Administration) and supranational regulatory bodies (such as the EASA). Military aviation medicine publications are more secretive and intentionally not shared broadly. Our group felt that the review of the available peer-reviewed literature and from our respective national publications (civil and air force) provides the highest possible level of actual information matching into 1 single manuscript.

RESULTS

In Europe, all cardiac surgery cases in pilots must be evaluated by an AME, the operating surgeon and a cardiologist postoperatively and will not be considered for a return to flight duties earlier than 6 months [8] following surgery and full assessment. All guidelines consider the high +Gz load environment and stress the importance of considering the effect of sustained Valsalva manoeuvres and high cardiac output. They all reiterate the need for optimal communication and co-ordination between the cardiac surgeon and the pilot's AME and state its central importance to the management of this professional group. This article summarizes the key parameters that permit a safe return to flight duties in accordance with the existing guidance material [1, 8] after cardiac surgery. This includes valve disease (general, aortic and mitral valve surgeries), coronary artery bypass grafting (CABG) surgery, aortic surgery and surgical intervention for genetic and congenital cardiac diseases. It is worth noting that many of the sections within the EASA regulations are controversial and differ significantly from clinical recommendations and standard practice in non-aircrew populations.

General considerations and regulations that apply to all aircrew following surgery include the requirement for no postoperative reduction in cardiac function (ejection fraction of 50% is usually the minimal accepted standard), and cardiac chamber dimensions are within normal limits and no aviation-relevant pathology is left untreated, even if usual clinical practice would deem it clinically of less significance. Aircrew are usually required to undertake their flight duties off most, if not all, postoperative cardioactive medications, especially if undertaking solo flight operations or high-performance flight (exceptions may include angiotensin-converting enzyme inhibitors and angiotensin II receptor blockers).

Valve disease in aircrew

Because of the nature of the aviation environment, it is necessary to maintain cardiac output under high preload conditions and any restrictions to cardiac output (chronotropic and inotropic response or fixed obstruction due to stenotic valve lesions) are poorly tolerated, meaning even mild stenosis may be prohibitive in high-performance flight. Mild regurgitant valve lesions are of less concern, but any lesion that impacts on ventricular function, increases arrhythmia risk or reaches moderate severity is likely to result in professional flying restrictions. Additionally, it appears that younger patients undertaking active flight duties have a higher prevalence of bicuspid aortic valve disease requiring surgery than age-matched non-aircrew [12, 13]. As previously discussed, anticoagulation still is often a disqualifying condition, especially in military aviation, although EASA has loosened its civil restrictions in recent years, to the concern of many aviation medicine practitioners who have concerns that both the bleeding and thrombosis risk associated with anticoagulants often fall outside the 1% rule.

Aortic valve surgery. Pilots undergoing aortic valve surgery face many limitations that restrict both the surgical and medical therapeutic options available to the surgeon, if the pilot is to continue to fly. Due to the ramifications of a limited cardiac output, aircrew may present with mild-to-moderate disease that would not usually be considered for surgery. If accepted for surgery, the restriction placed on aircrew with regard to the use of anticoagulation, meaning that mechanical valves are discouraged, even in young patients. The implanting surgeon must also pay close attention to the choice of prosthetic material, and it is strongly suggested that they consider preference for stentless devices [6, 7] or haemodynamically improved newer stented bioprostheses.

It is accepted that structural valve disease is the main issue in maintaining long-term fitness to fly; the 2012 ESC/EACTS guidelines on the management of valvular heart disease suggest that surgeons should plan any reoperation early to minimize any loss of license due to medical conditions and plan the reoperation ahead of the development of clinical symptoms. (Class IIa/Level C indication) and states: 'AVR should be recommended in asymptomatic patients' [14].

Following aortic valve surgery, additional restrictions will usually apply to pilots and there are minimum requirements for follow-up that must be adhered to, to retain licenses. Licensing requirements for aortic valve surgery mandate a bioprosthesis and will only consider a return to flying in those with no postoperative restrictions in cardiac function, off all postoperative cardioactive medications. Aortic surgeons must appreciate the central importance of prostheses with high-flow profile, such as stentless implants or newer haemodynamically improved stented bioprostheses. Furthermore, stentless implants may be preferred when applicable over stented ones due to their potentially improved coronary flow profile [6, 7, 15–17]. Professional pilots with Class 1 licenses may be restricted to multipilot operations (Class 1 OML) and those with Class 2 licenses may require a safety pilot (Class 2 OSL).

