SOME OBSERVATIONS ON LAMINATED GLASS WINDSCREENS AND THE INJURIES THEY CAUSE IN ACTUAL ROAD ACCIDENTS

by

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INTRODUCTION

This paper describes the results of a study aimed at examining the field performance of modern laminated windscreens in car accidents. It considers the nature of the head impacts with glass and the injuries sustained as a result. It also considers a number of other effects that have an influence on the impact performance of windscreens, such as pre-fracture, gasket separation and the position of initial contact. Consideration has been given to the insensitivity of the AIS for scaling minor and moderate soft tissue injuries. A Tissue Damage Scale has been developed to describe and scale the injuries to a finer degree than the AIS.

THE STUDY

In the 1950's and early 1960's laminated windscreens were produced with a 0.38mm plastic interlayer. High energy contacts allowed penetration of the head through the interlayer which resulted in deep and disfiguring lacerations. In 1966 the 0.76mm HPR interlayer was introduced. This had the effect of reducing the frequency of head penetration and the severity of head and face lacerations to a level that rarely exceeeds AIS 1 (Ref 1). In an attempt to reduce laceration frequency and severity further, Triplex Safety Glass Co, Limited introduced a windscreen in 1976 called Ten Twenty (Ref 2). This is a lightweight laminated windscreen, both plies of which are thermally toughened, the inner ply to a significantly high level. The toughening is designed to encourage crack propagation and thus smaller glass particles in the area of head contact. In laboratory tests using the Triplex Laceration Index (Ref 3), as a measure of the severity of laceration, the Ten Twenty windscreen shows a significant reduction in the amount of damage to simulated skin tissue over conventional laminated windscreens.

The results presented in this paper attempt to describe the injuries produced by actual head contacts by examining the performance of the two types of windscreen in real accidents.

THE SAMPLE

The fitting of Ten Twenty windscreens occurs in only some 1.6% of cars and thus head contacts with such glass are a fairly rare occurrence in the U.K.

For this reason it was necessary to collect data on a national level in order to compile sufficient cases for an analysis to be made. Co-operation was given by the British Insurance Association and a number of large Police Authorities to assist in gaining access to the vehicles involved in accidents.

Table 1 details the source of each accident investigated and the police classification of the injury severity.

Table 1

	Ten Twenty	Conventional
Press	4	1
Police	11	22
Insurance Companies	11	1
Classification of Accident Severity using the Police Definition		
Damage only	5	5
Slight	14	12
Serious	6	7
Fatal	1	0

We were concerned that the different sources of cases would introduce some bias into the two samples. For example police reported accidents may contain a greater proportion of injury cases than those collisions which are reported to insurance companies. The data in Table 1, however, suggests that this is not a demonstrable effect.

DATA COLLECTION

Detailed measurements were taken of the crash damage in order to estimate the 'equivalent test speed' (Ref 4), and the resultant effect on the occupant's head to windscreen velocity. Photographs were taken of the exterior and interior of the vehicle and any components that may have had an influence on the occupant's trajectory. The windscreen was studied in detail to ascertain the primary cause of fracture and the amount of damage caused by occupant contact. Only 'clean' head contacts were considered, where the injuries could be assigned specifically to the glass.

Medical information on the injuries sustained by the accident victims was gathered with the help of a medical team based at the Birmingham Accident Hospital. In selected cases further details of injuries were obtained by sending a questionnaire directly to the victims.

THE DATA

Tables 2 and 3 summarise the data collected on 26 Ten Twenty and 24 conventional laminate cases, for which full engineering and medical information is available for frontal collisions involving simple 'clean' head strikes on the windscreen.

Table 2. TEN TWENTY CASES

Case No.	Equivalent Test Speed (Kph)	Windscreen† Damage Category	Occupant† Injury Category	Frame Separation	Pre-Fracture	Driver or F.S.P.	Site of Contact on Head
1	32 - 40	4	4	No	Yes	D	2
4	32 - 40	5	4	Yes	No	D	2
5	40 - 48	4	5	No	Yes	P	2/3/9/7
6	16 - 24	2	2	No	No	P	8
7	32 - 40	3	3	No	No	D	8
12	32 - 40	1	2	No	No	D	10
15	32 - 40	5	5	No	Yes	D	1/2/3/5/7
17	24 - 32	4	4	No	Yes	D	1
23	32 - 40	4	5	No*	Yes	D	1/2/6
24	8 - 16	3	3/7	No	No	D	8
25	48 - 56	4	5	No	Yes	D	1
30	16 - 24	1	3	No	No	D	2
32	16 - 24	2	3/8	No	No	P	2
33	32 - 40	4	5/7	No	No	D	2
35	32 - 40	4	6	No	Yes	D	1
36	40 - 48	4	6	Yes*	Yes	P	2/3/9/7
37	24 - 32	2	3	No	No	D	5/9/6
40	16 - 24	2	3	No	No	D	8
41	40 - 48	2	3	No	No	D	2
45	32 - 40	4	3	No	Yes	D	2
52	32 - 40	2	5	No	No	D	8
54	24 - 32	2	3	No	No	D	8
55	40 - 48	2	3	No	No	D	2
68	16 - 24	2	2	No	No	P	10
81	32 - 40	4	4	No	No	D	2
85	16 - 24	2	2	Yes	No	D	10

