Spinal Injury Pattern due to Ejections

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Introduction

Spinal injuries are usually associated with emergencies in flight, either emergency escape by ejection or crash landing. Incidence of these injuries is quite high in both these situations. The incidence is well known in the case of ejections but is variable and unpredictable in crash landings. However analysis of data of a large number of accidents shows an emerging pattern of these injuries. Knowledge of this pattern of injuries will be useful in early diagnosis, proper treatment, rehabilitation after treatment, and prevention of spinal injuries in future. Certain common factors in these injuries could be identified and the systems could be suitably modified to reduce the incidence and severity of the spinal injuries. This paper presents data with regard to the aircraft in use in IAF and compares it with the available information for other Air Forces.

Spinal fractures due to ejections

Every attempt is made by the ejection seat designers to keep the accelerative forces well within the human tolerance limits. But due to the various conflicting requirements of the operational envelope of the aircraft, where escape may be necessary at low altitude at low speed, high speed at low altitude or at very high altitudes, the systems have to be designed to impart high escape velocities in a few mili seconds. As such the jolt and peak g imposed by the seat is very near the human tolerance limits. This holds good under ideal operating conditions, but variations of ambient temperature, weight of the pilot, posture of the pilot, restraint used, attitude of the aircraft and compressibility characteristics of the survival pack and parachute, alter these conditions very largely. With all precautions the incidence of fractures of spine is around 20–25% of the survived ejections.

In the IAF (1957-72) Verma et al[20] have reported an incidence of 30% in survived ejections by 105 pilots, in various types of ejection seats. In a recent survey, in IAF (1973-77) we have found an incidence of 30% in 66 survived ejections, in different types of ejection seats. The combined data for these two studies for IAF shows an incidence of 30% for a total of 171 survived ejections. (Data given in Table I).

Table I
Injury Pattern in Ejections in IAF : (1957–1977)

Period		EJECTIONS			INJURIES AMONG SURVIVORS			
		Total ejected (R)	Survivors (S)	Killed (K)	Spinal injuries (SI)	Other injuries (OI)	No injuries (NI)	Total
1957–72	No	147	105	42	32	11	62	105
(Verma et al)	%	100.0	71.4	28.6	30.5	10.5	59.0	100.0
1973–77	No	69	66	3	20	31	15	66
	%	100.0	95.7	4.3	30.3	47.0	22.7	100.0
Total for	No	216	171	45	52	42	77	171
1957–77	%	100.0	79.2	20.8	30.1	24.6	45.0	100.0

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The incidence of spinal injuries reported by Jones et al[13] in 165 US Navy Aviators was 21% of the survived ejections, using gun type ejection seats. Fryer,[8] has reported an incidence of spinal fractures in 19% of 220 RAF ejections using similar seats. Hirsch[12] reported 25% incidence in 33 Swedish AF ejections, using a different seat. Shanon et al[19] in a USAF survey, report an incidence of 31% in non combat ejections and 25% of combat ejections.

The incidence of spinal fractures in IAF is higher than the reported figures for US Navy,[13] RAF[8] and Sweden.[12] But it compares well with non combat ejections in USAF, though not with the combat ejections in USAF.

Seats manufactured by various countries are in use in the IAF and some of them have shown disporportionately high incidence. The Hunter, Marut, Vampire, Kiran and Canberra use the gun type Martin Baker (M B) seats and these show a collective incidence of 38% in 52 ejections, (Table II). Recent data, quoted by Verghese[21] for Martin Baker seats is 50% incidence of spinal fractures in Hunters (12 ejections) and 40% in Lightening aircraft (25 ejections). Thus the figures for RAF are higher than our Air Force. The MIG aircraft using a Russian designed gun type ejection seat show an incidence of 32.5% in 37 ejections, on the other hand the Rocket seat in S 22 aircraft has an incidence of 44%. Gnats using a different (Folland) ejection seat have an incidence of 22%. Data quoted by Verghese[21] for Gnats in RAF shows an incidence of 27% in 22 aircraft ejections. The French designed seats used on Toofani and Mystere aircraft showed a combined incidence of 10% only.

