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DEPARTMENT OF MOTOR TRANSPORT N.S.W.

ANATOMICAL FACTORS IN LAP/SASH SEAT BELT WEARING

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The Traffic Accident Research Unit was established within the Department of Motor Transport, New South Wales, in May 1969 to provide a scientific approach to the traffic accident problem.

This paper is one of a number which report the results of research work undertaken by the Unit's team of medical, statistical, engineering and other scientists and is published for the information of all those interested in the prevention of traffic accidents and the amelioration of their effects.

W Butler

Commissioner.

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ABSTRACT

The compulsory use of lap/sash seat belts has improved crash protection of car occupants but belts do not always provide absolute protection and, although they assist in prevention of severe injury to head and thorax, they can produce other injuries in some crashes.

An investigation of anatomical aspects of lap strap fit is reported. Radiographic techniques were employed to determine the relative dispositions of the bony pelvic structure and of the seat belt. Examinations of surface anatomy were used to demonstrate the effects of changes in seat belt geometry.

It is concluded that lap strap fit can be assessed from surface anatomy by a simple technique; that the most satisfactory seat belt geometry requires a lap strap to be steeply inclined when viewed from the side; that the existing ADR specification of seat belt geometry should be revised on the basis of locations of anatomical landmarks.

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INTRODUCTION

Most Australians wear lap/sash seat belts whenever they travel by car and the effectiveness of such belts in reduction of crash injuries is well established[1,2]. The protection afforded by lap/sash seat belts is not absolute however, since some wearers are known to be killed or injured in crashes of moderate severity[3,4]. One way in which this happens is by impact against the car's interior surfaces[5,6].

The seat belt itself can be a cause of injury if incorrectly worn although the severity of belt induced injuries should not be accepted necessarily as comparable to the injuries which occur when occupants are unrestrained. A locally based in-depth study of 135 fatally injured seat belt wearers indicated that 15 sustained abdominal injury attributable to seat belt forces and that these injuries were the probable cause of death in 8 cases[3]. Most injuries were to abdominal organs and were caused by the lap strap; in some cases the seat belt was worn very loosely and in some the subjects were elderly. The recent introduction of emergency locking retractors in front-mounted lap/sash seat belts should eliminate some of the injuries due to excessive slack, but rear installed lap sash belts are still of the manually adjusted type and are also thought to have the least satisfactory anchorage geometry. There is no reason to suppose that elderly occupants are more susceptible to abdominal injury because of anatomical peculiarities; rather, it is probable that these subjects wear their belts loosely and high on the body for reasons of comfort. Therefore it is probable that seat belt injuries are attributable mainly to poor anchorage geometry, particularly that of the lap strap.

Mackay et al[7] examined a sample of 82 car crashes in Britain comprising 108 front seated seat belt wearers. All belts were lap/sash type except for two sash-only cases. The criterion for inclusion in the study was that an occupant had sustained injuries rating at least 2 on the Abbreviated Injury Scale[8]. Thirty of the subjects suffered belt induced injury and causes could be determined for 16 of these. In 4 cases the belt was worn loosely, in 7 cases it was positioned incorrectly and the remaining 5 cases were of rear loading by other car occupants. The vehicles in that study would not have differed significantly from Australian cars in their seat belt geometry and in Britain at the time of the survey, seat belt use was voluntary; thus it might be argued that the belts were adjusted more carefully than would have been the case in a compulsory use environment. Nevertheless the proportion of belt-induced injuries was large.

The objective of the project reported here was to examine the anatomical basis of the fit of the lap strap portion of lap/sash seat belts. Sash strap fit was not considered, nor was the deflection of the lap strap by the sash. This latter problem is readily demonstrable and will be eliminated progressively as the use of rigidly-mounted buckles becomes more widespread. Optimum sash belt geometry has been discussed in some depth by Searle[9], Herbert and Leitis[10] and by Hoffman[11].

Buckle location for ease of access was investigated by Herbert and Corben[12].

LAP STRAP GEOMETRY IN MODERN CARS

Development of the lap/sash seat belt has produced a design in which the lap strap applies pressure downwards and rearwards on the thighs and hips of the wearer. In Australian cars the sideview inclination of the lap strap usually is found to be about 65° from the horizontal for a front bucket seated occupant of average stature; this angle is not as great in rear seating positions nor when a front seat is a bench type.

Reference to the literature revealed that side-view inclination of the lap strap was thought by some researchers to be an influential factor in the correct fit of seat belts[5,13,14,15,16]. Traditionally it was suggested that an optimum angle would be 45°[17,18], but in recent years, angles of the order of 60° have been proposed[5,14,15,16].

Seat belt geometry is controlled by Australian Design Rule number 5B[19]. The Rule places limits on the side-view inclination of straight lines drawn from each lap strap anchorage to any point on a pelvis reference locus*; these lines appear to approximate the centre line of

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* The Pelvis Reference Locus is defined in ADR 5B as the locus of a point fixed relative to the seat, coincident with the pelvis reference point when the seat is in rearmost design position and extending over the design driving or riding range of seat travel.

The Pelvis Reference Point is a point used in simulating the correct position of a lap strap or the lap strap of a lap/sash belt. It is the point which is located at a height of 95mm above and 70mm forward of the Seating Reference Point.

The Seating Reference Point is the manufacturer's design reference point which:

a. establishes the rearmost normal design driving or riding position for each designated seating position in a vehicle;
b. has co-ordinates established relative to the design vehicle structure;
c. simulates the position of the pivot centre of human torso and thigh, and;
d. is the reference point ('H' Point) employed to position the two dimensional templates described in SAE Standard J826a[20].

(Definitions taken from Australian Design Rules).

the lap strap for an average male wearer and the limits of inclination are not less than 25° and not more than 80° from the horizontal. This requirement is in broad agreement with legislated requirements in other countries[21,22,23].

The anatomical data, upon which most legislation was based, appear to have been sparse. Australian and American rules, for instance, are based on radiographic data reported by Geoffrey[24]. No other fundamental data were located relating to static or dynamic relationships between a seat belt and the wearer.

Although particular aspects of lap strap geometry may be considered desirable, in practice either engineering or anatomical considerations may preclude their implementation. Typical of these are: obstruction of the natural belt alignment by the seat; lack of structural strength in preferred anchorage locations; the range of wearer anthropometry. It is possible to eliminate these factors from an experimental project but they cannot be excluded necessarily from production vehicles. In order to establish an experimental technique for evaluation of seat belt fit it is necessary to consider functional requirements.

A seat belt should restrain its wearer by the application of forces, within the range of human tolerance, to those parts of the anatomy which can best resist and distribute them. A lap strap thus should load the bony structure of the pelvis and the most suitable location is the antero-lateral border, the bony ridge on each side between the anterior superior iliac spine and the anterior inferior iliac spine. The lap strap need not always be worn in the precise location required for application of crash forces but should be configured so that any such application will cause it to move into its optimum loading position. The lap strap must not be allowed to apply forces above the iliac spines at any time if abdominal injury is to be avoided.

A lap strap position satisfactory for normal use is on the upper surface of the thighs; the correctly adjusted strap should then be in its minimum path configuration. In the event of a crash the strap should drag rearwards, relative to the wearer, until it reaches the pelvic borders at the intersection of thigh and pelvis. During this sequence, the side view strap inclination will decrease and allowance must be made for this change in geometry during design of a seat belt installation. Other factors affecting geometry are the range of occupant anthropometry, the range of seat adjustment and seat cushion compression.

ANATOMY OF THE PELVIC REGION

It must be recognised that although crash forces should desirably be transmitted to the pelvic bone structure, the belt is unlikely to displace the overlying tissues and assume close contact with the pelvis. The seat belt forces thus have to be applied through an unstable layer of fatty tissue and musculature.

The anatomy of the human pelvis is well known, but anatomical relationships in the seated position are not well documented and the disposition of seat belt and pelvis has not been established athough it is often assumed[13,15]. Although anatomy is readily defined in some pelvic areas, the bony outline of the pelvis inferior to the anterior superior iliac spine (ASIS), is not. The region which transmits belt loads is obscured by musculature and fat in the lower abdomen and the thighs. The upper surfaces of the thighs generally intersect the pelvic borders just below the anterior superior iliac spines leaving a small area on each side of the body which can satisfactorily sustain the lap strap forces. This area is illustrated in Figure 1. The choice of seat belt geometry must be made with this restricted contact area in mind.

Some data relating to anatomy of the seated position are available in the literature[25,26,27,28,29], but an independent investigation was also found to be necessary. Figure 2 was prepared from examinations of dissected specimens and from reference to standard texts. Figure 2 shows that the area inferior to the ASIS is bridged beneath the

