Human centrifuge in aero medical evaluation

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ABSTRACT

Human centrifuge is an age-old tool, which helps the aviation physiologists in studying effects of G-stresses on ground. Initially it was used for experiment on animals, but later centrifuges in which research on human subjects could be carried out were built. The Human Centrifuge is a tool, which has been used extensively throughout the world for training, medical evaluation and research. The Human Centrifuge at Institute of Aerospace Medicine (IAM) was installed and commissioned in 1966. This paper has reviewed its role as an evaluation tool in our context. The collected data over a span of 27 years i.e., from Jan 1975 to Dec 2001 has been reviewed. A total of 223 cases of different disabilities have been evaluated during the above said time period. However, the total number of evaluations in the human centrifuge has been 263 i.e., some cases have been evaluated more than once during the course of reaching its finality. Recommendations are also made for specific medical conditions regarding the suitability of exact investigative procedure in Human Centrifuge.

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KEY WORDS: Human Centrifuge, Aeromedical Evaluation, Aircrew

India had procured a human centrifuge (HC) system from the erstwhile West Germany in 1966. It has been extensively used for indoctrination and training of students (both pilots, doctors), evaluation of pilots and flying clothing and research and development of countermeasures against +Gz. Since its installation, the centrifuge has been modified independently from time to time to update it as well as to keep it serviceable. Presently, it has a microprocessor-based control with on-line physiological monitoring facilities along with recording and archival system (Digital Acquisition and Retrieval Equipment DARE) [1,2]. At present, the HC is utilized for research in acceleration physiology, indoctrination to students reporting for various courses in Aviation Medicine (including High-G indoctrination), evaluation of aircrew, development and evaluation of aircrew clothing and aircrew training. Evaluation of aircrew in low medical category at various stages of their disability is done for variety of reasons. These evaluation consist of a large number of cases of spinal injuries (post ejection and accident), air sickness, G-related neck injuries, low G-tolerance, vaso-vagal syncope, low backache, prolapsed inter-vertebral disc (PIVD), episodic unconsciousness, head injury, giddiness, vertigo, ECG abnormality, fear of flying, spatial disorientation in flight, post abdominal surgery and few miscellaneous cases in last three and a half decades. This has resulted in early re-flighting of a number of aircrew.

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The various disorders evaluated in the human centrifuge are given Table-I. Recommendations are also made for specific medical conditions regarding the suitability of exact investigative procedure in Human Centrifuge. In this study we have reviewed the collected data over a span of 27 years i.e., from Jan 1975 to Dec. 2001. This includes the data from 1984 to 1998 [3].

**Table-I**

<table>
<thead>
<tr>
<th>Name of the system</th>
<th>Disabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Nervous system</td>
<td>Episodic Unconsciousness/Loss of Consciousness (LOC) in the air, Repeated blackouts during aerobatics, Vasovagal-Syncope, Giddiness/Vertigo, Head injury, Fear of flying</td>
</tr>
<tr>
<td>Cardiovascular System</td>
<td>Low G-tolerance, Hypertension, ECG abnormality, Mitral valve prolapse</td>
</tr>
<tr>
<td>Spine</td>
<td>Post ejection spinal injuries, Non-ejection spinal injuries, Low backache, Cervicalgia/Spondylosis, Lumbar Spine contusion/ Spondylosis, PIVD</td>
</tr>
<tr>
<td>ENT</td>
<td>Air sickness, Spatial Disorientation</td>
</tr>
<tr>
<td>Eye</td>
<td>Evaluation with corrective glasses, Retinal injury</td>
</tr>
<tr>
<td>Abdomen</td>
<td>Organomegaly, Inguinal hernia, Cholelithiasis, Polycystic kidney</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Ulnar neuropathy, Thalassaemia</td>
</tr>
</tbody>
</table>

**Aim of the Paper**

(a) Importance of the use of the human centrifuge as an evaluation tool.

(b) Number of different types of cases evaluated so far in our centrifuge.

(c) Knowledge about the different types of cases, which have been evaluated in the human centrifuge.

(d) Recommendations for specific medical conditions regarding the suitability of exact investigative procedure in human centrifuge.