Most of the M B seats, except in Vampire have a 80'/sec gun which imposes higher accelerations. In addition they have compressible survival packs in the seat pan. The Vampire seat had only 50'/sec gun,

TABLE II

Injury Pattern in IAF, Aircraft Wise, 1957–1977

Aircraft type	EJECTIONS					INJURIES AMONG SURVIVORS						
	Number			Percentages		Number				Percentages		
	R	S	K	S	K	SI	OI	NI	Total survival	SI	OI	NI
Hunter	42	30	12	71.4	28.6	10	5	15	30	33.3	16.7	58.0
Marut	8	7	1	87.5	12.5	3	3	1	7	42.9	42.9	14.2
Kiran	6	6	0	100	0	3	3	0	66	50.0	50	—
Canberra	4	2	2	50	50	2	0	0	2	28.6	—	71.4
Vampire	9	7	2	77.8	22.2	2	0	5	7	100	—	—
Total for M & B	69	52	17	76.8	23.2	20	11	21	52	38.4	21	40.6
MIG	44	37	7	84.1	15.9	12	14	11	37	32.5	37.8	29.9
S–22	32	25	7	78.1	21.9	11	7	7	25	44.0	28.0	28.0
Gnat	33	27	6	81.8	18.2	6	9	12	27	22.2	33.3	44.5
Mystere	22	21	1	95.4	4.6	3	—	18	21	14.3	—	85.7
Toofani	15	8	7	53.3	46.7	—	1	7	8	—	12.5	87.5
Total for French seats	37	29	8	78.3	21.7	3	1	25	29	9.6	3.2	87.2

Note: R — Total Ejected
S — Survivors
K — Killed
SI — Spinal injuries
OI — Other injuries
NI — No injuries

S-22 seats have an additional rocket pack. But both these seats have parachutes packed in the seat pan with a compressible survival pack also. Gnat has a 60'/sec gun and a rigid fibre glass survival pack. The Mystere and Toofani seats had a 56'/sec and 50'/sec guns respectively. These had much lower accelerations and lesser injury potential.

The likely factors which contribute to the higher incidence of spinal fractures in IAF are given below:

(*a*) Lack of adequate training to aircrew leading to:
  (*i*) Incorrect posture.
  (*ii*) Delayed ejections in a hurry.

(*b*) Spinal deformities of pilots not excluded by X-ray spine at entry.
(X-ray spine has been started in 1977 for all aircrew at entry in IAF).

(*c*) Low weight of pilots – high accelerations.

(*d*) High ambient temperatures – high accelerations.

(*e*) Seat pan adjustment for sitting height not carried out properly – improper alignment.

(*f*) Compressible survival packs and parachutes in seat pan.

Distribution of vertebral fractures

The vertebrae involved in the cases reported by Verma[20] et al are T_{12} 25%; L_1 24% and C_5 9%. Ewing[6] reports the peaks at T_{12} 14%; T_8 14.4%; T_9 12.9% and L_1 13.7%. Fryer[8] has reported maximum of 22.5% at T_{12} and 12.5% at L_1; and 12.5% at T_{10} with 11% at T_{11}. The incidence reported by Smiley[17] and Symeonides[19] et al for the RCAF and Greek AF shows the peak at T_{12} 25% and L_1 25%. Rotondo[4] found that the incidence was maximum around T_{12} (30%); and L_1 (21%) with distribution from T_4 to L_4. Our data for 32 fractures in 20 pilots shows the peak at T_{12} 25% and other high incidence T_{11} 18% and L_1 15%. The combined data for IAF for 52 pilots showing 87 fractures shows high incidence at T_{12} 25%; L_1 20.8% and T_{11} 12.7%. Another small peak is seen at C_5 5.8%. Combining the data from all these authors for a total of 374 fractures in 206 aircrew, (Fig. 1) the peak is at T_{12} 20.9%;