Licensing will exclude high +Gz environments, usually over +3Gz, and usually exclude ejection seat aircraft, (although low-performance delivery flights, where aircraft are not flown to their usual capability may be allowed).

It should be noted that EASA have studied the possibility of permitting mechanical valves for non-professional pilots. Since

Table 1: Follow-up investigations after aortic valve surgery

Items	Value
Prosthetic valve function	ΔP_{mean} at rest <20 mmHg
Transvalvular flow pattern and in LVOT	Laminar
Dimensions of sinus portion and aorta	<4 cm and <4.5 cm, respectively
Other heart valves	No pathologies
Dimensions of the heart chambers	LVEDD <5.6 cm
LV muscle mass, free wall and septum	<1.1 cm
LV biplane ejection fraction	≥50%
No rhythm disturbances	48 h Holter recording

LV: left ventricular; LVOT: left ventricular outflow tract; LVEDD: left ventricular end-diastolic diameter.

Table 2: Follow-up investigations after coronary revascularization

Items	Value
Exercise ECG	No myocardial ischaemia No conduction disturbances
Echocardiogram	No dyskinesia, no akinesia LV biplane ejection fraction ≥50%
Holter ECG 24 h	No significant rhythm disturbances
After PCI	Myocardial perfusion scan Alternatively: stress echocardiogram
After CABG	Within 5 years of surgery: perfusion scan or equivalent
If any doubt about perfusion	Myocardial perfusion scan
Symptoms or signs of ischaemia	In all cases, coronary angiography at any time

CABG: coronary artery bypass grafting; ECG: electrocardiogram; LV: left ventricular; PCI: percutaneous coronary intervention.

2011, EASA have been considering defining 'stable anticoagulation' as ≥5 international normalized ratio (INR) values within the normal range the last 6 months, where the target range of each particular implanted device was met in ≥4 of these INR measurements. This debate continues with strong advocates on both sides of the argument.

The minimum follow-up schedule after aortic valve surgery for aircrew includes an initial 6-month postoperative follow-up with subsequent review according to age and Part-MED plan. These consultations are required every 6 months for both Class 1 and Class 2 pilots over 40 years in a single-pilot commercial air transport operations with passengers and for all pilots over 60 years old. These reviews must be conducted by a cardiologist acceptable to the national aeromedical section (AMS). Follow-up investigations after aortic valve surgery are outlined in Table 1.

Mitral valve surgery. Mitral valve surgery may be required in any aircrew with moderate regurgitation or in those with abnormal ventricular dimensions, or function, secondary to valve disease. Mitral valve replacement is usually a disqualifying procedure. This was stated in the ICAO regulations in 2008 but is no longer mentioned in the current EASA guidelines. Return to flying duties is possible following mitral leaflet repair, provided that LV function is satisfactory, LV systolic and diastolic dimensions are not increased and that there is not more than minor residual mitral regurgitation postoperatively. Importantly, when undertaking mitral valve repair, surgeons should consider left atrial appendage (LAA) exclusion (due to the incapacity risk associated with thromboembolic disease). However, it should be noted that the guidelines surrounding LAA excision in aircrew are inconsistent in the regulatory literature. These state that return to flying is permitted only when LAA 'resected' (JAR FCL-3 2002) that LAA amputation 'may be' an advantage (ICAO 2008) or not mentioned at all (EASA Part-MED 2011).

Coronary artery bypass grafting

Aircrew with proven significant coronary artery disease (CAD) require 'complete' revascularization [no stenosis >70% left untreated, respectively, >50% for left main stem (LMS)] to ensure that, after intervention, those without symptoms have reduced any vascular risk within the 1% rule. In the context of aviation, a very low post-revascularization major adverse cardiac event rate is needed before certification and licensing can be considered. This requires a different approach to standard CABG or percutaneous coronary intervention (PCI) in that even moderate bystander disease may require intervention to ensure relicensing is possible. Note that for PCI a 'complete' revascularization is compulsory for consideration to revalidation. PCI in diabetic patients should not be acceptable due to the high subsequent event rate. Furthermore, in multivessel disease, PCI reaches less complete revascularization than surgery [1, 10]. No surgical evidence supports revascularization of stenosis <70% (<50% for the LMS) in any vessel including graft; neither does it apply to PCI. Radial artery should not be used to graft stenoses less than critical (<90%) [18, 19].