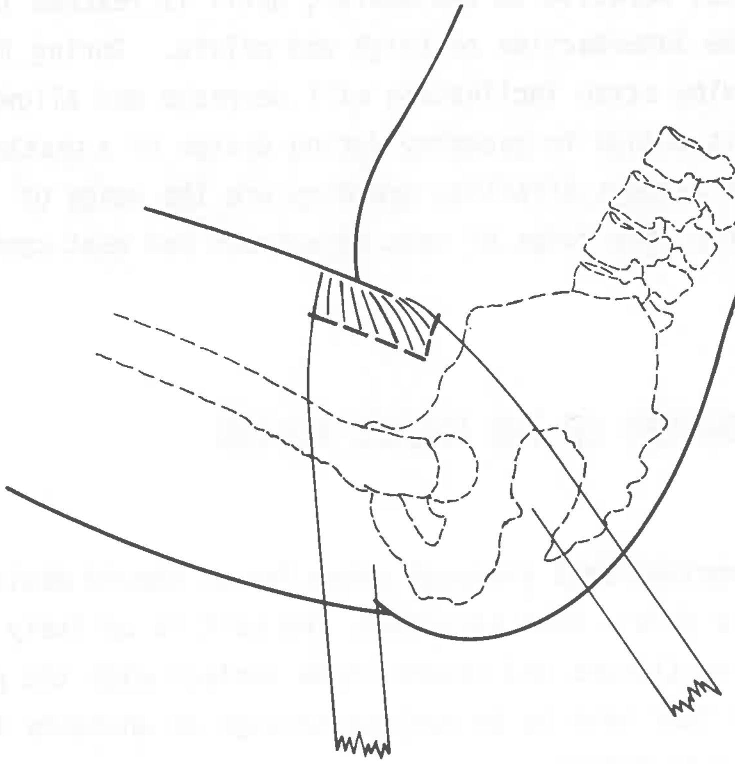

FIGURE 1: Lap strap loading areas

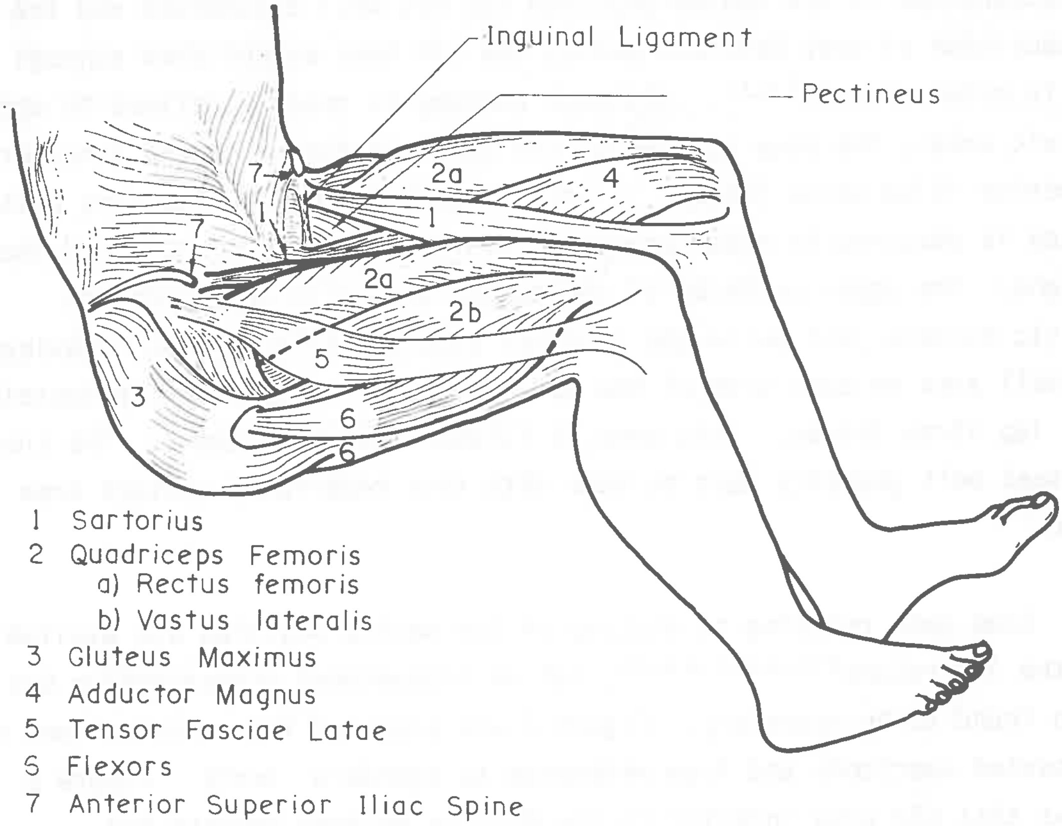

FIGURE 2: Anatomy of the seated position

superficial tissues medially by a band of fibrous tissue, the inguinal ligament. Between this ligament and the underlying pelvis is a layer of muscles, the iliopsoas, running over the pelvic border from within the pelvis to the femur. The major muscle mass of the thigh is the quadriceps femoris and its most superficial section, the rectus femoris, attaches partially to the anterior inferior iliac spine (the AIIS). Running over this medially from the ASIS is the sartorius.

The ASIS protrudes from the main pelvic outline; it, and the greater trochanter of the femur, are located easily by surface examination, but the pelvic border inferior to the ASIS cannot be palpated readily. It seemed that an accurate assessment of the belt/pelvis relationship required radiographic techniques.

RADIOGRAPHIC INVESTIGATION

Ten male subjects were x-rayed in the seated position. Selection of subjects was made on the basis of mass and stature in such a way as to cover a range of male anthropometry; this met with only limited success since the number of potential subjects was small (only medical students were sought as volunteers in order to obtain informed consent to radiography).

Each subject was seated on a rigid wooden seat having proportions representing a single car seat. A simple lap strap was worn and was adjusted to a minimum path length around the wearer's body. The edges of the seat and of the lap strap were marked by radio-opaque tracers and a marker was affixed to the wearer's body at the location of the ASIS. Gonadal protection was provided.

The side view inclination of the lap strap could be altered by selection of predetermined anchorage locations. It was anticipated that the inclination at a particular anchorage setting would vary between subjects and therefore all lap strap angles recorded in the radiographic investigation were those actually measured. The seat's backrest inclination was adjustable by means of a hinged pivot point at its lower end. Seat back angle was set by direct measurement.

In each case the x-ray apparatus was focussed laterally on the subject's ASIS; the first four subjects constituted a pilot sample and only one exposure was made of each; the remaining six subjects were each subjected to two exposures with intervening change of lap strap angle or seat back inclination. A lateral photograph was taken at the same time as each x-ray exposure. Subsequent to processing of the x-ray plates and photographs, pelvis, seat and belt were delineated and the relationships examined. Figure 3 shows the delineated pelvis superimposed on the corresponding photograph of a seated subject. Radiographic data are summarised in Table 1 (p.28).

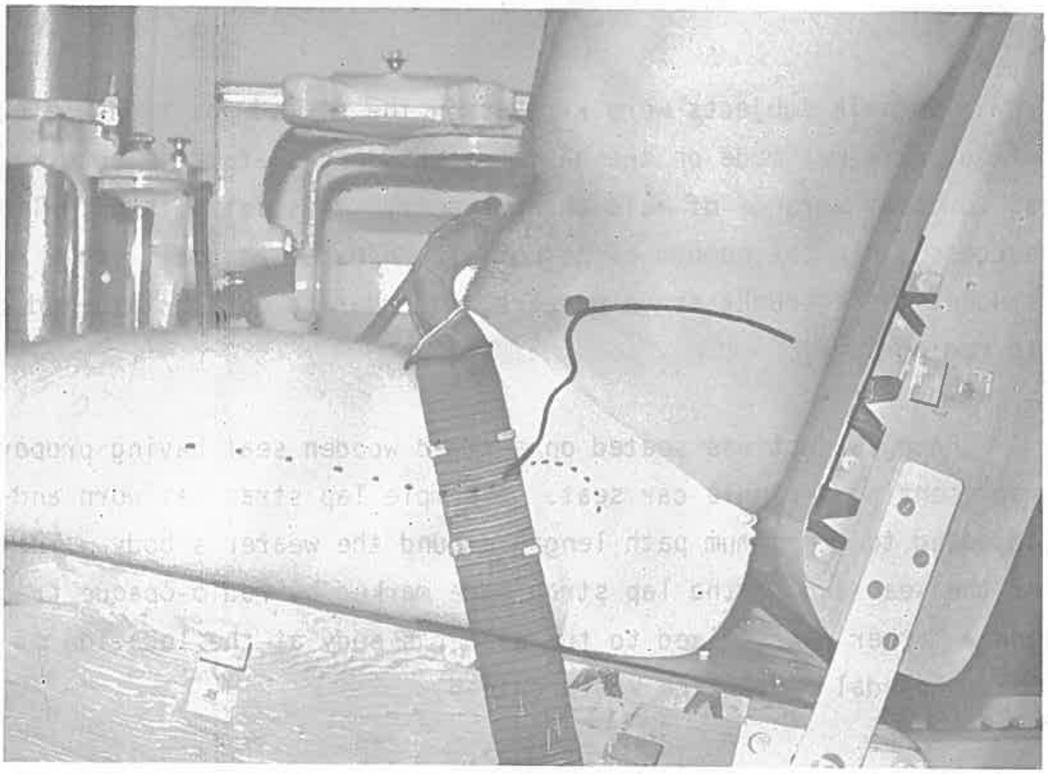

FIGURE 3: Result typical of radiographic investigation

RESULTS OF RADIOGRAPHY

Examination of the radiographic data indicated that, in the normally seated position, the pelvic border between ASIS and AIIS could be approximated by a line drawn from the ASIS to the greater trochanter of the femur. This relationship was maintained over the range of subjects and seating positions examined.

The line from ASIS to greater trochanter was nominated as the "pelvic reference line" (PRL); the angle between this line and the horizontal was designated as the "pelvis inclination". These terms and others are illustrated in Figure 4.

The radiographic investigation presented in Table 1 (p.28) indicated that pelvis inclination was approximately equal to the back-rest angle of the wooden seat. This relationship was thought to be useful in that it permitted estimation of the PRL in cases where the greater trochanter was difficult to palpate. Figure 5 illustrates the observed relationships.

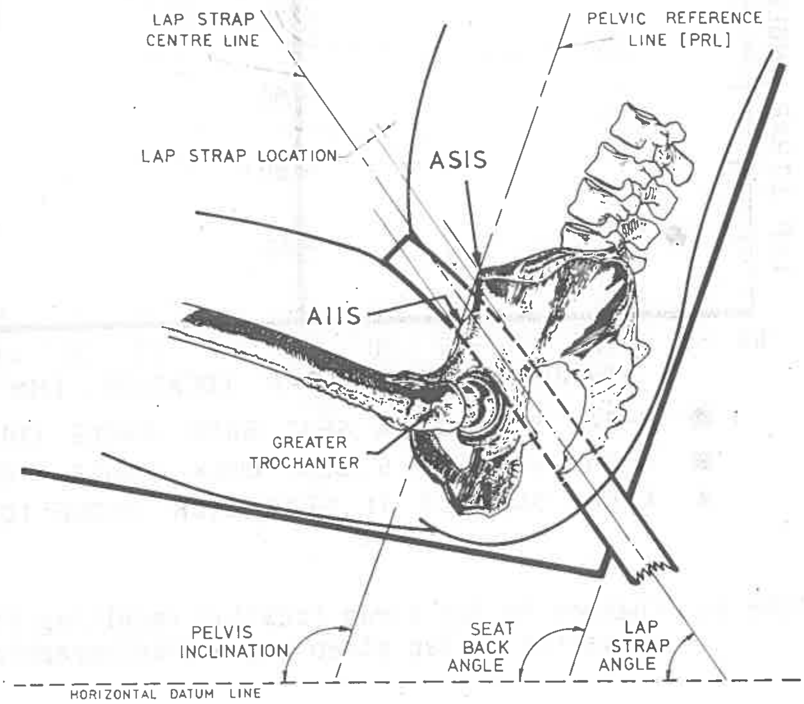

FIGURE 4: Illustration of terms used relating to seat belt fit on pelvis

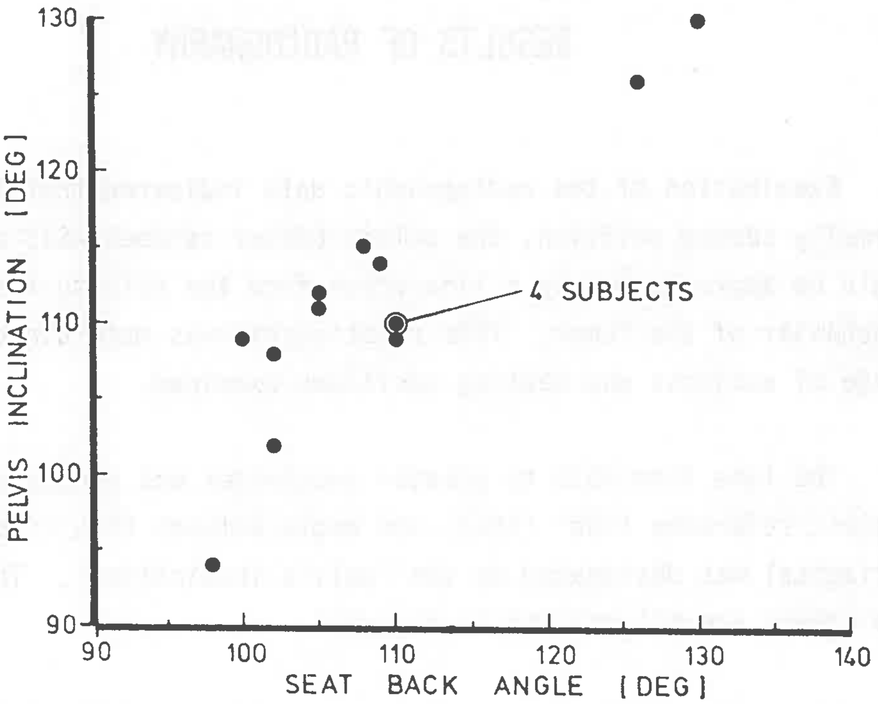

FIGURE 5: Relationship of pelvis inclination and seat back angle on wooden seat (all subjects)