* Rubber Gasket Mounting

† see text for definition of scale

Table 3. CONVENTIONAL LAMINATE CASES

Case No.	Equivalent Test Speed (Kph)	Windscreen† Damage Category	Occupant† Injury Category	Frame Separation	Pre-Fracture	Driver or F.S.P.	Site of Contact on Head
27	16 - 24	3	2	Yes	No	P	8
28	24 - 32	2	4	No	Yes	P	8
29	40 - 48	4	6	Yes	No	P	2/4/6
29	40 - 48	3	4	Yes	No	D	2
38	40 - 48	4	5	Yes	No	D	1/2/3/7
42	24 - 32	2	3	No	No	D	9
46	24 - 32	2	3	No	No	D	1
47	24 - 32	4	4	No	No	D	2/9/6
49	16 - 24	4	5	No	No	P	2/9
50	24 - 32	4	2/7	No	No	D	10
53	24 - 32	4	4	Yes	No	P	1
56	16 - 24	2	4	No	No	P	2
57	16 - 24	3	4	Yes	No	D	2
60	32 - 40	4	5	Yes	Yes	D	8
62	16 - 24	4	5	Yes	No	D	2/5/6
63	16 - 24	2	3	No	No	D	8
70	32 - 40	4	4	Yes	No	D	2
70	32 - 40	4	6	Yes	No	P	1/2/4/5/7
71	16 - 24	4	5	No	No	D	2
71	16 - 24	4	4	No	No	P	2
73	16 - 24	4	3	No	No	P	1
75	16 - 24	4	6	Yes	Yes	D	1/2/5/7
90	32 - 40	4	4	Yes	No	D	2
90	32 - 40	4	6	No	Yes	P	2/3/9/7

† see text for definition of scale

CRASH SEVERITY

Table 4 and Graph 1 show the distributions for the two groups of cases by crash severity. No significant difference is measureable between these two groups. There is a suggestion that the Ten Twenty group is somewhat more severe in terms of the equivalent test speed. The mean speed for the Ten Twenty group was 36 k.p.h. and for the conventional group it was 29 k.p.h.

Table 4.

E.T.S. Kph	Ten Twenty N	Ten Twenty %	Conventional N	Conventional %
8 - 16	1	3.8	0	0
16 - 24	6	23.1	9	37.5
24 - 32	3	11.5	6	25
32 - 40	11	42.3	5	20.8
40 - 48	4	15.4	4	16.7
48 - 56	1	3.8	0	0
Total	26	99.9	24	100.0

WINDSCREEN DAMAGE 1. Definition

The amount of damage to the windscreen as a result of a head contact has been tabulated using one of the following general descriptions:

1. Head contact but no fracture of either ply
2. Outer ply only fractured
3. Both plies fractured but no apparent interlayer bulge
4. Interlayer stretch with resultant bulge
5. Interlayer bulge and tearing of interlayer
6. Severe damage

Graph 1

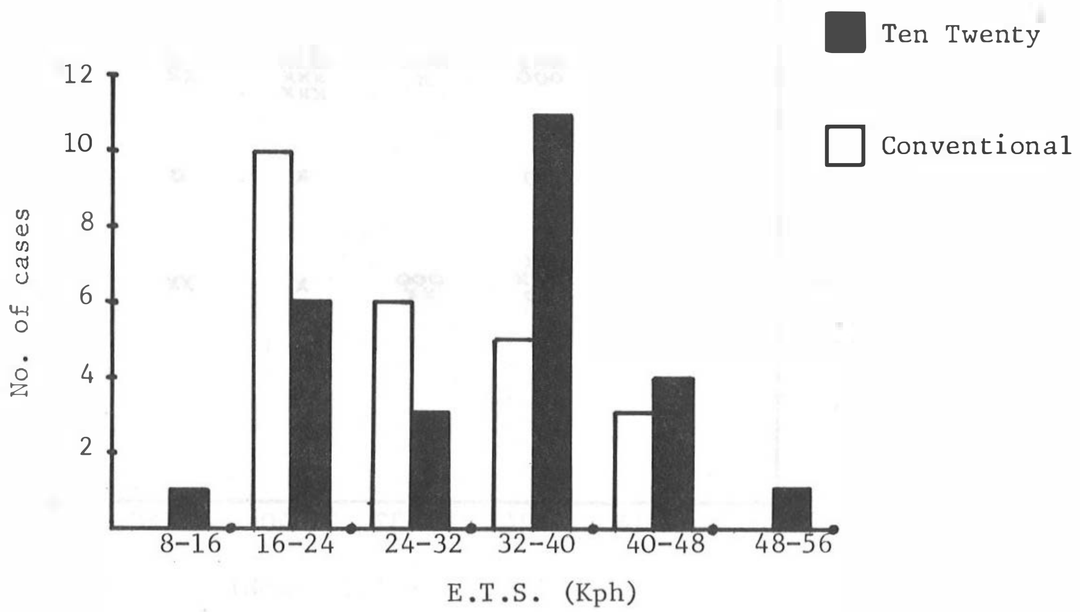


Table 5 shows the frequency of the different types of windscreen damage for the two glass types. These data suggest that a lower proportion of Ten Twenty cases have fractures of the inner ply.