As with valve surgery, all aircrew require an initial 6-month review, and if they fulfil the regulatory criteria this will allow a return to flying with a multipilot limitation (OML or OSL in civil flight operations). The usual investigation schedule is shown in Table 2. Any anti-anginal medication, when used to control cardiac symptoms, is not acceptable if pilots wish to return to flying duties. All aircrew should be on acceptable and aggressive secondary prevention treatment. Subsequent follow-up should be at minimum annually and include at least a review by a cardiologist, following an exercise ECG and full cardiovascular risk assessment.

To fulfil the regulatory criteria following revascularization, a coronary angiogram obtained at the time of, or during, the ischaemic myocardial event and a complete detailed clinical report of the ischaemic event and operative procedure must be available to the licensing authority [10]. The criteria that must be met include the following: (i) no stenosis >50% in any major untreated native vessel or graft or stent and (ii) no more than 2 stenoses ≥30 but ≤50% within the vascular tree. Depending on the threshold levels of stenosis and their localization (LMS, proximal LAD etc.), aircrew may have to undergo anatomic reassessment prior to relicensing.

It can be readily appreciated that there is a clear discrepancy between clinical guidelines and the more stringent requirements that must be met for relicensing for aircrew. Although the current ESC/EACTS guidelines recommend revascularization for >50% stenosis within the LMS and >70% stenosis for other locations for aircrew relicensing, complete coronary tree assessment is

Table 3: Management of the aortic dilation in relationship to diameter, comorbidities and concomitant surgical procedures

Diameter (cm) of ascending aorta	Condition	Action
Any	At the time of diagnosis of Marfan syndrome	TTE then repeat TTE 6 months after to determine the rate of enlargement of the aorta
>4.0	All, asymptomatic	Search for connective tissue disorder Initiate ß-blocker therapy Strict blood pressure control <120/80 mmHg Moderately restrict physical activity Provide pregnancy counselling Yearly imaging with TTE and/or CT/MRI
>4.0	Bicuspid aortic valve	Yearly imaging with TTE and/or CT/MRI Initiate ß-blocker therapy
>4.0	Women with Marfan	Operative treatment: repair aortic root and replace ascending aorta
>4.2 by TOE (internal diameter) >4.4 by CT/MRI (external diameter)	Connective tissue disorder Loeys–Dietz syndrome TGFBR1/TGFBR2 mutation Desired pregnancy Family history of aortic dissection Growth >0.5 cm/year	Operative treatment
>4.5	Concomitant aortic valve surgery	Operative treatment
<5.0	In Marfan patients: if maximal cross-sectional area (cm^2) of root or ascending aorta divided by patient's height (m) exceeds a ratio of 10	Operative treatment
>5.0	Any connective tissue disorder Bicuspid aortic valve	Operative treatment: repair aortic root and replace ascending aorta
>5.5	All, asymptomatic	Operative treatment

CT: computed tomography; MRI: magnetic resonance imaging; TOE: transoesophageal echocardiography; TTE: transthoracic echocardiography.

Table 4: Management of the aortic arch dilation in relationship to diameter

Diameter (cm) of aortic arch	Condition	Action
<4.0	All	CT or MRI every 12 months
>4.0	All	CT or MRI every 6 months
>5.5	Patients with low operative risk with isolated degenerative or atherosclerotic aneurysm	Operative treatment

CT: computed tomography; MRI: magnetic resonance imaging.

mandatory and any untreated stenosis >30% in the LMS or proximal LAD is not acceptable. Residual, non-clinically significant, CAD must therefore be considered for revascularization in pilots and other aircrew. This presents a real challenge to surgeons as surgical intervention on a stenosis of <50% stenosis in the LMS and <70% stenosis in any other coronary vessel is not recommended, as the remaining competitive flow from the native vessel is likely to lead to an early graft failure.