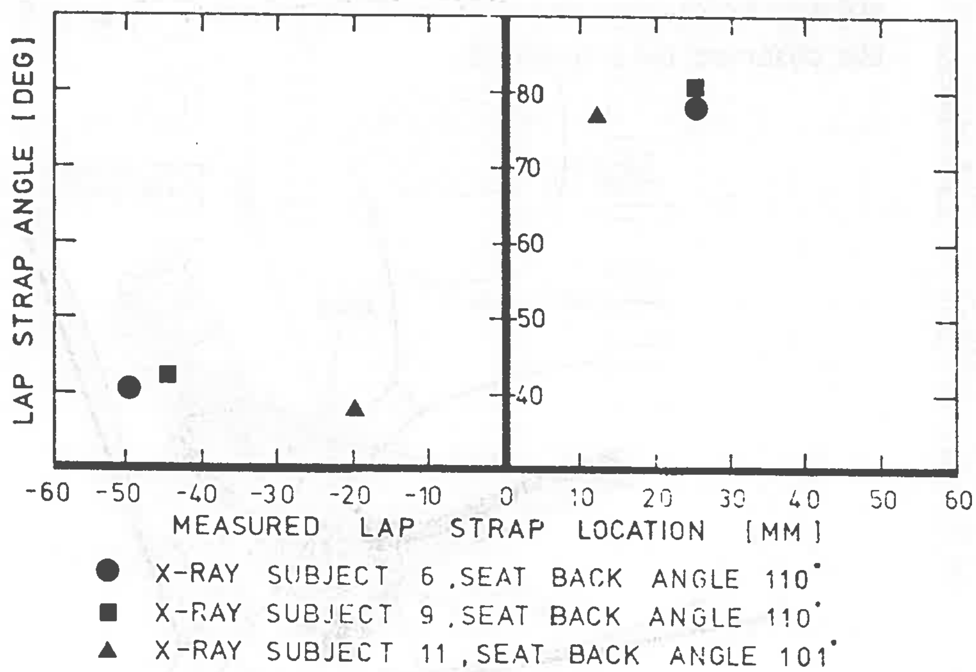

FIGURE 6: Changes in lap strap location resulting from variation of lap strap angle (Radiographic examination)

In the cases where lap strap or seat back angles were changed, the resulting changes in seat belt fit were examined. "Lap strap location" was defined as the projected distance, in side view, from the upper edge of the seat belt lap strap to the ASIS of the subject; the measurement was made in a direction normal to the belt's centre-line. Where the ASIS was above the edge of the strap, lap strap location was nominated as positive; when ASIS was below the edge, lap strap location was nominated as negative.

It was found that improvements in lap strap location, that is, positive increments, were associated with increases in side view lap strap angle and also with upright seat back angles. Such relationships could be regarded as no more than indications since only two measurements were made with each subject.

The change in lap strap location with lap strap angle is shown in Figure 6. The effect on belt location of changes in seat back angle is shown in Figure 7.

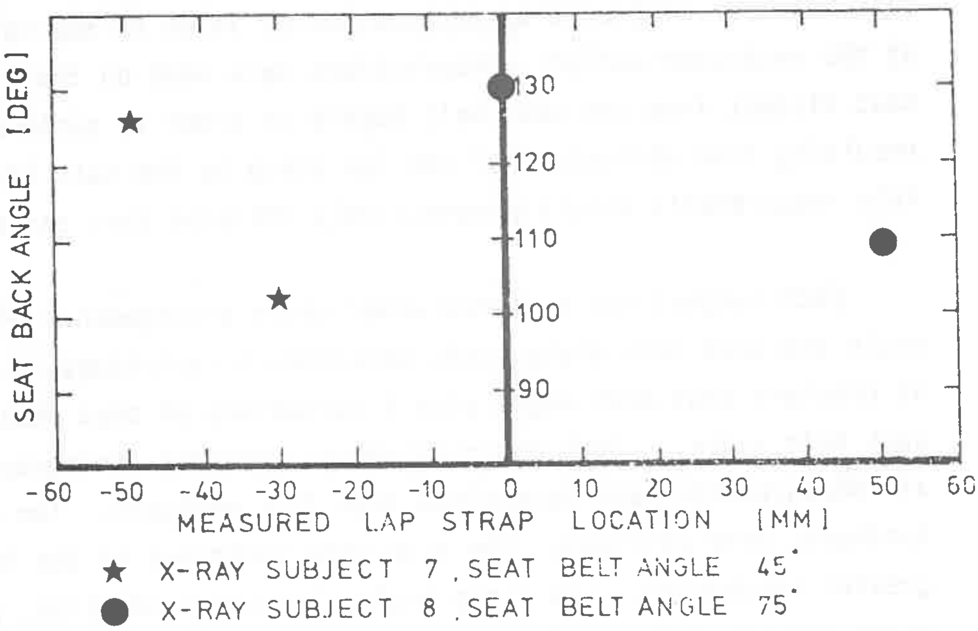

FIGURE 7: Changes in lap strap location resulting from variation of seat back angle (Radiographic Examination)

In view of the observation that the pelvic reference line could be estimated from the locations of the ASIS and greater trochanter, it was possible to measure the effects of changes in seat and seat belt geometries in detail without further recourse to radiography. Accordingly, further investigations of surface anatomy were commenced.

INVESTIGATION BY SURFACE ANATOMY

Thirteen male subjects were selected from staff members' of the Unit on the basis of mass and stature in order to obtain the widest possible range of anthropometry. Each subject was seated in an upholstered bucket seat from a production car and wore a lap/sash seat belt which incorporated an emergency locking retractor on the sash strap. The seat belt was secured around each subject by one of the researchers and the same procedure was followed in every case; the belt was withdrawn from the retractor and held with the lap strap at 45° from the horizontal, it was then wrapped around the subject in one motion so that the buckle tongue moved directly to the buckle, the belt was then tightened by application of force to the vertical strap at the retractor outlet. Observations were made on the side of the seat distant from the seat belt buckle in order to avoid any difficulties resulting from deflection of the lap strap by the sash (Australian Design Rule requirements should progressively minimise this deflection).

Each subject was examined under seven arrangements of seat belt angle and seat back angle; this permitted 4 variations of belt angle at constant seat back angle plus 4 variations of seat back at constant seat belt angle. Each observation was recorded photographically and all measurements were determined from film analysis. Two anatomical landmarks were utilised: the side view locations of the ASIS and greater trochanter. Lap strap angle, lap strap location, pelvic inclination and the distance from ASIS to greater trochanter were determined subsequently from the photographic record. Seat back inclination was preset by direct measurement, the reported figure being the nominal angle for the unoccupied seat.The profile of the compressed seat back did not appear to vary with its inclination and thus any relationship between pelvis inclination and seat back inclination should have been maintained. The inclination of the lap strap was varied by selection of any one of four preset anchorage locations. These locations were chosen by use of a test device representing the 50th percentile American male and with this device lap strap angles of 30°, 50°, 65° and 80° were obtained; these were referred to as the "nominal" lap strap angles. It was anticipated that lap strap angle would vary according to the physical characteristics of the individual subjects examined so all lap strap angles which were recorded with human subjects were referred to as "measured" lap strap angles. All subjects wore their belts in a minimum path location on the body. The anthropometric data recorded during the investigation of surface anatomy are presented in Table 2 (p. 29), examination results are presented in Table 3 (p.30).

SURFACE ANATOMY RESULTS

Examination of surface anatomy confirmed the indications of radiography that positive values of lap strap location were associated with steeply inclined lap straps. However the relationship between backrest inclination and lap strap location established for a hard seat was not maintained in the upholstered seat.

Figure 8 presents ASIS location relative to the car seat for the thirteen subjects of external examination at a seat back inclination of 115°. Figure 8 is drawn full size and the range is compared with a range of ASIS locations recorded by Herbert and Corben [30] who measured ASIS location for 130 subjects using the same seat as that used in this project. It is notable that although both ranges of ASIS locations were small, they did not coincide. This discrepancy is attributed to the difference of experimental techniques; our subjects were seated carefully in a controlled posture with their buttocks well back on the seat; the subjects observed by Herbert and Corben were not so restricted and adopted a seated posture which presumably was affected by tasks which they were required to perform (and which were the main objective of that project). Another reason for the discrepancy is the difference