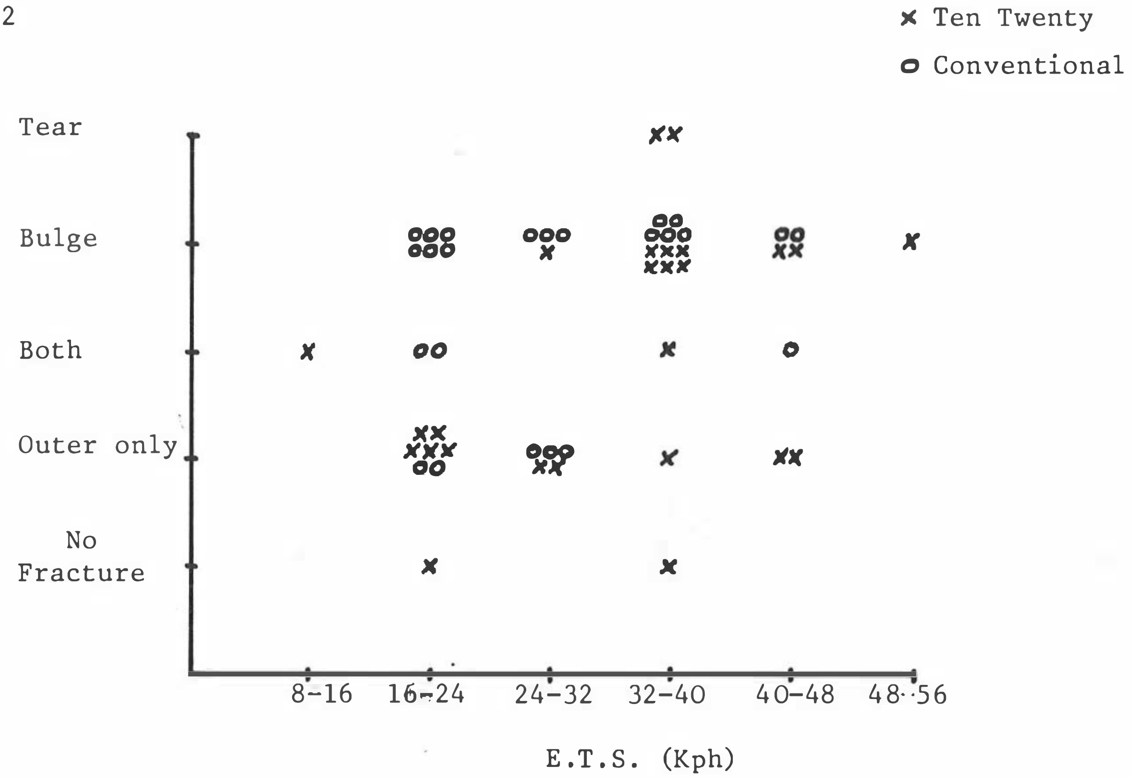
Table 5

Windscreen Damage	Ten Twenty N	Ten Twenty %	Conventional N	Conventional %
No fracture (1)	2	7.7	0	0
Outer only (2)	10	38.5	5	20.8
Both plies (3)	2	7.7	3	12.5
Bulge (4)	10	38.5	16	66.7
Interlayer (5)	2	7.7	0	0
Total	26	100.1	24	100.0

Also a smaller proportion of Ten Twenty cases resulted in a bulge in the interlayer even though the Ten Twenty sample had a higher crash severity. This is illustrated in Graphs 2 and 3, where it appears that Ten Twenty not only requires a higher speed to cause fracture of the inner ply but the onset of a discernible bulge also requires a higher speed.