**Methodology**

Case records available in the department from 1975 were evaluated and data recorded. The evaluation basically consists of G-loading of the spine. The G-loading is given mainly in the form of rapid onset runs (ROR), gradual onset runs (GOR) and simulated air combat manoeuvre (SACM) runs to find out the subject’s relaxed tolerance and straining tolerance while doing the Anti-G Straining Manoeuvre (AGSM) and with/without an anti-G suit. In some cases helmets and oxygen masks are also used. Certain specific neck movements are done during the plateau phase of some high-G runs in cases of cervicalgia. All cases of spinal disabilities undergo low frequency (4-12 Hz) vibration runs before they are subjected to centrifuge runs. If they are found sympatomatic during the vibration run, centrifuge runs are not recommended i.e.; the clinical recovery is not complete and therefore G-loading may worsen the clinical situation. Aircrew evaluated are those who will be subjected to G-loads in their aircraft in excess of 4 to 5 G. The different types of runs used during evaluation of different cases are summarized in Table-II.

**Results of Investigation**

A total of 223 cases of different disabilities have been evaluated during the time period of 1975 to 2001. Total number of evaluations in the human centrifuge have been found to be 263. which mean some cases have been evaluated more than once in the course of time till it has reached its finality. Out
of the 223 cases evaluated, 33.63% are post ejection spinal injuries, 16.14% are of air-sickness, 9% are of episodic unconsciousness, 9% are of low backache, 5.38% of cervicalgia, 3.1% of vaso vagal syncope, 2.7% of PIVD, 2.7% of low G tolerance, 1.79% of non-ejection spinal injuries and 16.56% of other cases have been found. The details are given in Table III.

Discussion

Air Sickness

Air sickness is more common in ab-initio trainee pilots than in trained aircrew population. It occurs during their introduction to aerobatic manoeuvres in flight. Usual complaints are nausea and emesis during flight. Once they are referred to IAM, they report to the department of Psychology/Psychiatry for treatment. At IAM they undergo vestibular desensitization (by doing vestibular desensitization exercises and use of parallel swing) and biofeedback therapy. Therefore, what is the role of centrifuge in evaluation of such cases? A centrifuge produces angular accelerations and decelerations during the onset and offset phases before reaching a plateau phase or before coming to a halt respectively. This angular acceleration is a sufficiently strong stimulus for the vestibular system and can precipitate motion sickness in susceptible individuals. Hence, a centrifuge run is extremely essential to assess the efficacy of the above therapies on the affected aircrew. Therefore, centrifuge runs (both ROR and GOR runs are used with a deceleration rate of 0.2G/sec in such cases) are given in airsickness cases before and after the therapy and difference in the intensity of symptoms (i.e., nausea, sweating vertigo or emesis) are judged to come to a final decision of re-flying. In last 27 yrs a total of 40 cases of airsickness have been evaluated in the human centrifuge. Out of these 15 were flight cadets, two Naval pilots, four pilots from Army aviation, three navigators and 16 were trained pilots. One flight cadet was made unfit for flying and change of branch was recommended. Four flight cadets had shown frank symptoms of motion sickness on centrifuge evaluation even after treatment (disposal not known). Two fighter pilots were re-streamed (one on account of motion sickness and the other on account of low G-tolerance). The remaining aircrew had shown definite reduction in the intensity of their symptoms and have been re-flighted after undergoing successful therapy at IAM.

In-Flight G induced loss of consciousness

The commonest non-pathological cause of LOC in the air is G-induced loss of consciousness (G-LOC) [4]. These cases are assessed in centrifuge after the routine physical, clinical, bio-chemical and other special laboratory investigations have ruled out any