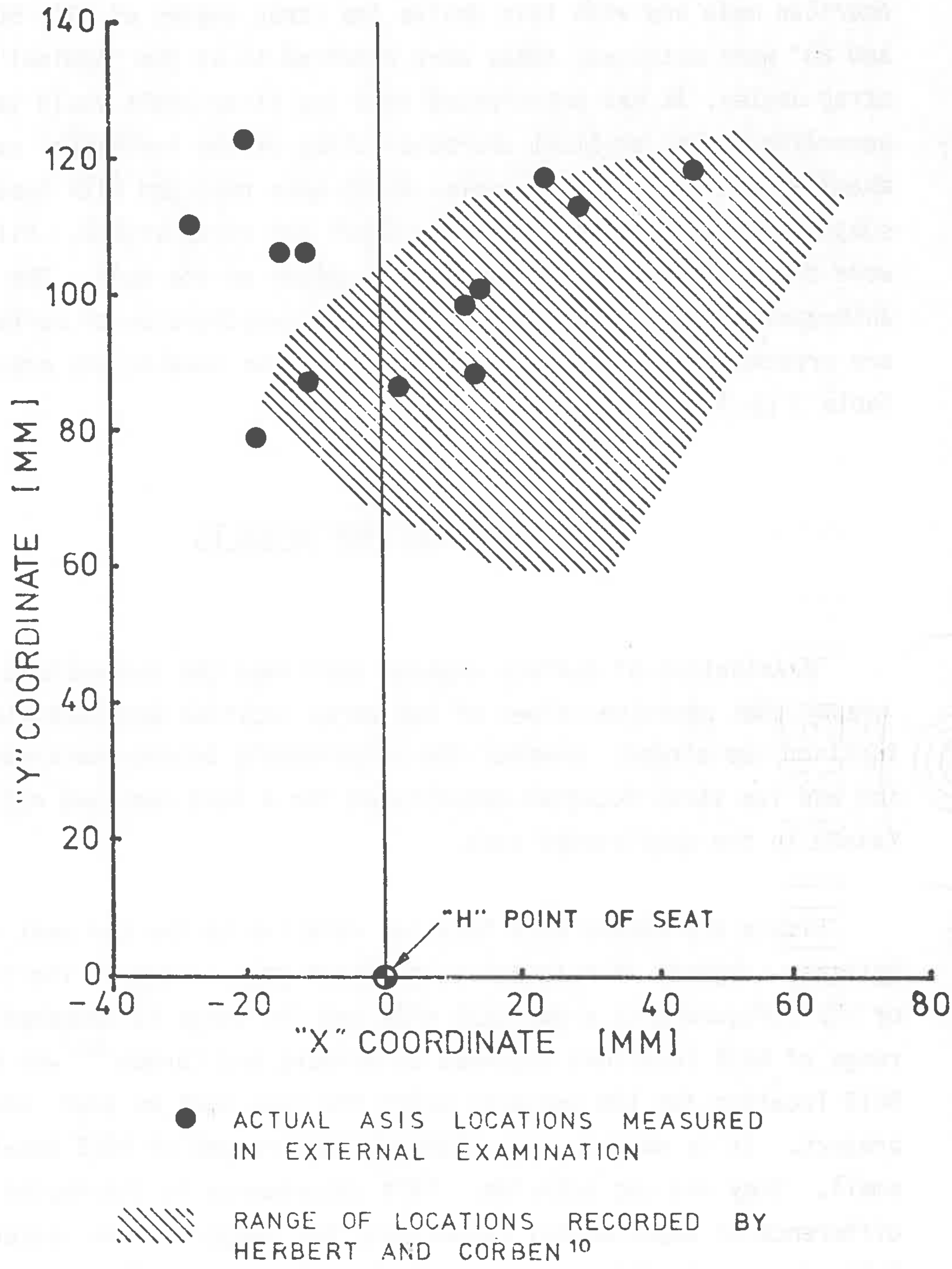

FIGURE 8: Comparison of ASIS locations

between the subjects; our subjects were young males selected in order to demonstrate extremes of anthropometry; the subjects utilised by Herbert and Corben were sampled in a random manner from 3000 Head Office employees of the N.S.W. Department of Motor Transport, they comprised both sexes and no age restriction was applied. Taking into account these basic differences between subject groups, the ranges of the two sets of ASIS locations were thought to be comparable. The radiographic survey subjects could not be included in the comparison because their seating system was different.

Appendix 1 presents individual plots of the relationship of lap strap angle and lap strap location at constant seat back angle. In general, it was evident that steeply-inclined lap straps were associated with large positive values of belt location for all subjects. Negative or small positive values were associated with relatively shallow inclinations.

Some clustering of points was observed in the plots of Appendix 1, particularly at steep lap strap angles. This is explained by consideration of the actually measured strap angles; in a number of cases, change of lap strap anchorages from the 65° position to the 80° position did not produce a proportionate variation in the measured angle. In practice, nominal 65° angles measured from 58° to 78° and nominal 80° angles from 69° to 78° . At these steep angles, small variations in anthropometry appeared to result in large changes in lap strap angle.

An attempt was made to relate pelvis inclination to belt location, assuming that the pelvis was tilted by seat back inclination as was suggested by results of the radiographic survey. In this case however the pelvis was seen to remain essentially upright over the chosen range of seat back angles. This is demonstrated by the figures in Appendix 2 where lap strap location is plotted against seat back angle. This lack of correlation was attributed to the difference in seat structures; the rigid seat required that the subject's spinal column be flat against the backrest whereas in the cushioned seat, some lumbar support was provided which became more pronounced as the seat back reclined and subjects conformed to the inclined backrest by bending of the lumbar spine with only slight tilting of the pelvis.

An attempt was also made to relate lap strap location to anthropometric factors. This was not successful, probably because of the small number of subjects and the overrepresentation of extreme anthropometry with few average subjects sampled. It appeared that lap strap location was most satisfactory for tall subjects of slender build although one of these consistently returned negative values for all variations of lap strap angle. Heavily built subjects generally had low values of lap strap location indicating that the lap strap lay close to the top of the pelvis but two of these had high values which resulted from forward displacement of the belt by abdominal obesity. Appendix 3 presents plots of lap strap location against mass per unit stature for all subjects at four lap strap angles. No relationship was determinable from these figures but it was notable that the number of positive lap strap locations in the sample increased as seat belt angle became steeper. When nominal seat belt angle was 30° there was one positive belt location in a sample of 13; this rose to 2 in 13 at 45°, 10 in 13 at 65° and 10 in 12 at 80°.

DISCUSSION OF RESULTS

Radiography indicated that the lap strap did not locate firmly on or near the pelvis under normal wearing conditions. In most cases, the thickness of the subject's thighs, in combination with abdominal tissues, caused the belt to rest at about the level of the ASIS and somewhat forward of it. A steep lap strap angle appeared to improve the lap strap location relative to the ASIS and this suggested definite relationships between seat belt geometry and belt location. The factor having the most direct effect on lap strap fit appeared to be lap strap side view angle; seat back angle did not appear to be as important since inclination of a cushioned seat back did not result in a corresponding inclination of the pelvis. The suitable lap strap contact areas were seen to be quite small as shown by Figure 1 (p.10) and the associated discussion. In a given seat, the locations of these areas did not appear to vary relative to a fixed datum as can be surmised from Figure 8 (p 18).

ASIS location may be preferable to the ADR 5B Pelvis Reference Point as an anatomical landmark for use in specification of seat belt geometry. If the lap strap were required to locate below the worst case ASIS location in normal use and geometric requirements were met, it is probable that crash protection would be enhanced. The restricted range of ASIS locations also suggests that it is longitudinal seat adjustment (which allows for car occupant leg length) that necessitates the large range of permitted strap geometry is most legislation; if lap straps were attached to the relevant seat structure rather than to the car floor then the permitted limits of strap angle could be restricted substantially, with beneficial effects for seat belt wearers.

The lack of variation of pelvis inclination with backrest inclination was significant in that it appeared that the use of reclined seats might not necessarily be associated with poor lap strap fit; however upright seating position seemed to be associated with good lap strap location in general. Verification by crash simulation is required in this area. It should be noted that all subjects were seated with their buttocks against the seat back. Under normal circumstances in a reclined seat, a car passenger would be expected to sit with his buttocks forward of the position selected in this project. Such a position could allow more pelvis inclination and would be degrading for lap strap location on the basis of reduced lap strap angle.

The work described in this report relates to seat belts in the normal (non-crash) situation. It is possible to predict some aspects of seat belt behaviour in a crash on the basis of crash simulation experience, field observations and basic mechanical principles. Ultimately, however, these predictions can only be proven by crash tests, preferably making use of human subjects. Such tests need not be of great severity since the main interest occurs in the initial crash phase as the belt moves into its optimum loading position; tolerance to peak restraint forces is not involved. The Unit is not yet equipped to undertake such tests.

SUMMARY

Anatomical investigations, using x-ray techniques and surface anatomy, indicate that seat belt lap strap fit is directly related to the angle of the strap viewed from the side. Steeply inclined lap straps can be adjusted low down on the wearer's thighs so that in a crash, the belt force will be applied to the massive bony structure of the pelvis. Shallow angled lap straps adopt a natural position across the wearer's stomach where crash loading can result in severe internal injuries. Seat back adjustment did not appear to affect lap strap fit under the closely controlled conditions of the study.

The most significant anatomical point for assessment of lap strap fit is the anterior superior iliac spine, the prominent bone on each side of the hip. The location of this point relative to the car seat was found to be quite insensitive to the size or shape of the seat's occupant. Seat belt lap straps generally are anchored to the car's floor and thus the belt angle varies according to the seat adjustment. An improvement could be made in lap strap fit if the belt were anchored to the seat frame. Some cars already have such installations without any apparent cost penalty.

CONCLUSIONS

1. Assessment of a seat belt's lap strap fit in the pelvic region is readily made by observation of surface anatomy. The use of radiography is of value in the establishment of basic anatomical relationships.

2. Shallow lap straps, permitted by Australian Design Rules, are associated with unsatisfactory fit. The permitted minimum angle should be substantially increased from the present figure of 25°

3. The basis of specification of seat belt geometry should be revised to ensure that the lap strap always locates below the range of anterior superior iliac spine locations for the nominated range of wearers. The existing specification of a theoretical line from the anchorage to a pelvis reference locus is unsatisfactory.

4. Seat belt lap strap fit would be improved for most wearers if the lap strap were to be attached to the seat rather than the car's floor.

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TABLE 1

RESULTS OF RADIOGRAPHIC INVESTIGATION

Case	Subject		Seat back angle	Lap strap angle	Pelvis inclin-ation	Lap strap location mm.
	Mass kg	Stature m.				
1	94	1.85	105°	65°	112°	-15
2	60	1.80	108°	68°	115°	+ 5
3	105	1.90	105°	65°	111°	0
4	71	1.77	102°	66°	108°	+15
5	69	1.83	110°	53°	110°	0
6	79	1.75	110°	78°	110°	+25
	79	1.75	110°	41°	109°	-50
7	65	1.90	126°	49°	126°	-50
	65	1.90	102°	45°	102°	-30
8	81	1.71	130°	80°	130°	0
	81	1.71	109°	72°	114°	+50
9	92	1.85	110°	42°	110°	-45
	92	1.85	110°	80°	110°	+25
10	73	1.78	100°	76°	109°	+55
	73	1.78	98°	74°	94°	+30

TABLE 2

ANTHROPOMETRIC DATA RELATING TO SUBJECTS OF SURFACE EXAMINATION

Subject	Mass (kg)	Stature (m)	Mass / Stature (kg/m)	Pelvic girth (mm)	Pelvis* depth (mm)	ASIS location** x (mm)	ASIS location** y (mm)
1 (JS)	77.6	1.91	40.6	900	120	-20	122
2 (RF)	80.4	1.84	43.7	885	120	12	98
3 (PH)	62.7	1.79	35.0	795	110	-14	106
4 (EK)	87.6	1.60	54.8	985	123	24	117
5 (JM)	108.9	1.67	65.2	1150	136	46	118
6 (DE)	88.5	1.91	46.4	970	142	28	113
7 (AL)	80.8	1.82	44.4	895	128	-28	110
8 (DS)	72.2	1.72	42.0	875	105	14	101
9 (CC)	71.7	1.64	43.2	870	102	-11	106
10 (PK)	55.4	1.57	35.3	765	112	2	86
11 (PJ)	67.8	1.74	39.0	875	92	24	113
12 (NG)	63.1	1.69	37.3	820	111	-18	79
13 (RW)	62.6	1.75	35.8	830	90	13	88

* Pelvis depth is side view distance from ASIS to greater trochanter

** ASIS location is measured relative to the 'H' point of the seat. (H determined in accordance with SAE J826a[20]). Positive 'X' indicates ASIS forward of H, positive y indicates ASIS above H. ALL ASIS locations were measured with the seat back inclined 115° from the horizontal (Figure 4 refers).