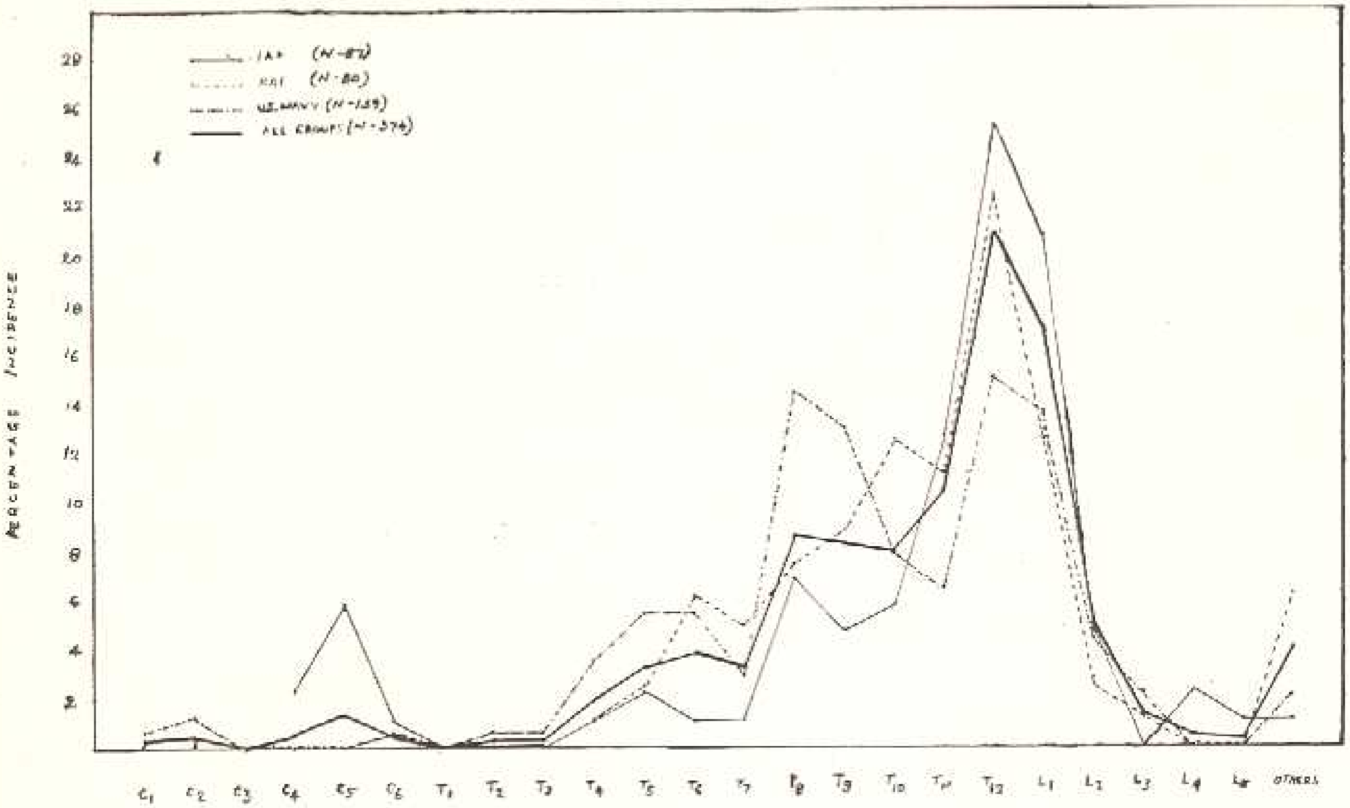

Fig. 1
Distribution of Vertebral Fractures for IAF (N = 87), RAF (N = 80), US Navy (N = 139) and Cobined data (N = 374).

L_1 17.1% and high incidence around T_{11}, T_{10}, T_9 and T_8 all at 8 to 10% of total fractures (Table III). From all this data, it is obvious that with gun type of ejection seats the commonest fractures are at the T_{12} and L_1 area with some cases above this level.

At the level of T_{12} spinal column has the smallest transverse width, is most movable and is acted upon by the greatest leverage. The breaking strength of various vertebrae as worked out by Ruff[15] and Stech[18] shows that the weakest area with high loads is at the T_{12} and L_1 vertebrae. (Table IV). It shows that the load at T_{12} and L_1 is 50% of body weight and the static G loading required to cause compression fractures is the least *i.e.*, 22.4G. The breaking strength under dynamic load conditions changes a lot, but the weakest area of the vertebral column is obviously at this hinge point.

The spine is least able to withstand compression loads, when flexed as the load is then concentrated on the anterior lips of the vertebrae. The centre of gravity of the upper trunk lies in front of the spine,