<table>
<thead>
<tr>
<th>Type of run</th>
<th>Rate of onset</th>
<th>Magnitude</th>
<th>Duration</th>
<th>Rate of offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-up</td>
<td>0.5 G/sec</td>
<td>2.5 G</td>
<td>15 sec</td>
<td>0.2 G/sec</td>
</tr>
<tr>
<td>GOR</td>
<td>0.1 G/sec</td>
<td>9.0 G</td>
<td>2 sec</td>
<td>1.0 G/sec</td>
</tr>
<tr>
<td>ROR 1</td>
<td>1.0 G/sec</td>
<td>4.0 G</td>
<td>15 sec</td>
<td>1.0 G/sec</td>
</tr>
<tr>
<td>ROR 2</td>
<td>1.0 G/sec</td>
<td>5.0 G</td>
<td>30 sec</td>
<td>1.0 G/sec</td>
</tr>
<tr>
<td>ROR 3</td>
<td>1.0 G/sec</td>
<td>6.0 G</td>
<td>30 sec</td>
<td>1.0 G/sec</td>
</tr>
<tr>
<td>ROR 4</td>
<td>1.0 G/sec</td>
<td>7.0 G</td>
<td>15 sec</td>
<td>1.0 G/sec</td>
</tr>
<tr>
<td>SACM</td>
<td>1.0* G/sec</td>
<td>2G for</td>
<td>300 sec</td>
<td>1.0 G/sec</td>
</tr>
<tr>
<td>SD Run</td>
<td>0.5 G/sec</td>
<td>2G for</td>
<td>60 sec</td>
<td>0.5 G/sec</td>
</tr>
</tbody>
</table>

* 4 and 6.5 G at least for 15 sec each
organic cause or clinical abnormality of unconsciousness in flight. Runs are given in the course of 2 to 3 days. Initially the relaxed tolerance of the aircrew is found out. During straining tolerance (G-level tolerance and duration tolerance) the aircrew is given an anti-G suit and performs the AGSM he is used to and his straining tolerance is noted. Thereafter, he is indoctrinated to the effects of G-forces on human physiological system and taught the preventive measures. In this, he is taught the correct technique of performing anti-G manoeuvre and performs the AGSM, which gives a G-protection of 3.5 to 4G. He is also explained about the effects of empty stomach, pre-flight meals, fatigue, drugs, other aviation stresses, any illness etc. on G-tolerance, which has been documented [5,6].

Unconsciousness of a pilot/cadet in flying while pulling G’s (e.g., roll of a top 2 vs 2 combat etc) is not very uncommon in fighter flying. Centrifuge is an ideal and safe medium to simulate or replicate the G-environment of flight on ground. Hence, a pilot can be tested on ground for a situation like G-LOC in the air and re-flighting of aircrew without loss of trained manpower. To date 20 cases have been evaluated of which seven were flight cadets. One flight cadet and two other cases were made unfit for fighters on account of low G-tolerance. One was made unfit for high performance aircraft. The balance of 16 cases have been reflighted.

**Repeated blackouts in Aerobatics**

Total of three cases have been evaluated so far. One was made temporary unfit and advised to undergo physical / gymnasium training. Two were found to be using improper technique during AGSM, which was corrected.

**Cervicalgia/Cervical Spondylosis**

Incidence of neck injuries is increasing because of increase in aircraft capability and the need to move the head during aerial combat [7]. Cervicalgia usually results from head drop during high-G manoeuvres or during ‘check six’ (looking for enemy aircraft behind) action. After clinical recovery the aircrew is subjected to G-loading of the cervical spine with full flying clothing assembly. During the run he is asked for any complaints of neck pain and
observed for any head drop. Post run evaluation also should not reveal any cervical muscle spasm or any restriction in mobility of the neck. In the absence of any positive finding, the aircrew can be cleared for flying. Twelve cases of cervicalgia/cervical spondylosis have been reviewed of which three had been made unfit for fighters (fit for transport and helicopters). Nine cases were re-flighted after the centrifuge evaluation.

Post Ejection Spinal Injuries

All cases of ejection with or without spinal injuries undergo review at IAM for evaluation after a minimum period of 6 weeks, provided they are fit clinically and radiologically (MRI). Low frequency vibration run is mandatory before centrifuge evaluation in all such cases. Non-ejection spinal injuries also have to undergo the same evaluation procedure. Centrifuge provides the dynamic loading of the spine and any instability that manifests under loading during the run (pain, discomfort). A post run para-spinal muscle spasm or local tendencess gives an indication of the problem. To date we have evaluated 75 cases and two cases have been made unfit for fighter flying. 60 cases had spinal fractures, seven cases had no spinal injury at all and four cases had only contusion of the cervical spine. The remaining four cases, each had associated injuries in the form of head injury, post ejection vertigo, post ejection dislocation of elbow and PIVD respectively. 73 cases have been re-flighted over the period of time.