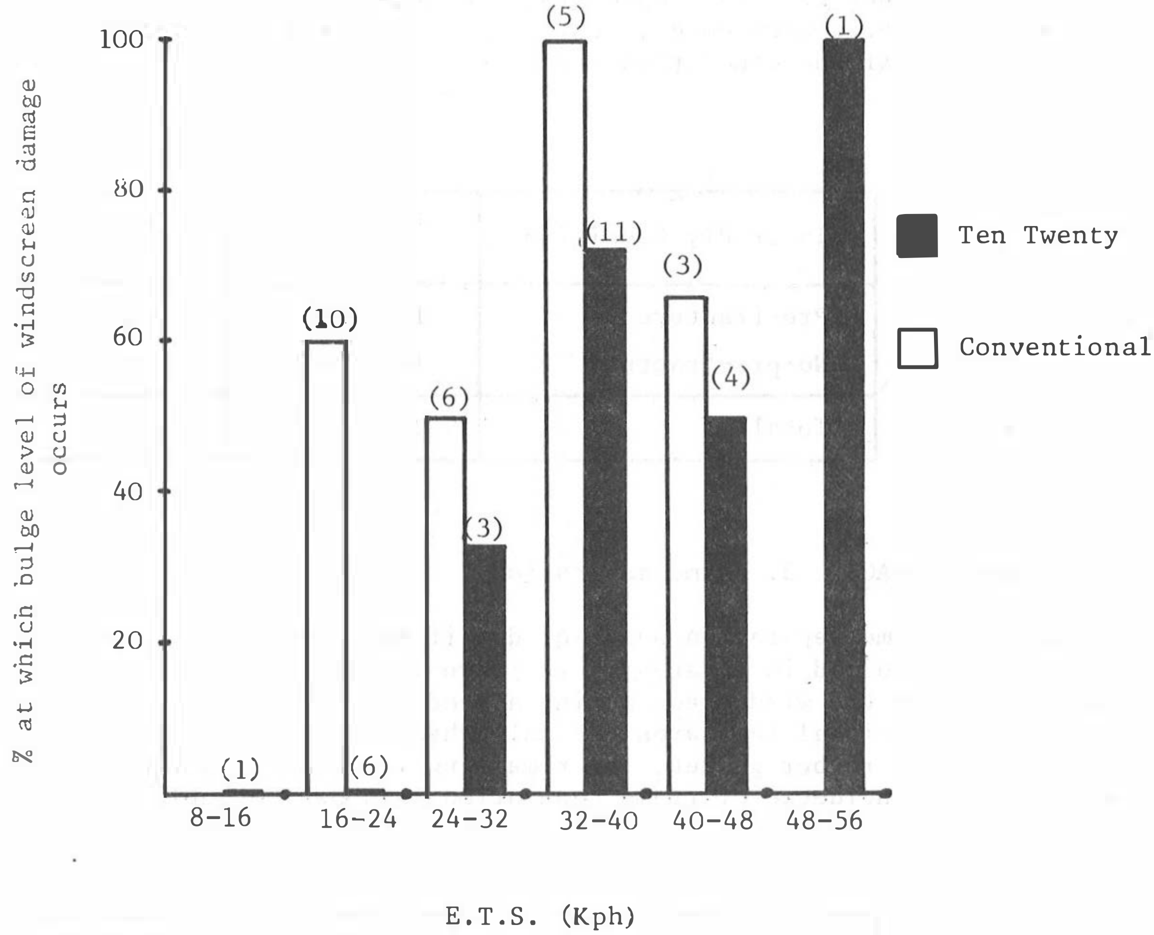
Because of the skewed nature of the crash severity distribution it therefore follows that Ten Twenty may well exhibit fewer cases where inner ply fracture occurs in comparison to conventional laminates, and also significant bulging of the interlayer should occur less frequently.

Graph 2



A close examination of the impacted area of a damaged windscreen will reveal separation of the individual glass fragments allowing shelf edges to be formed and exposed. These shelf edges we believe are a major contributor towards the removal of skin, and hence they control the severity of lacerations. They are only produced when the windscreen deforms enough to produce a bulge.

Graph 3 Figures in brackets indicate sample size



WINDSCREEN DAMAGE 2. Pre-fracture

Particular emphasis was placed on locating and defining the origin of fracture of both plies of the laminate and particularly the inner component of Ten Twenty windscreens. The occurrence of fracture prior to head contact with Ten Twenty laminates may well be significant in reducing the stress of the inner glass and in turn reducing the possibility of fine fragmentation. Pre-fracture is important with conventional laminates where crack surfaces and shelves are produced which lie across the direction of the head trajectory. Pre-fracture may well reduce the penetration resistance of windscreens, and it would seem important that future experimental impact studies should include pre-fractured samples.

Table 6 details the occurrence of pre-fracture for the cases examined. These cases show that pre-fracture occurs more than twice as frequently with Ten Twenty than with conventional windscreens. This is because the bonnet latch on the Rover, the predominant car model to occur in the Ten Twenty sample, is located centrally at the rear of the bonnet which by design is forward-hinged. In an impact the bonnet latch is easily displaced into the base of the windscreen and this occurs prior to any occupant head contact occurring. Other designs of bonnet are less susceptible to displacement into the plane of the windscreen. The consequence of this design may well be to diminish the effectiveness of the windscreen under real-world crash conditions.

Table 6.

Inner Ply Condition	Ten Twenty N	Ten Twenty %	Conventional N	Conventional %
Pre-fracture	10	38	4	17
No pre-fracture	16	62	20	83
Total	26	100	24	100

WINDSCREEN DAMAGE 3. Frame separation

Windscreen frame separation was recorded if the degree and position of the separation occurred in an area where it would play a significant role in the performance of the windscreen during a head impact. It should be noted that all the conventional laminates but only three of the Ten Twenty cases were glazed using a rubber gasket, the remaining Ten Twenty cases were adhesively glazed. The incidence of frame separation is shown in Table 7.

Table 7.

	Ten Twenty N	Ten Twenty %	Conventional N	Conventional %
Separation	3	12	12	50
No relevant separation	23	88	12	50
Total	26	100	24	100

Clearly the separation of the Ten Twenty mounting occurs much less frequently than with the conventional windscreens. It is worth recalling the work of Cornell Laboratory (Ref 5), which noted that a significant amount of the benefit obtained from HPR interlayer, in comparison to the old 0.38mm interlayer type was lost if an adhesive bond was used in comparison to a gasket mounting.

THE HEAD CONTACTS 1. Occupant position

Table 8 details the occupant position for the two types of windscreen.

Table 8.

Occupant position	Ten Twenty N	Ten Twenty %	Conventional N	Conventional %
Driver	21	81	14	58.3
Front seat passenger	5	19	10	41.7
Total	26	100	24	100.0

THE HEAD CONTACTS 2. Site on windscreen

The initial point of contact on a windscreen can usually be located by evidence of a grease mark. It is interesting to note that the first point of contact does not always coincide with the origin of fracture of one of the plies.

Table 9 gives a summary of the horizontal zone in which the head contact occurred.

Table 9.