TABLE III

Spinal Injury Pattern in IAF, RAF, US NAVY, RCAF and GAF

	US Navy No.	%	RAF No.	%	IAF No.	%	RCAF and GAF No.	%	Total	%
C1	1	0.7							1	0.3
C2	2	1.4							2	0.5
C4					2	2.3			2	0.5
C5					5	5.8			5	1.3
C6	1	0.7			1	1.1			2	0.5
T2	1	0.7							1	0.3
T3	1	0.7							1	0.3
T4	5	3.6	1	1.2	1	1.1			7	1.9
T5	7	5.5	2	2.5	2	2.3	1	1.4	12	3.2
T6	7	5.5	5	6.2	1	1.1	1	1.4	14	3.8
T7	4	2.9	4	5.0	1	1.1	3	4.4	12	3.2
T8	20	14.4	6	7.5	6	6.9	Nil		32	8.6
T9	18	12.9	7	8.6	4	4.6	2	2.9	31	8.3
T10	11	7.9	10	12.5	5	5.8	4	5.8	30	8.0
T11	9	6.5	9	11.2	11	12.7	18	14.7	39	10.4
T12	21	15.1	18	22.5	22	25.3	17	25.0	78	20.9
L1	19	13.7	10	12.5	18	20.8	17	25.0	64	17.1
L2	6	4.3	2	3.5	4	4.6	6	8.8	18	4.8
L3	3	2.2	1	1.2	—	—	1	1.4	5	1.3
L4	—	—	—	—	2	2.3	—	—	1	0.5
L5			—	—	1	1.1	—	—	1	0.3
Others	3	2.1	5	6.2	1	1.1	6	8.6	15	4.0
Total fractures	139	100.8	80	99.9	87	99.9	68	99.6	374	100.00
Total Pilots	78		40		52		36		206	

IAF — Indian Air Force, RAF — Royal Air Force UK, US Navy — United States Navy, RCAF — Royal Canadian Air Force, GAF — Greek Air Force.

TABLE IV

Breaking Strength of Human Vertebrae

Vertebrae	% body weight carried	Weight carried 160 lb man in pounds	Breaking strength in pounds	Breaking load in G
T1	9	14.4	360	25
T2	12	19.2	400	25
T3	15	24.0	600	25
T4	18	28.8	720	25
T5	21	33.6	840	25
T6	25	40.0	1000	25
T7	29	46.4	1160	25
T8	33	52.8	1315	24.9
T9	37	59.2	1493	25.2
T10	40	64.0	1632	25.5
T11	44	70.4	1700	24.2
T12	47	75.2	1757	23.4
L1	50	80.0	1790	22.4
L2	53	84.8	1925	22.7
L3	56	89.6	2161	24.1
L4	58	92.8	2168	23.4
L5	60	96.0	2366	24.6

at the manubrium sterni[9] (Fig. 2) and as such a bending moment will always be applied to the spine during ejection. Any factor which leads to loads being applied at an angle to the long axis of the spine will thus tend to increase the risk of fracture. A loose shoulder harness allows greater forward flexion of the trunk to take place during ejection. Inadvertent and unprepared ejections are more likely to be initiated with a loose shoulder harness, and have more often led to compression fractures at T_{12}, L_1 region. An additional factor is the presence of the included angle between the line of thrust and the long axis of the spine (Fig. 2). Such an included angle imposes an increased forward thrust on the upper part of the torso on ejection. With adequate head restraint and a good harness, included angles upto 18° can be permitted.

Correct alignment of the spine can be achieved by accurate contouring of the back rest in order to support the normal spinal curvatures and also by shaping the upper surface of the seat pack so that the lower end of the spine is kept well back in the seat pan. Such a position is most comfortable also (Fig. 3). Ewing[9] suggests that hyperextension at

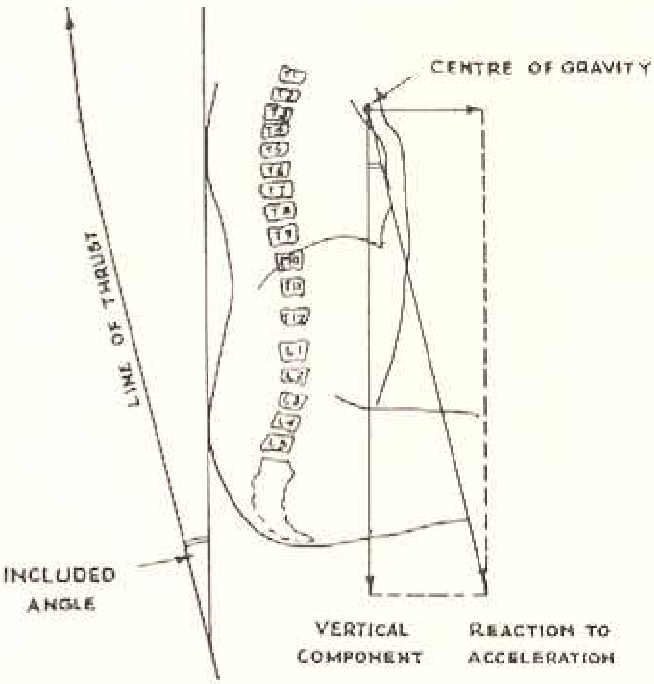

Fig. 2

The included angle between the line of thrust and the back of the subject, showing the forces acting about the centre of gravity of the upper part of the body. As the included angle increases, so will the magnitude of the force tending to flex the spine also increase.