TABLE 3

DATA RECORDED DURING SURFACE EXAMINATION

Subject / Case	Lap strap angle measured	Lap strap angle nominal	Seat back angle	Lap strap location (mm)	Pelvis inclination
1/1	66°	65°	100°	15	104°
1/2	68°		115°	25	106°
1/3	72°		130°	20	109°
1/4	72°		150°	22	114°
1/5	75°	80°	115°	27	111°
1/6	49°	45°		8	105°
1/7	37°	30°		4	106°
2/1	63°	65°	100°	-12	87°
2/2	65°		115°	8	90°
2/3	68°		130°	14	110°
2/4	74°		150°	-14	122°
2/5	73°	80°	115°	- 8	101°
2/6	48°	45°		-10	98°
2/7	37°	30°		-19	100°
3/1	62°	65°	100°	22	94°
3/2	68°		115°	3	113°
3/3	70°		130°	11	113°
3/4	71°		150°	14	115°
3/5	73°	80°	115°	13	115°
3/6	48°	45°		4	110°
3/7	38°	30°		-20	108°

TABLE 3 (continued)

Subject / Case	Lap strap angle measured	Lap strap angle nominal	Seat back angle	Lap strap location (mm)	Pelvis inclination
4/1	62°	65°	100°	1	99°
4/2	65°		115°	1	100°
4/3	67°		130°	3	107°
4/4	70°		150°	7	109°
4/5	73°	80°	115°	3	103°
4/6	47°	45°		-6	109°
4/7	35°	30°		-41	108°
5/1	58°	65°	100°	7	93°
5/2	62°		115°	7	75°
5/3	67°		130°	-2	88°
5/4	72°		150°	3	108°
5/5	69°	80°	115°	15	101°
5/6	46°	45°		-10	101°
5/7	34°	30°		-17	102°
6/1	62°	65°	100°	3	99°
6/2	65°		115°	-2	104°
6/3	67°		130°	-8	108°
6/4	71°		150°	-23	111°
6/5	71°	80°	115°	6	109°
6/6	47°	45°		-30	108°
6/7	35°	30°		-42	105°
7/1	65°	65°	100°	14	107°
7/2	68°		115°	14	108°
7/3	70°		130°	6	113°
7/4	73°		150°	4	120°
7/5	74°	80°	115°	9	111°
7/6	80°	45°		-8	106°
7/7	39°	30°		-19	106°

TABLE 3 (continued)

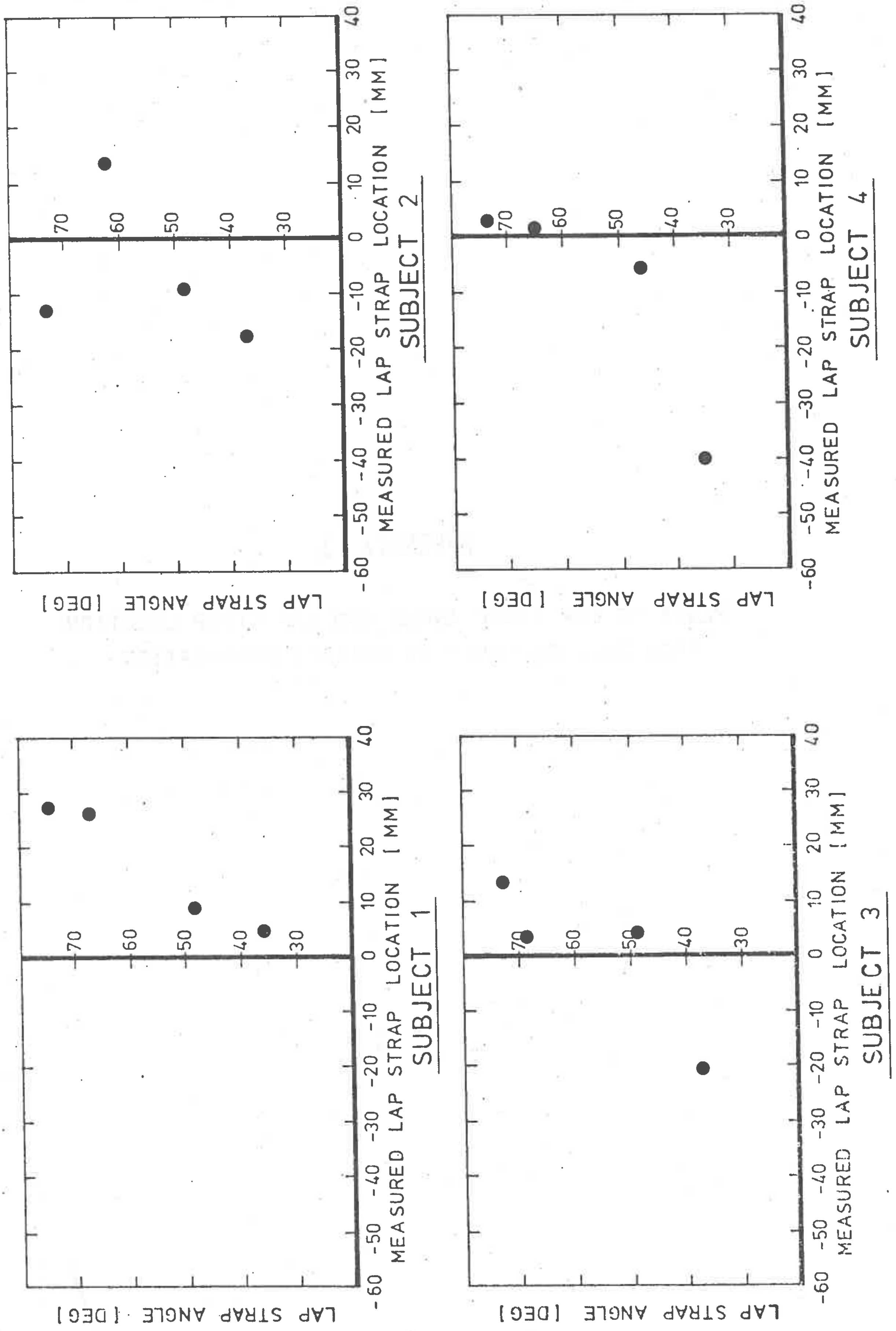
Subject / Case	Lap strap angle measured	Lap strap angle nominal	Seat back angle	Lap strap location (mm)	Pelvis inclination
8/1	67°		100°	-7	102°
8/2	69°	65°	115°	4	110°
8/3	72°		130°	4	110°
8/4	76°		150°	-2	115°
8/5	71°	80°		0	100°
8/6	52°	45°	115°	-15	103°
8/7	40°	30°		-12	103°
9/1	65°		100°	25	108°
9/2	65°	65°	115°	11	112°
9/3	69°		130°	17	95°
9/4	72°		150°	22	103°
9/5	72°	80°		20	101°
9/6	48°	45°	115°	-1	111°
9/7	34°	30°		-6	102°
10/1	64°		100°	-1	97°
10/2	67°	65°	115°	-3	103°
10/3	69°		130°	-1	104°
10/4	71°		150°	-4	112°
10/5	72°	80°		6	103°
10/6	48°	45°	115°	-16	107°
10/7	36°	30°		-51	107°
11/1	43°		100°	0	97°
11/2	60°	65°	115°	0	104°
11/3	61°		130°	14	115°
11/4	66°		150°	5	120°
11/5	69°	80°		33	118°
11/6	44°	45°	115°	-11	104°
11/7	29°	30°		-29	104°

TABLE 3 (continued)

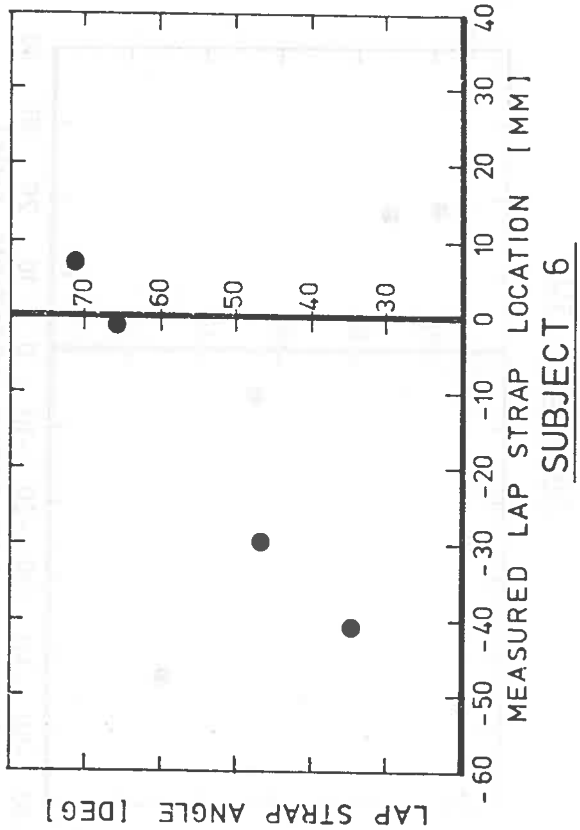
Subject / Case	Lap strap angle measured	Lap strap angle nominal	Seat back angle	Lap strap location (mm)	Pelvis inclination
12/1	70°	65°	100°	14	104°
12/2	65°		115°	17	108°
12/3	67°		130°	12	116°
12/4	70°		150°	10	116°
12/5	71°	80°	115°	18	120°
12/6	47°	45°		-7	124°
12/7	35°	30°		-44	119°
13/1	72°	65°	100°	-12	108°
13/2	76°		115°	-16	117°
13/3	78°		130°	0	119°
13/4	69°		150°	-27	128°
13/5	71°	80°	115°	-5	112°
13/6	30°	45°		-59	125°
13/7	44°	30°		-37	128°

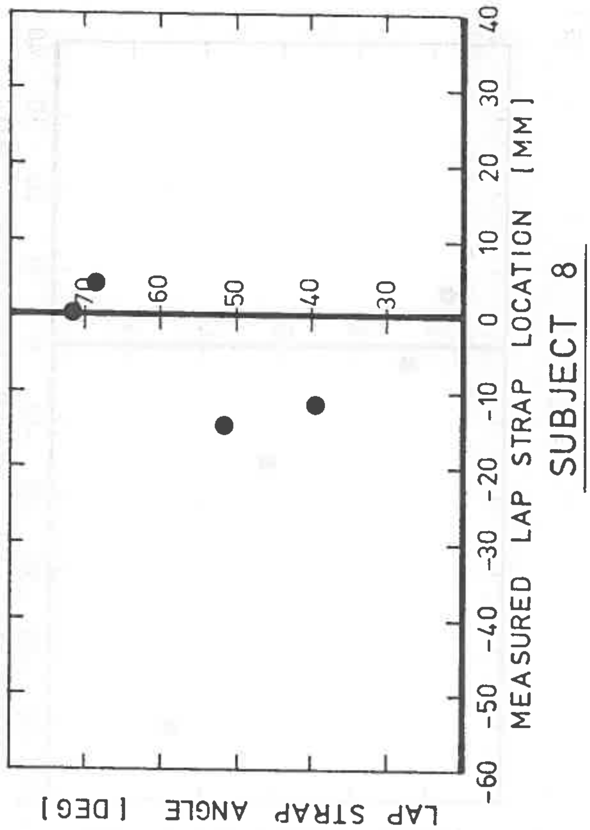
APPENDIX 1

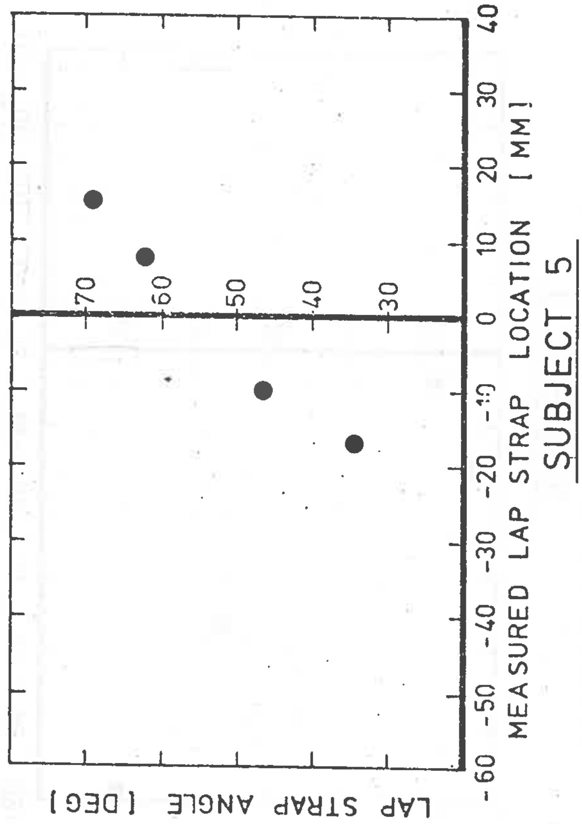
PLOTS OF LAP STRAP ANGLE AND LAP STRAP LOCATION
FROM DATA RECORDED IN SURFACE EXAMINATION