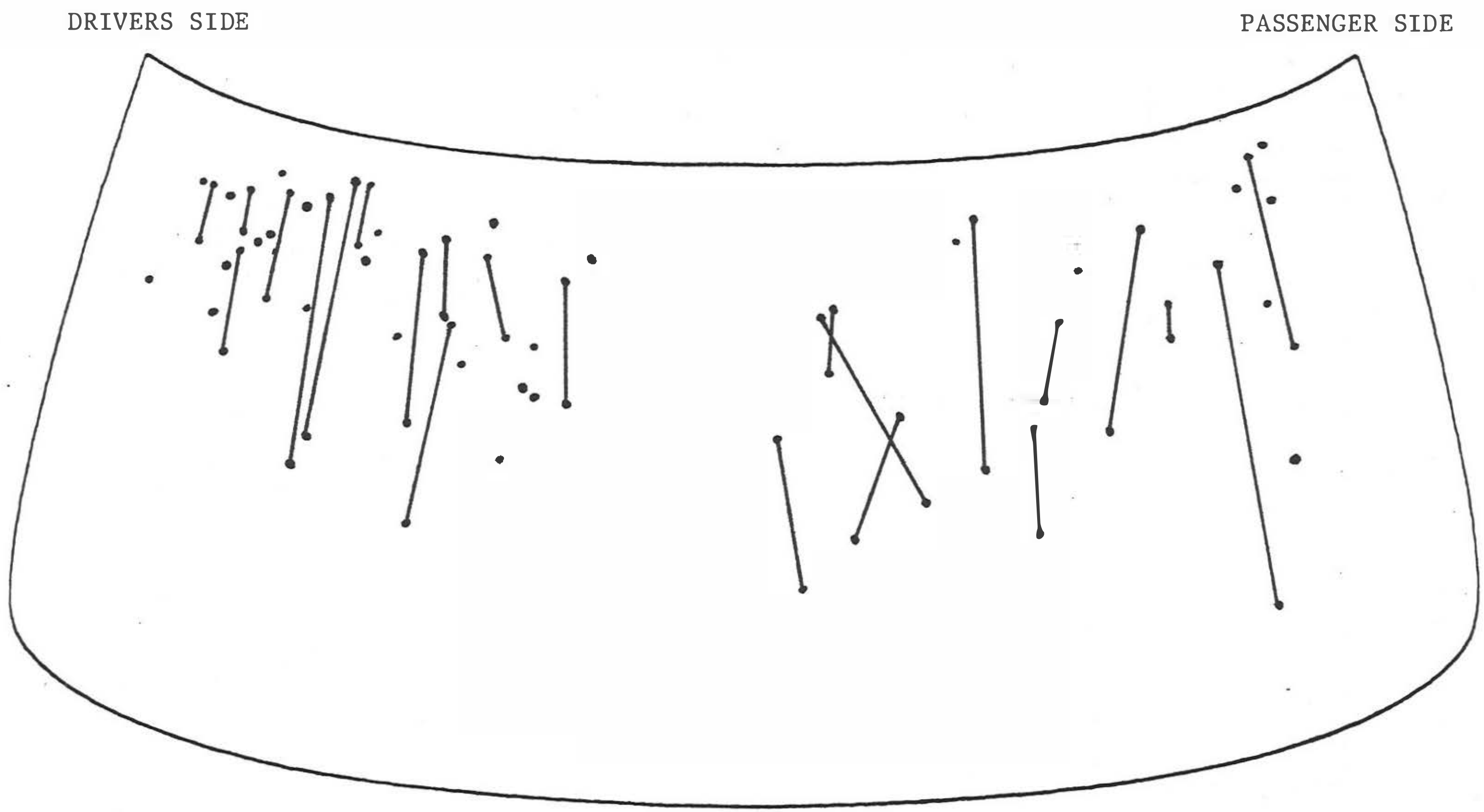
	Ten Twenty				Conventional			
	Driver		N.S.F.		Driver		N.S.F.	
	N	%	N	%	N	%	N	%
Upper third	15	76	4	80	12	86	8	80
Middle third	5	24	1	20	2	14	2	20
Lower third	0	0	0	0	0	0	0	0
Total	21	100	5	100	14	100	10	100

It is clear that over three-quarters of all head contacts occur in the upper third of the windscreen regardless of car type. None occur in the lower third.

Figure 1 illustrates the positions of the head contacts and the linear dimensions of any relative head to glass movement which occurred. No differences were found in the locations of the head contacts for the two glass types and they are plotted together on Figure 1. Not all of the cases illustrated by linear travel on the glass represent fracture. It is possible to have a sliding action of the head down an unbroken windscreen.