Aortic surgery: ascending aorta, aortic arch and thoracic aorta

Pilot applicants with an aneurysm of the thoracic aorta may be assessed as fit, subject to satisfactory cardiological evaluation and regular follow-up. They may be assessed as fit after surgery for a thoracic aortic aneurysm subject to satisfactory cardiological and surgical evaluation to exclude the presence of CAD [8].

Aortic aneurysm involves dilation of the aorta, and in one-sixth of cases, it involves more than 1 segment. The condition is 4 times more common in men aged >55 years than in women. The prevalence in this age group is 3%. A luminal diameter >5 cm is associated with a significant increase in risk of rupture. Thoracic aneurysms show less age-related increase in incidence, the descending, ascending and arch portions being involved in that order [1]. An ascending aortic diameter >5.5 cm, a sinus portion of >5.5 cm or a growing rate >0.5 cm/year are conservative indications for surgery in the absence of concomitant bicuspid aortic valve disease or connective tissue disorders [14, 20] (Tables 3 and 4). More details to operative indications were summarized earlier [14, 21, 22].

Genetic and congenital cardiac diseases

Congenital connective tissue disorders such as Marfan's syndrome, Ehlers–Danlos and Loeys-Dietz are uniformly assessed as unfit in pilot applicants. This is often due to the wider skeletal and systemic manifestations of these conditions in addition to their cardiac disease. In case of late presentation in pilots and other aircrew, mild forms of disease may be acceptable, if no systemic manifestation exceeds the acceptable regulatory requirements. Usual clinical management (Table 2) should be followed in the first instance.

Common congenital cardiac diseases may be compatible with pilot licensing, usually if mild or if surgically corrected in childhood or early teens. Cyanotic heart disease is universally incompatible with aircrew duties. Common congenital cardiac disease that may present in aircrew includes coarctation of the aorta, patent ductus arteriosus (PDA), hypertrophic cardiomyopathy and tetralogy of Fallot (ToF).

In individuals with coarctation, unrestricted certification may be considered in those who have had an operative repair and are normotensive, provided the operation was performed between age 12 and 14 and regular follow-up with transthoracic echocardiography has been performed [1, 3]. Concomitant dilation of the ascending aorta is a disqualifying finding. There are no data available with regard to postoperative evolution of repaired or native coarctation under high +Gz environment and a history of coarctation is a disqualifying condition in those wishing to undertake high-performance or military flying.

PDA closure is a safe procedure with an excellent long-term prognosis; 25-year mortality after surgical closure is <1% with no late deaths reported. However, PDA is associated with bicuspid aortic valve, subaortic stenosis, pulmonary stenosis and aortic root disease, all of which may preclude initial, or renewal, of aircrew licensing. These associated conditions must be assessed as part of the aviation medicine consideration in patients with prior surgical intervention for PDA. If the applicant is free of additional pathology, unrestricted certification may be considered in those with a history of PDA [23].

Hypertrophic cardiomyopathy has a prevalence of about 1 in 500 adults. Although often asymptomatic, 1–2% die each year, half of them suddenly and usually due to ventricular arrhythmia, thromboembolism and heart failure. Risk factors for sudden cardiac death include previous cardiac event, family history of sudden death, stroke at young age, ventricular tachycardia, abnormal blood pressure response (a fall of >20 mmHg from peak pressure) on exercise electrocardiogram, left ventricular wall thickness ≥30 mm and subaortic gradient ≥30 mmHg [24]. Half of the sudden deaths occurring in young male athletes >35 years of age are due to the condition. Atrial fibrillation may prove incapacitating and is a disqualifying condition. Asymptomatic civil applicants are generally assessed as unfit or required to be restricted to multicrew operation [1, 3]. Hypertrophic cardiomyopathy is a disqualifying condition for military aircrew applicants.

ToF is probably the most complex congenital heart condition that would be considered for (limited) aircrew licensing. The operated ToF has a similar survival rate as the normal population [25] but is associated with a steep increase in the incidence of ventricular tachycardia, sudden death and atrial tachyarrhythmia around 20 years following surgery [26]. This presents challenges in the aviation environment. If operated on before the age of 12 years, with no evidence of residual right ventricular hypertrophy, pulmonary regurgitation or ventricular arrhythmia and subject to regular monitoring by a cardiologist may allow pilot applicants initial unrestricted certification until the age of 40 years. If >40 years, ToF is not compatible with unrestricted certification in any environment and will result in OML/OSL restrictions at a minimum. ToF is a disqualifying condition for military aircrew applicants.