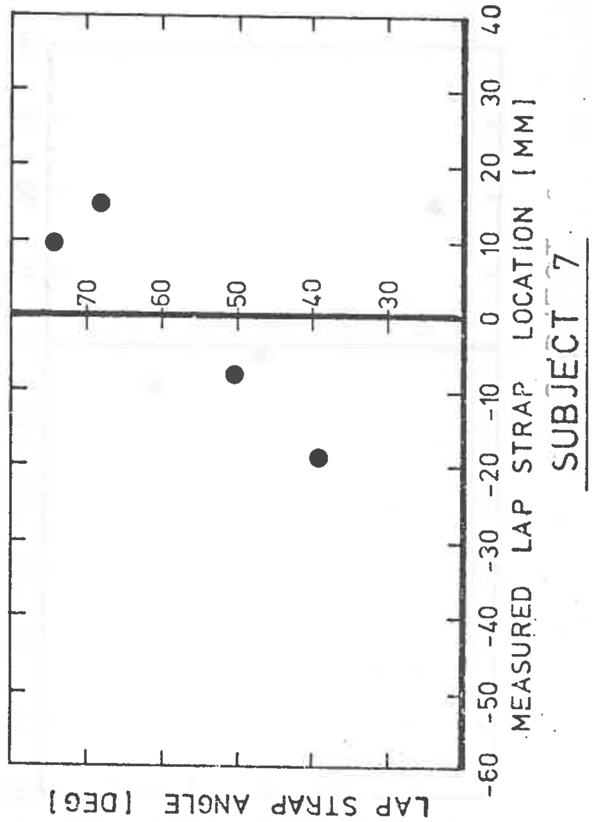


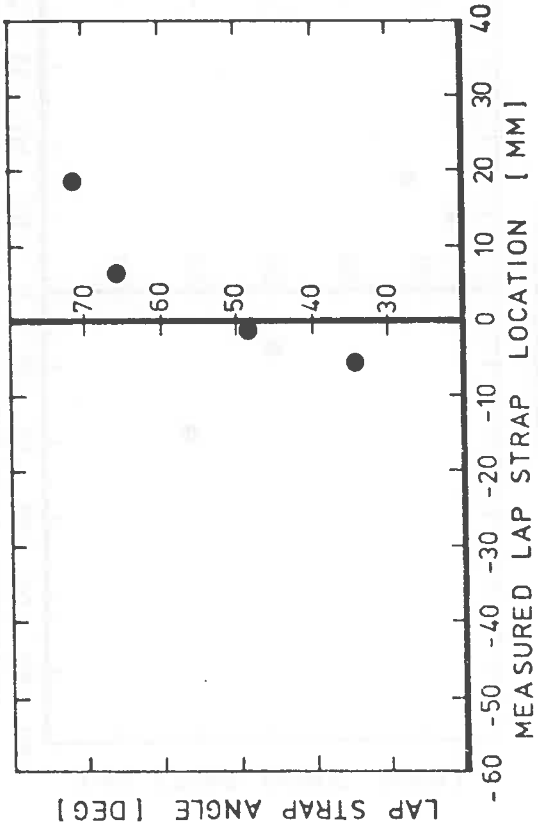
LAP STRAP ANGLE [DEG]
MEASURED LAP STRAP LOCATION [MM]
SUBJECT 1
SUBJECT 2
SUBJECT 3
SUBJECT 4


LAP STRAP ANGLE [DEG]
MEASURED LAP STRAP LOCATION [MM]
SUBJECT 6


LAP STRAP ANGLE [DEG]
MEASURED LAP STRAP LOCATION [MM]
SUBJECT 8


LAP STRAP ANGLE [DEG]
MEASURED LAP STRAP LOCATION [MM]
SUBJECT 5


LAP STRAP ANGLE [DEG]
MEASURED LAP STRAP LOCATION [MM]
SUBJECT 7



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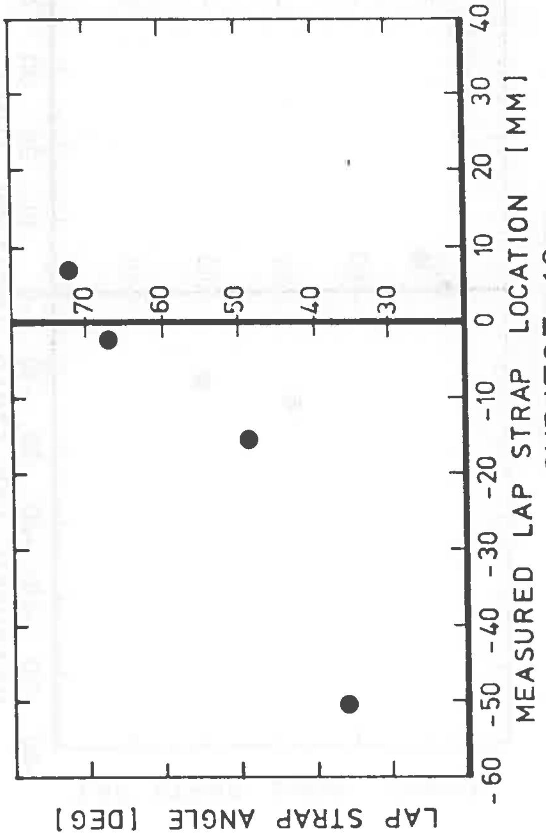

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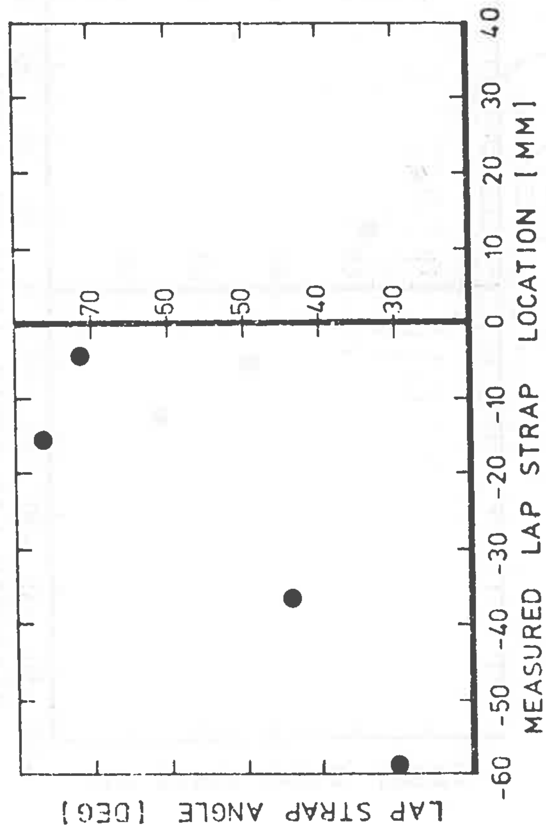

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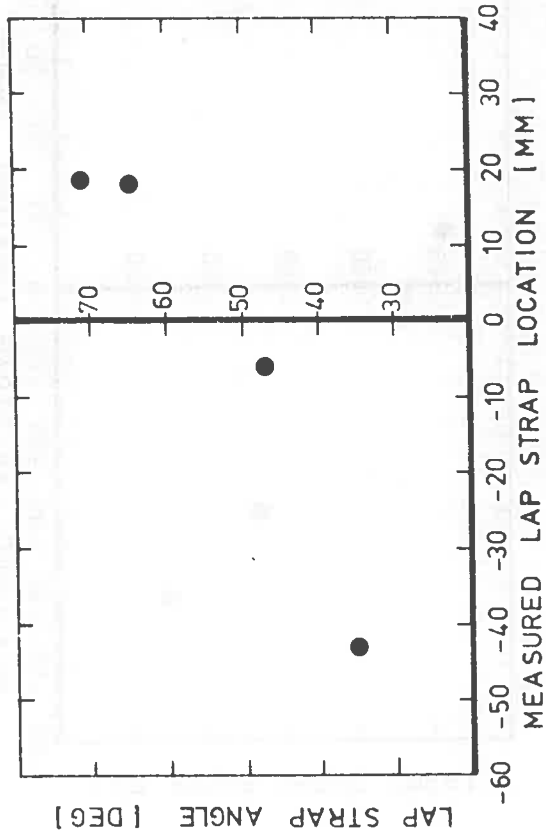