FIGURE 1

HEAD CONTACT SITES



Sliding action with length of movement defined

No head/glass movement

Scale x 0.14

THE INJURIES 1. Definition

Most injuries sustained as a result of contact with a modern laminated windscreen are of relatively low severity when assessed on any threat to life scale, very few exceeding AIS 1. It was thought necessary therefore to formulate a 'laceration scale' based on experience gained with earlier studies of head/windscreen contacts. The following Tissue Damage Scale has been used throughout the analysis:

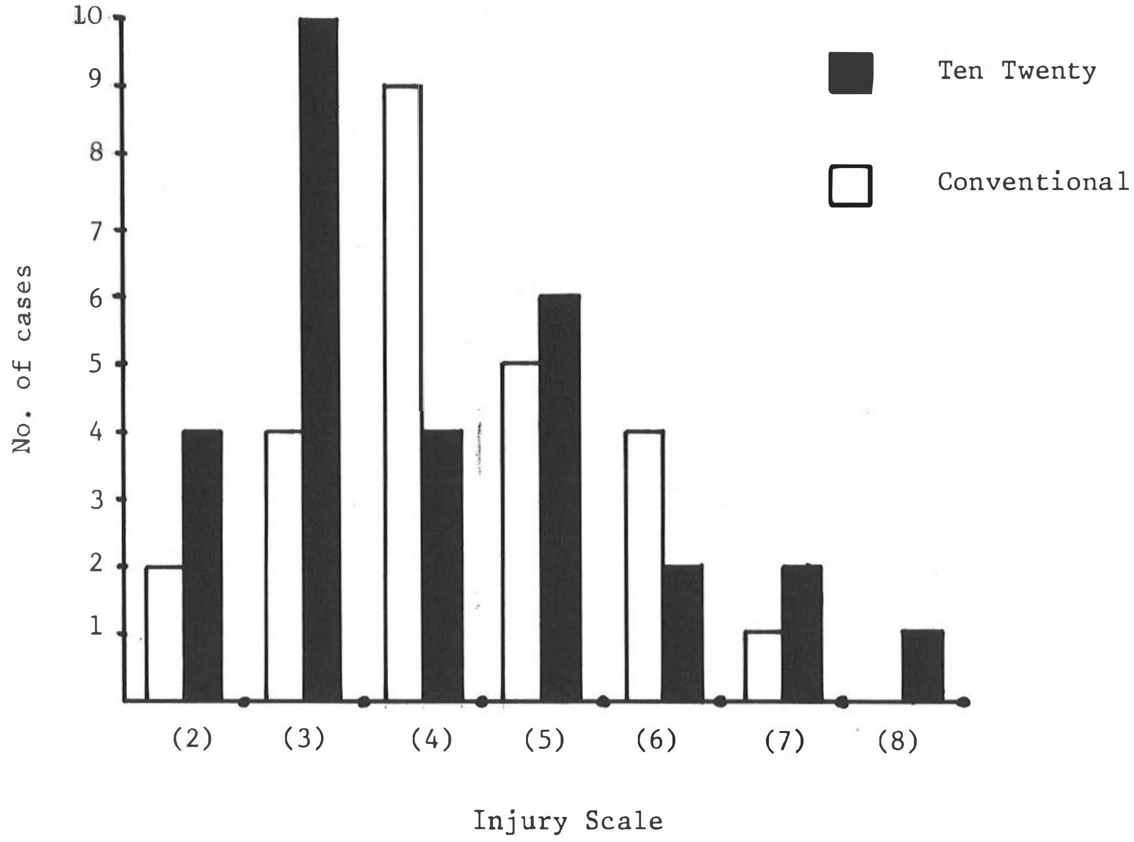
1. Injury not known
2. No injury reported
3. 'Bump' or bruising (no tissue damage)
4. Minor abrasions (tissue damage but no measureable cuts)
5. Lacerations (no stitches)
6. Lacerations (with stitches)
7. Concussion (with a period of unconsciousness)
8. Fatal (where prime cause of death can be attributed to the windscreen).

Clearly there are two dimensions to this scale, laceration and brain injury. Thus an individual can be rated twice. The frequencies of these various classes of injury are given in Table 10, for the two glass types, and are shown graphically in Graph 4.

Table 10

	Ten Twenty		Conventional	
	N	%	N	%
1. Injury not known	0	0	0	0
2. No injuries reported	4	15.4	2	8.3
3. 'Bump' or bruising	10	38.5	4	16.7
4. Minor abrasions	4	15.4	9	37.5
5. Lacerations (no stitches)	6	23.1	5	20.8
6. Lacerations (with stitches)	2	7.7	4	16.7
7. Concussion	2	7.7	1	4.2
8. Fatal	1	3.8	0	0
Total	26	100.1	24	100.0

Graph 4



<u>THE INJURIES</u> 2. Location of Injury

The anatomical location of the injuries on the head and face is outlined in Table 11. These data show that there are no significant differences between the two glass types. It is interesting that three quarters of the injuries occur at the level of the eyebrows or above. This is in marked contrast to experimental work (Ref 6) which indicates a high frequency of laceration to the nose and the chin in dummy tests. These results suggest that an occupant's trajectory in actual accidents may well be different from dummy kinematics. The reconstruction of real world trajectories is an important area for future research. No major differences were detected in the data between drivers and passengers for the location of lacerations.

<u>THE INJURIES</u> 3. Severity

Table 10 outlines the severity of the injuries according to the Tissue Damage Scale. No very marked differences are apparent although there is a suggestion that conventional windscreens cause more abrasive type injury than does Ten Twenty.