Non-Ejection Spinal Injuries

Four cases have been evaluated till date. One case was a fall from horse, two were due to road traffic accident and one due to crash landing of a Mig-21 aircraft. All cases were re-flighted.

Low Backache

A total of 20 cases have been evaluated. 16 were from fighters, two from helicopters, one from transport and one was a flight cadet. One was made unfit for fighters and 19 were re-flighted.

PIVD

This disorder in an aircrew usually results from sudden jerk associated with improper posture either in the air or on the ground. We had six cases of PIVD who were subjected to G-loading and assessed for any pain during the run or post run paraspinal muscle spasm/ tenderness. In absence of positive findings all of them were cleared at different stages.

Vaso-Vagal Syncope(VVS)

Till date seven cases of VVS have been evaluated. The last case is still under review. All the others have been cleared from G-tolerance point of view. They all have been advised to do regular physical conditioning, more in the form of anaerobic training than aerobic training, which will reduce the resting parasympathetic tone and increase their G-tolerance.

Low G-Tolerance

Relaxed tolerance of less than 3.5 G with Peripherial Light Loss at 52° to 56° as end point is considered as a case of low G-tolerance. Such cases are considered unfit for fighter flying [3]. A total of six cases have been evaluated. Three of them have been made unfit for fighter flying but fit for transport flying. The other three have been reflighted.

Giddiness

A total of four cases have been evaluated. All were found to have normal G-tolerance on centrifuge evaluation. All have been re-flighted.
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Head Injury

Three cases reported so far. All were found to have normal G-tolerance on centrifuge evaluation. However, psychomotor and cognitive functions were not assessed under G-stress.

Lumbo-Sacral Spine Contusion

Two cases of lumbo-sacral spine contusion have been evaluated. Both were found fit on centrifuge evaluation, which helped in their reflighting.

Hypertension

Three cases of hypertension have been evaluated. All were borderline hypertension cases. Blood pressure recording before and after the centrifuge run was taken. No ECG abnormality was recorded. Two were made unfit for fighter flying but fit for transport flying as they had shown increased BP response in the post run period and subsequently put on drugs for controlling the blood pressure. The other case was found to have normal G-tolerance and blood pressure recording on centrifuge evaluation.

ECG Abnormality

Three cases have been evaluated. The last case being evaluated in 1979. All were found to have normal ECG response on G-run. ST-T changes are known to occur during centrifuge runs. However, they assume significance only when the ST-T changes are marked. A variety of arrhythmias also occur under G stress, but only a few are significant [6].

Organomegaly (Liver/Spleen)

Two cases of organomegaly were evaluated. Both were found to have normal G-tolerance.

Spatial Disorientation (SD) in Flight

SD is not uncommon in any type of flying. Two cases reported for evaluation, one in 1979 and other case in 1982. In one of the cases SD occurred during night flying in a Canberra aircraft and the subject had a feeling of bank to the right while levelling out in a cloud. His centrifuge evaluation did not reveal any problems in orientation or any symptoms of motion sickness. Both the aircrew were indoctrinated about the effects of SD in flight and declared fit for flying.

Mitral Valve Prolapse (MVP)

Till date only one case of MVP has been sent for centrifuge evaluation in the year 2000. The diagnosis of MVP was made after detection of an ECG abnormality during medical review followed by Echocardiography. Cardiologist at Command Hospital Bangalore opined that the MVP was not significant and declared the ECG findings as non-specific. Evaluation for coronary artery disease (CAD) was normal. He was evaluated in the human centrifuge with online monitoring of ECG. He completed the runs without any symptoms and ECG during Gz stress did not reveal any abnormality (arrhythmia or ischaemic changes). He was recommended fit for flying.

Adult Polycystic Kidney Disease (APKD)

A solitary case of APKD was evaluated in 1990. A fighter pilot reported for CVS (Inv) and was found to have bilateral polycystic kidney. Blood pressure was 140/90 mmHg. Several centrifuge runs were given with anti-G suit and AGSM upto 6 G. Post run he was asymptomatic and he had a normal G-tolerance. Further disposal of the case is not available with us. However, as per world literature adult polycystic kidney disease (1 in 350 incidence) may manifest itself as a severe disease and accounts for 5% to 8% of patients with renal failure requiring transplantation or dialysis. The disease may become symptomatic early in teens or as late as the eighties. Complications of polycystic disease include urinary tract infection, renal calculi, hypertension and the development of...
chronic renal failure. Polycystic kidney disease is also associated with cystic disease/aneurysms of other organs of the body such as the brain, liver and pancreas. One third of these patients die of renal failure, another third die of hypertension and the last third die of unrelated causes [8,9].