the level of L_1 by use of a 6" x 4" x $2\frac{1}{4}$" wooden block (back pad) will reduce the incidence of compression fractures. His contention is that much higher acceleration loads are required to cause fracture in hyperextension than in erect posture or the flexed posture.

Fractures of the vertebral bodies, injury to the vertebral end plates and intervertebral discs are often missed. Henzel[11] has expressed the view that end plate damage can occur at lower accelerations than fractures of the vertebral bodies. In follow up of ejectees, this injury and its sequalae have to be kept in mind, so that such cases are not missed altogether.

The high incidence (5.8%) of fractures at C_1 and C_2, seen in the IAF data, needs special mention. These fractures have been reported mainly from Gnat aircraft. In the Gnat, pilots with large sitting height and short pilots opting to sit very high in the seat, suffer the cervical fractures. This is caused

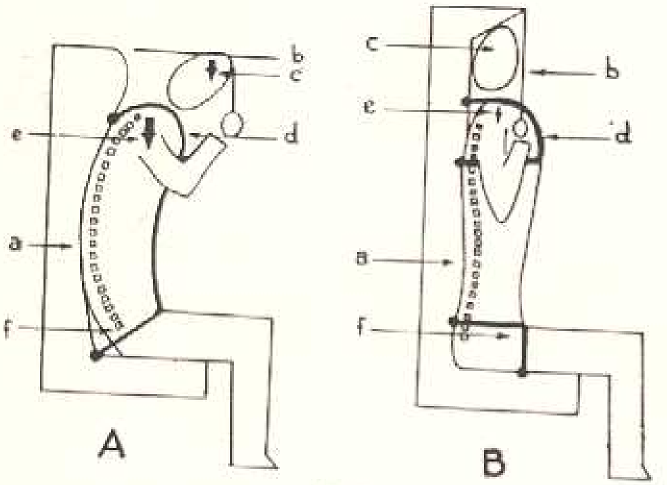

Fig. 3

A. Unsatisfactory Seat: (a) poor seat back contour; (b) face curtain induced flexion; (c) face curtain induced force; (d) poor harness restraint system resulting in induced flexion; (e) harness restraint induced force; (f) "submarining" permitted by poor harness restraint system.

B. Improved Seat: (a) improved back contour; (b) proper face curtain; (c) no vertical face curtain induced force; (d) reduced shoulder harness flexion; (e) reduced shoulder harness force; (f) adequate lower torso restraint.

by neck flexion, induced by the overhead firing handle, bringing the face blind over the bone dome and causing neck flexion.

Conclusions

Incidence of spinal injury in successful ejections in IAF is higher than other Air Forces. Factors contributing to these have been enumerated and highlighted. Incidence of spinal injury in crash landings is not very high, in view of the few successful crash landings possible in modern aircraft.

The distribution of spinal fractures due to ejections and crash landings is around T_{10} to L_1 area as seen by most other workers.

Recommendations

(*a*) Adequate training of aircrew on the ground and ejection seat towers is necessary to reduce the spinal injury.

(*b*) Seat design to be improved, to reduce the Gz loads and the jolt factor.

(*c*) Harness/restraint system to be so designed as to prevent flexion.

(*d*) Pilots to fly and eject only with tight harnesses.

(*e*) Proper posture of hyperextension of spine to be maintained to reduce spinal fractures by proper design of seat back contour.

(*f*) Proper design of face blind to avoid neck flexion.

(*g*) Proper helmets to prevent flexion of spine.

(*h*) The included angle should be as small as possible.

(*j*) Proper packing of parachutes and survival packs to avoid compressibility effects.

(*k*) Proper adjustment of seat pan for the sitting height of the pilots.

(*l*) Pre-selection of aircrew after X-ray spine, to eliminate spinal deformities.

(*m*) Indoctrinate pilots to eject in time — Avoid delayed ejections.

(*n*) Follow-up of pilots after ejection and crash landing for early diagnosis and treatment.

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