If, however, the injuries are examined in relation to crash severity, and if

Table 11. INJURY SITE ON HEAD

Category	Description	Ten Twenty N	Ten Twenty %	Conventional N	Conventional %
1	Above hairline	5	20	7	22.6
2	Between hairline and eyebrows	13	52	14	45.2
3	Eyebrows	3	12	2	6.4
4	Around eyes (not incl.eyebrows)	0		2	6.4
5	Below eyes	1	4	3	9.7
6	Multiple (2 injury sites)	2		3	
7	Multiple (3+ injury sites)	3		4	
8	Precise site of injury N/K	6		4	
9	Nose	3	12	3	9.7
10	No reported head injury	2		1	
	Total	25	100	31	100.0

Injuries occurring at eyebrows or above	21	84%	23	74.2%
Injuries occurring above eyebrows	18	72%	21	67.8%

a division is made between those cases where some tissue damage occurred and those where there was no tissue damage, then some trend is discernible as illustrated in Graph 5. Those data suggest that tissue damage is occurring more frequently with conventional glass than with Ten Twenty and this is perhaps more marked in low speed crashes.

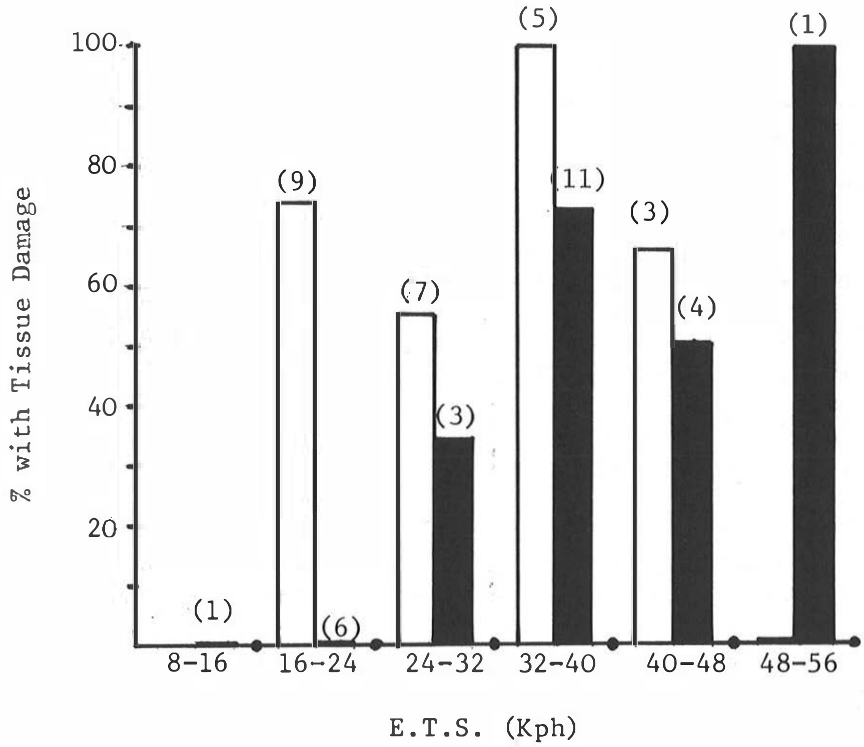
If the cases are grouped into those below 32 k.p.h. and those above, then the trend is illustrated more clearly in Graph 6. These data are statistically different (using the Fisher Exact Probability Test) and they suggest that Ten Twenty may well be generating less tissue damage than does conventional glass.

If the frequency of tissue damage is related to windscreen damage (Graph 7) it appears that once a bulge develops there is tissue damage, to some degree, in most cases.

From these data there is a suggestion that the toughening of the inner ply of Ten Twenty results in a windscreen which is less easily fractured than conventional ones.

Graph 5

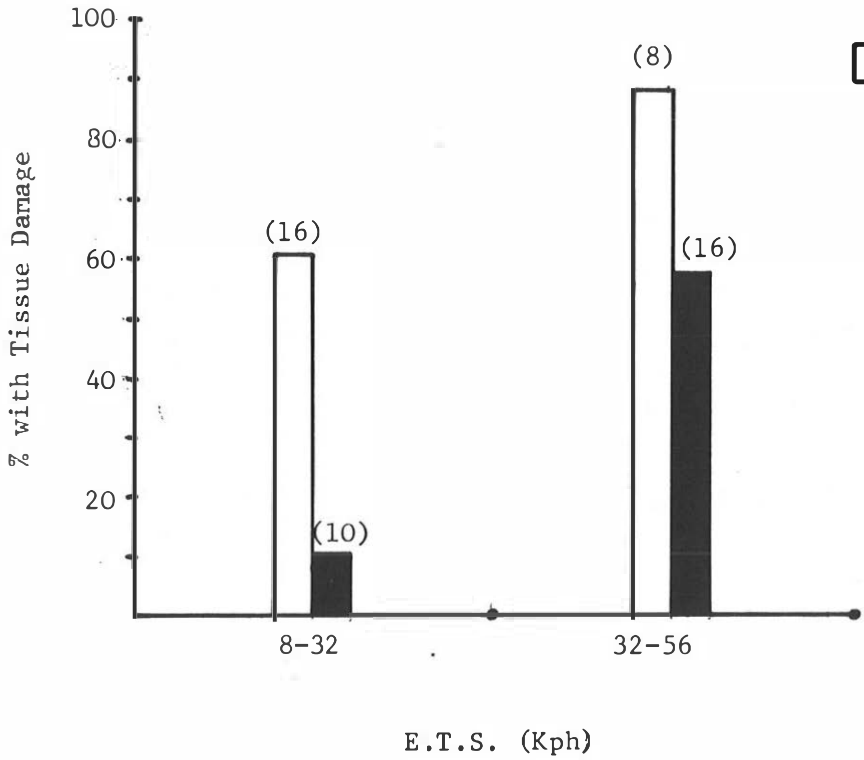
Figures in brackets indicate sample size