Large polycystic kidneys are not compatible with high performance flying because G forces cause the enlarged and heavier kidney to pull on the pedicle and may result in bleeding. A waiver is possible if renal function is normal and the aviator remains asymptomatic. Waiver criteria include a low probability of recurrent problems, adequate renal function and a likelihood that the problem will not conflict with the performance of the military aviators duties even under the most adverse of conditions [8,9]. Therefore, centrifuge evaluation becomes a must under such circumstance as in the above case.

**Evaluation with Corrective Glasses**

One case was evaluated for flying high performance aircraft with corrective glasses in 1985. He was given centrifuge runs with full flying clothing along with oxygen mask. No dislocation of corrective glasses was noted during the run. He was cleared for flying. In this connection it will be worthwhile to mention that IOL implants in non-aircrew were tested in human centrifuge and no ill effects were found till 3G [2]. However, IOL are not permitted in fighter flying [7].

**Fear of Flying**

Two cases have reported so far. Centrifuge evaluation was normal. Both were found fit in full medical category and administrative disposal was recommended.

**Cholelithiasis (operated)/ Inguinal Hernia (operated)**

One case each of cholelithiasis (operated) and inguinal hernia (operated) was evaluated in 2001. Both were found fit on centrifuge evaluation. There is 70% recovery of aponeurotic wound by 1-year time. Thereafter wound recovery is slow [10]. Intragastric pressure changes while doing L1/M1 manoeuvre is 111 mm Hg at + 1 Gz, 146 mm Hg at + 4 Gz and 176 mm Hg at + 7 Gz respectively [11]. However, no centrifuge evaluation is done for such cases at present. Only 12 weeks of post operative observation on ground is mandatory.

**Retinal Injury**

One case of retinal injury was evaluated. He was found fit on centrifuge evaluation.

**Thalassemia Minor**

Two cases have been evaluated. Both were senior fighter pilots and were found to have normal G-tolerance and were cleared for fighter flying [12]. However, oxygen saturation at peak G levels should be checked with pulse oximetry in such cases because respiratory effects of high Gz reduce the oxygen saturation and in combination with pre-existing anaemia could affect performance.

**Ulnar Neuropathy**

One case was evaluated in 1993. He was found to have normal G-tolerance. Aim was to find any arm pain during high G.

From the above discussion it is obvious that the human centrifuge has proven to have definite role in determining the aeromedical disposal of a large number of pilots/cadets with different disabilities and has also definitely hastened their re-flying. There are certain disabilities, where a larger data bank is required to prove its definite role in deciding the disposal.

**Recommendations**

1. Spinal disabilities of any nature should continue to undergo HC evaluation, once the aircrew is asymptomatic.
2. All cases of air sickness must have centrifuge evaluation prior to reflighting.
3. All cases of episodic unconsciousness/G LOC in the air must be cleared on the HC before re-flighting.

4. Following head injury in flighter pilots, high-G stress must be given to bring out post head injury cognitive abnormalities. If any, Psychomotor tasks during SACM and Cog Screen-A after SACM would increase the confidence of the aircrew and the medical evaluation team.

5. Specific arrhythmias like VPC’s and SVT’s/ WPW syndrome after clearance from the concerned specialist should undergo G-stress with online ECG monitoring to see any abnormality.

Conclusion

Human centrifuge at IAM is used for aeromedical evaluation of aircrew at various stages of their disability. The reasons for which the centrifuge is used as an evaluation tool are varied and no system of the body is left untouched. A detailed account of the experiences for the last 27 years has been presented in this paper. The authors feel that the centrifuge has certainly had an important role in evaluation of spinal injuries, air sickness, cervicalgia/cervical spondylosis, lumbar spondylosis/ strain, PIVD, episodic unconsciousness/G-LOC in the air, low G-tolerance and low backache cases. However, its role in evaluation of other disabilities requires a larger study before any specific recommendation can be made.

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