DISCUSSION

Cardiac surgery need not be the death knell for pilots' flying careers, even for professional pilots. However, a prolonged period of observation and intensive postoperative investigation is mandatory and return to flying is not considered earlier than 6 months postoperatively. Sternum stability after median sternotomy will be assessed clinically in aircrew as in the general population. Should a suspicion of sternal malunion arise at this stage, a computed tomography scan might be considered. Pilots who have undergone cardiac surgery and meet the regulatory requirements may be considered 'fit to fly' by the AMS. We emphasize the importance of documentation of all lesions as per Part-MED [8] to avoid any unnecessary licensing restrictions thereafter.

In valvular surgery, we would highlight the central importance of biological prostheses with high-flow profile. Furthermore, stentless implants may be preferred when applicable over stented ones due to the improved coronary flow profile [6, 7]. Nevertheless, newer stented bioprostheses with improved haemodynamic characteristics shall be considered as well. Redo valve surgery must be planned well ahead, before clinical manifestations jeopardize the pilot's ability to fulfil the privileges of his license. Surgeons and AMEs should not wait for licensing disqualification due to structural valve disease and plan the redo surgery pre-emptively. We view EASA's approach towards mechanical valves and the associated INR monitoring policy with concern as we believe it lacks evidence to assure the INR is indeed stable. We believe, in its current form, the risk of thromboembolism, in particular, does not meet the usual standard applied under the 1% safety rule for sudden incapacitation.

Assessment and management of aircrew, and pilots being considered for, or having undergone CABG is almost certainly going to increase significantly for both the AME and the surgeon, as pilots fly longer and non-invasive investigations for CAD improve [27]. The superiority of CABG over PCI for revascularization of left main, left anterior descending and multivessel disease has been demonstrated and is well documented [10]. We note, with concern, that neither bilateral internal mammary artery graft use instead of a single internal mammary artery graft nor total arterial revascularization is mentioned in the current EASA regulations. Additionally, PCI is known to be less effective than surgery in obtaining full revascularization in complex CAD, which is a criterion for revalidation in aircrew and the numerous iterations of the SYNTAX study offer substantial evidence for an optimized surgical choice of procedure [28, 29].

There is clearly significant debate to be had with regard to the evidence for whether intervention on untreated stenosis >30% is acceptable; there is no evidence of any benefit in grafting such coronary lesions [10] and with regard to revascularization, the current ESC/EACTS guidelines recommend surgical intervention only in stenosis levels of >50% for the left main and >70% for other localizations in the coronary tree. Revascularization of <50% stenosis in the left main and <70% stenosis in any other coronary vessel is not recommended, as the remaining competitive flow from the native vessel is likely to lead to an early graft failure. No surgical evidence supports revascularization of stenoses <70% (<50% for the LMS) in any vessel including graft. Neither does it apply to PCI. The radial artery should not be used to graft stenoses less than critical (<90%) [18, 19]. Interestingly in a population where risk assessment is paramount, graft flow measurement upon revascularization completion is not mentioned in current aviation guidelines, and as this quality control item becomes increasingly routine in surgery, threshold values for the graft flow and pulsatile indices will need to be defined and included in the regulatory requirements for aircrew.

Aortic surgery and congenital cardiac diseases are fortunately rare among the aircrew population, especially pilots, but nevertheless require the same systematic approach based on current evidence and surgical options [14, 20–22].

CONCLUSIONS

To fly as a pilot after cardiac surgery is possible, but special attention to perioperative planning is mandatory. Choice of procedure (e.g. full revascularization and arterial grafts) and prosthetic material (e.g. stentless bioprosthesis) are crucial for license renewal. Licensing restrictions are likely to apply and the postoperative follow-up requires a tight scheduling. Enhanced knowledge transfer between the surgical and cardiological societies and the aviation authorities ought to support future revisions of the medical regulations for flight crew licensing. The cardiac surgeon should always consider the professional ramifications of the surgical management of pilots and maintain close liaison and communication with the pilot's AME prior to and following cardiac surgery.

Conflict of interest: none declared.

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