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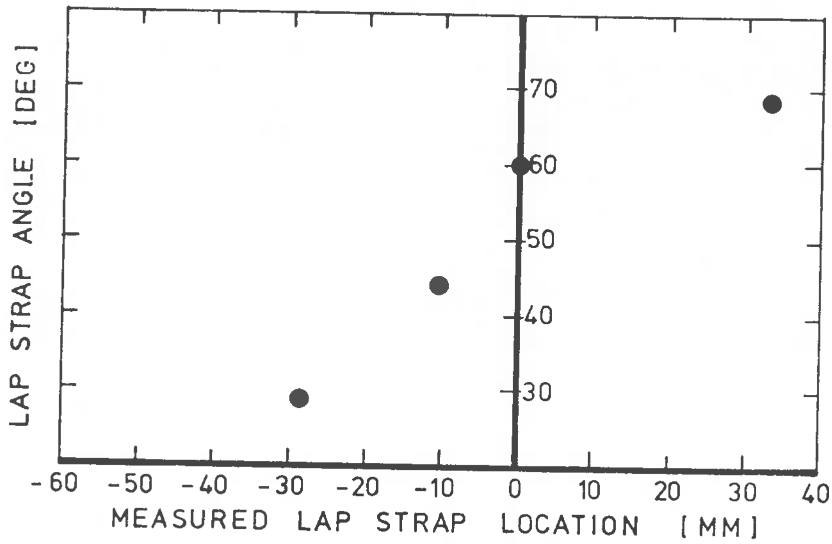
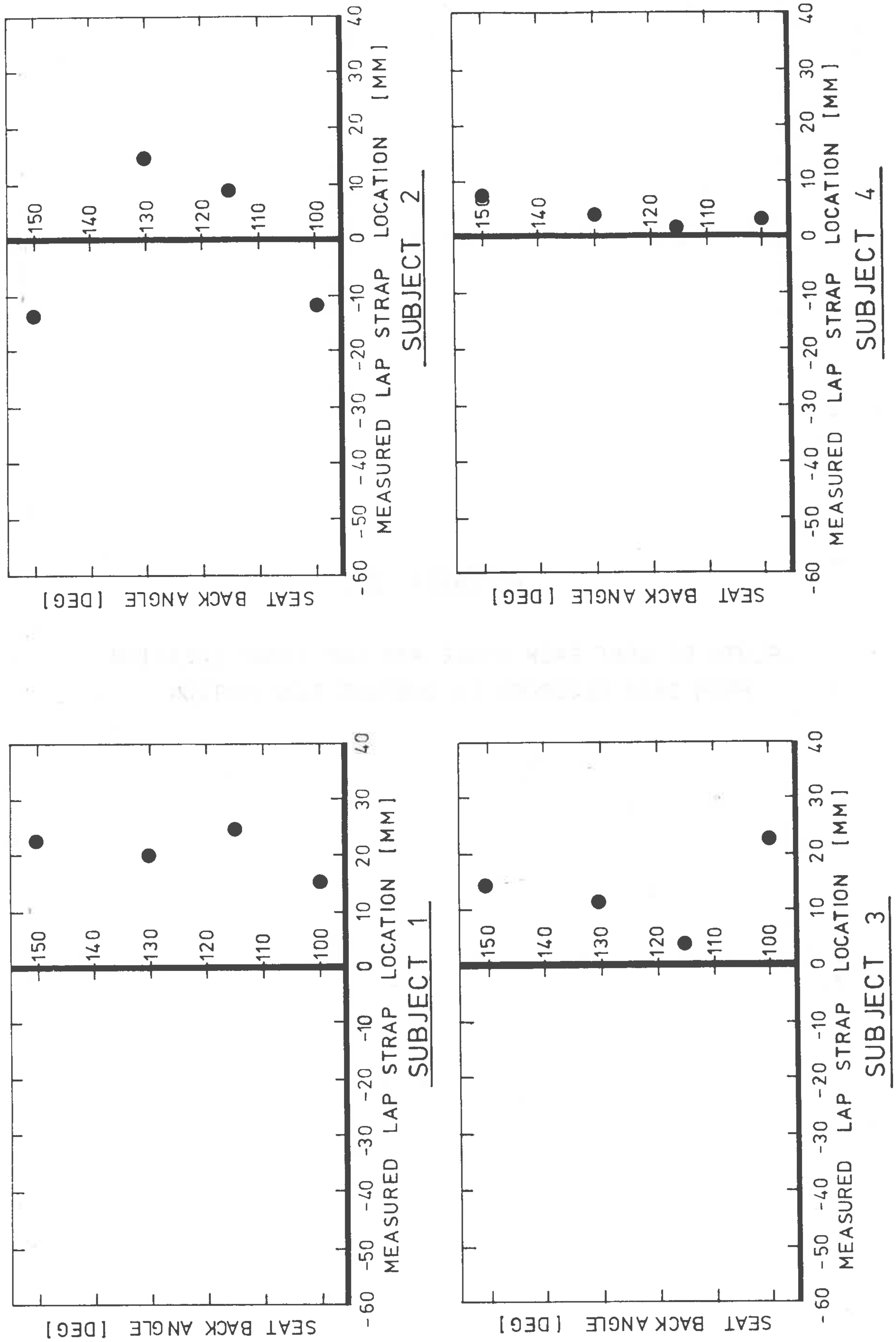
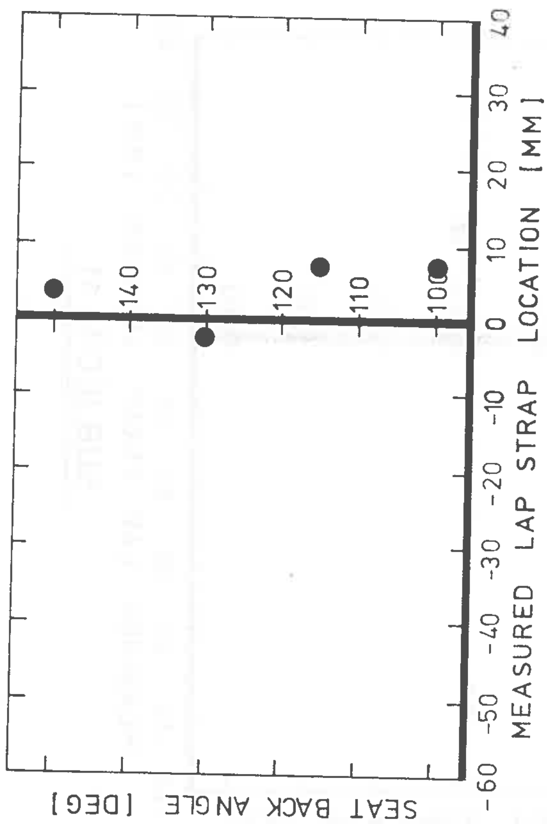

LAP STRAP ANGLE [DEG]
70
60
50
40
30
-60 -50 -40 -30 -20 -10 0 10 20 30 40
MEASURED LAP STRAP LOCATION [MM]

SUBJECT 13

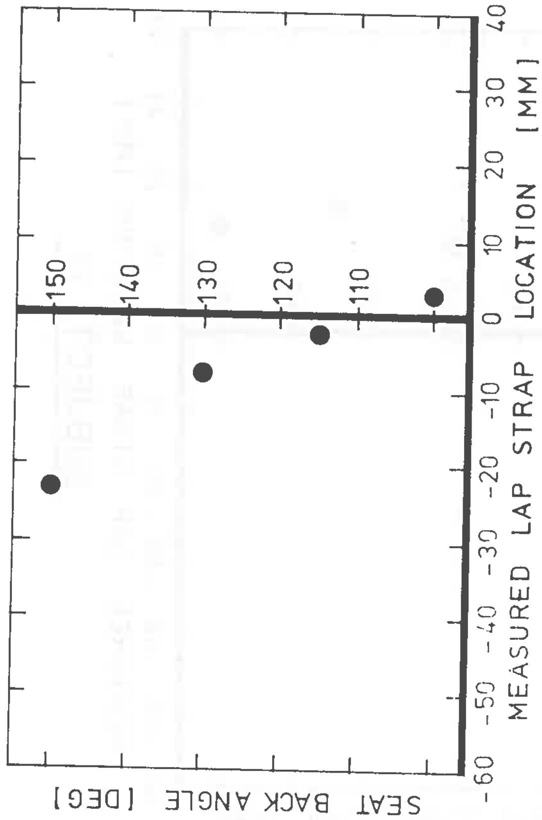
APPENDIX 2

PLOTS OF SEAT BACK ANGLE AND LAP STRAP LOCATION FROM DATA RECORDED IN SURFACE EXAMINATION


SUBJECT 2
SUBJECT 4
SUBJECT 1
SUBJECT 3
MEASURED LAP STRAP LOCATION [MM]
SEAT BACK ANGLE [DEG]
-60 -50 -40 -30 -20 -10 0 10 20 30 40
100 110 120 130 140 150



SUBJECT 5



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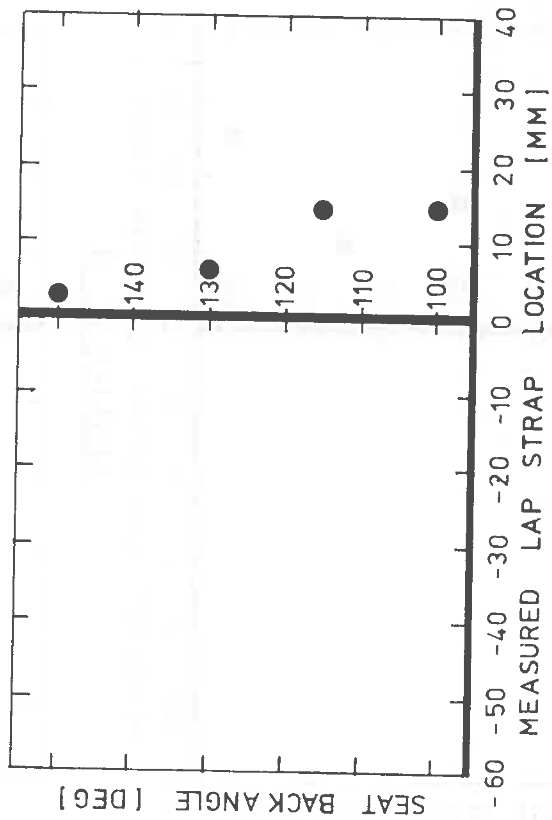

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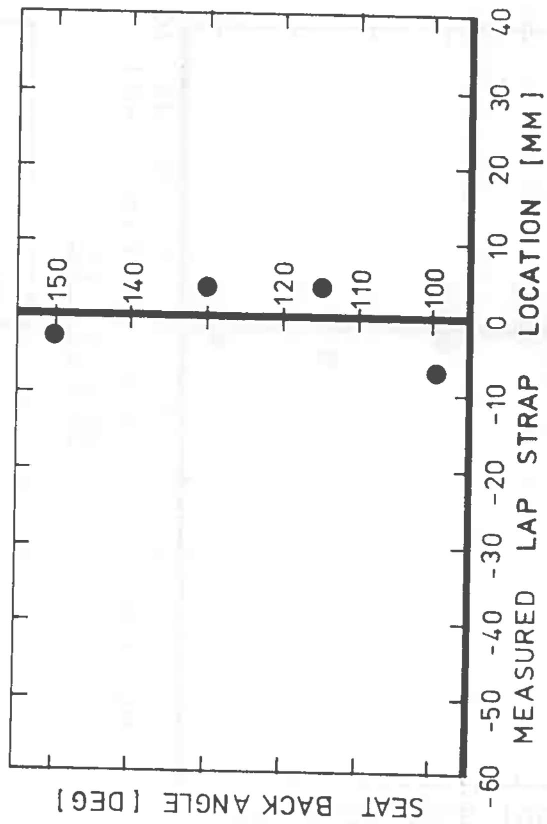

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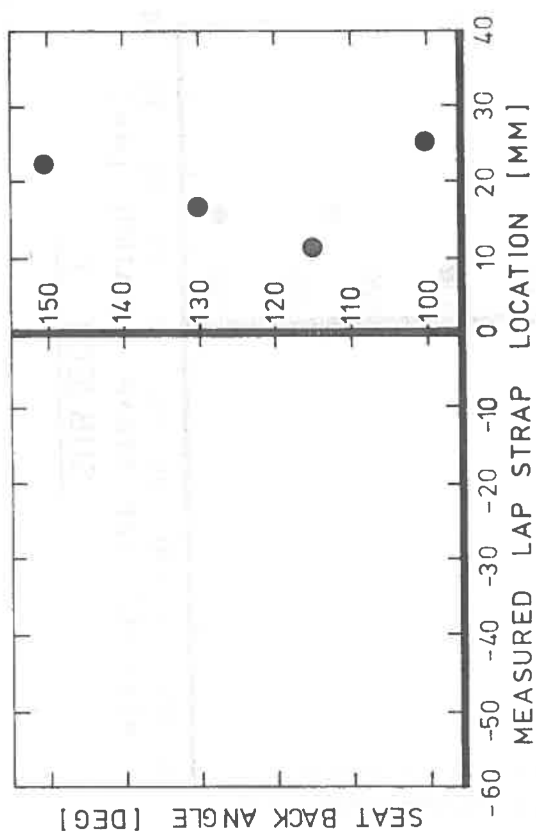

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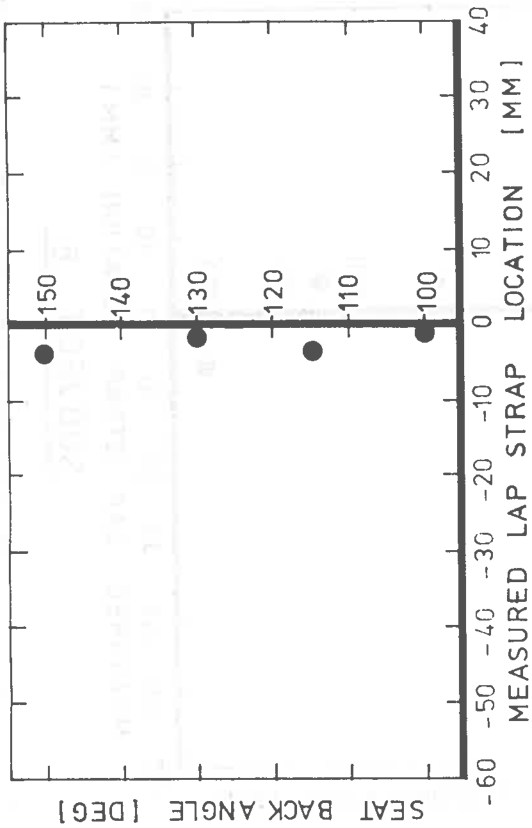

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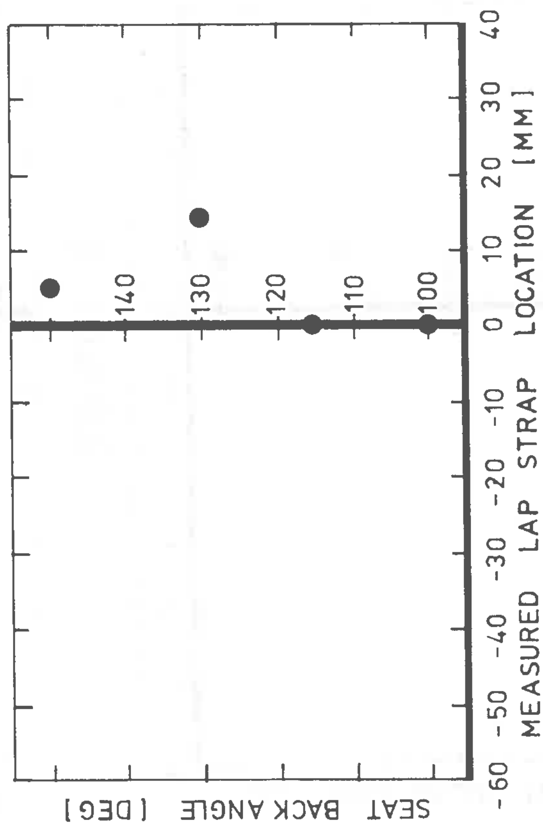

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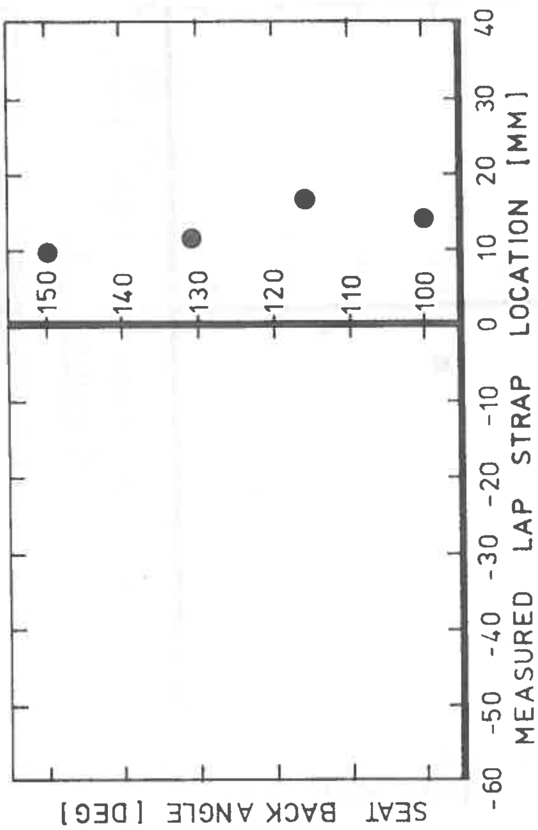
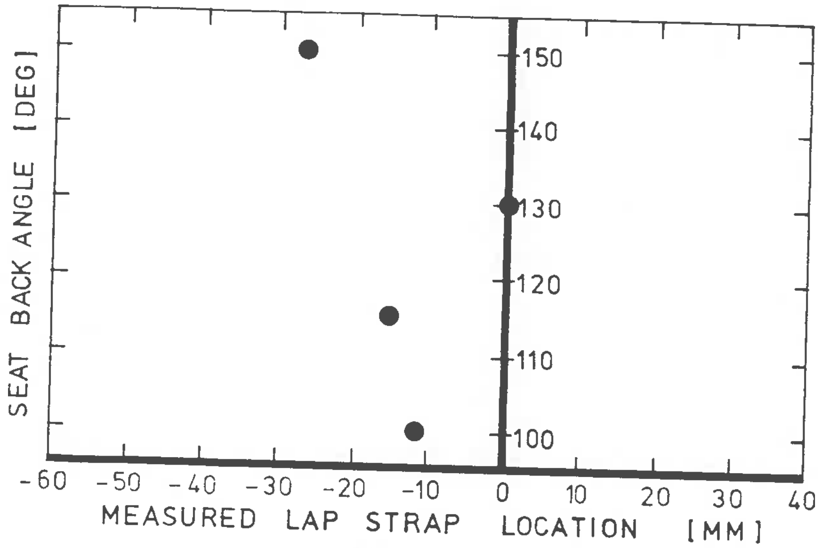


SUBJECT 12

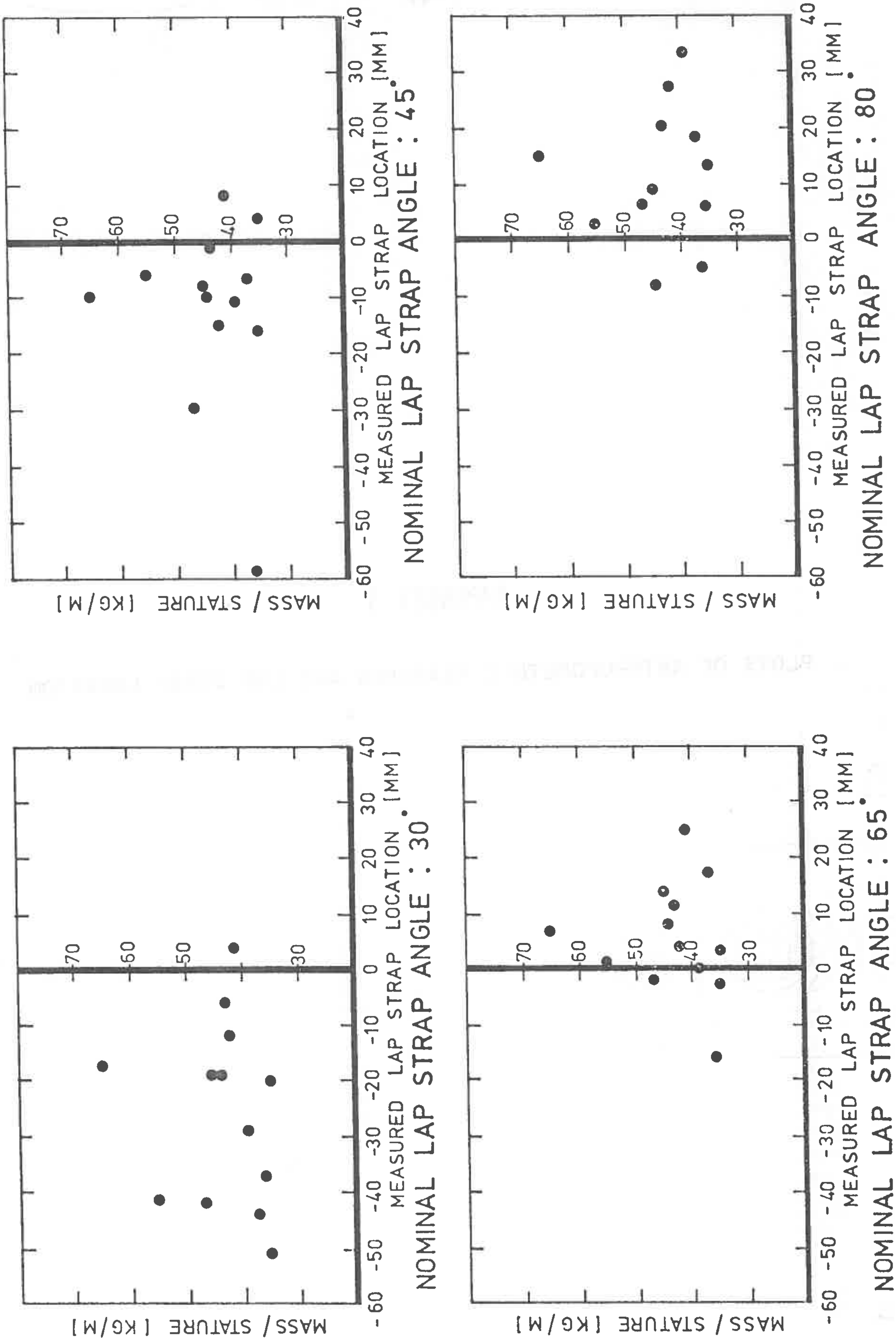


SEAT BACK ANGLE [DEG]
150
140
130
120
110
100
-60
-50
-40
-30
-20
-10
0
10
20
30
40
MEASURED LAP STRAP LOCATION [MM]

SUBJECT 13

APPENDIX 3

PLOTS OF ANTHROPOMETRIC MEASURES AND LAP STRAP LOCATION


MASS / STATURE [KG/M]
MEASURED LAP STRAP LOCATION [MM]
NOMINAL LAP STRAP ANGLE : 45°
MASS / STATURE [KG/M]
MEASURED LAP STRAP LOCATION [MM]
NOMINAL LAP STRAP ANGLE : 80°
MASS / STATURE [KG/M]
MEASURED LAP STRAP LOCATION [MM]
NOMINAL LAP STRAP ANGLE : 30°
MASS / STATURE [KG/M]
MEASURED LAP STRAP LOCATION [MM]
NOMINAL LAP STRAP ANGLE : 65°