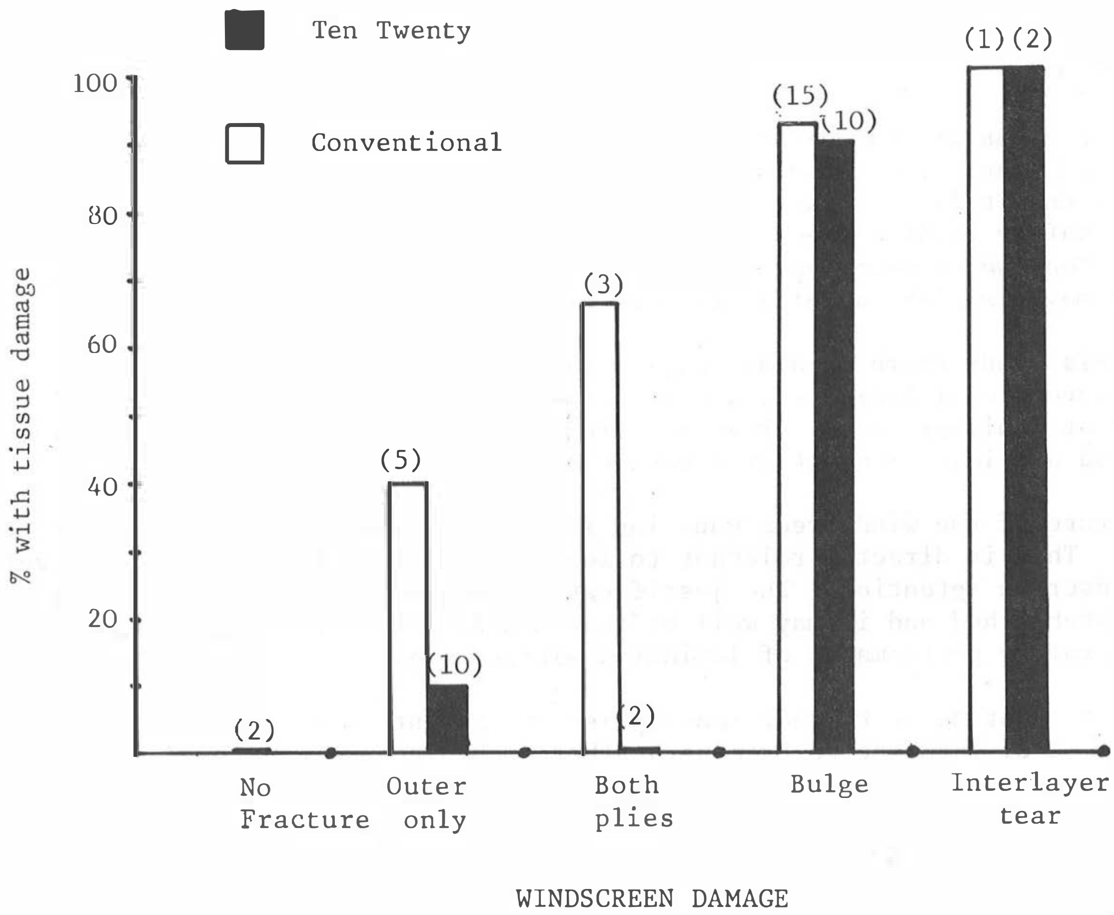
Graph 6

Ten Twenty

Conventional



Graph 7



Consequently, the onset of tissue damage with Ten Twenty appears to be delayed to a higher head-to-glass speed. Because of the skewed nature of collision severities, in that there are many low speed impacts and fewer at higher speeds, it can be suggested that Ten Twenty is providing a benefit at the low end of the collision speed spectrum.

THE INJURIES 4. Brain Injury

In the Ten Twenty sample there were two cases where concussion occurred both at the AIS 2 level. In the conventional sample there was one such case. On the numbers available this absence of concussion from windscreen contacts should be treated cautiously but it appears that significant brain injury from hitting a laminated windscreen is not a problem in reality. This brings into question the use of the HIC as a measure of the safety performance of a windscreen. Experimental work has shown that 'HIC' values (measured on a headform) between 200 and 800 can be obtained. If field accident studies show that concussion is in reality of no consequence then the grading of the safety performance of windscreens in the laboratory ought to be done using laceration as a criterion rather than deceleration.

There was one fatality in this study. The fatal spinal lesion was at the

C1/C2 level in a 67 year old man who exhibited marked pre-existing osteo-arthritic degenerative changes in the vertebrae. The inner ply of the wind-screen was unbroken by his head contact.

CONCLUSIONS

This paper has presented the results of a small scale investigation of laminated windscreen crash performance. It illustrates perhaps some of the reasons why it is important to monitor the actual performance in real accidents of all safety related items. For example the high frequency of pre-fracture of the Ten Twenty cases shows how an apparently unconnected piece of body design may diminish the effectiveness of some other item.

From this study there is a suggestion that Ten Twenty fractures less easily than conventional laminates, and also the onset of bulging of the interlayer occurs at a higher speed. This in turn suggests that soft tissue injuries of the head are less frequent as a consequence.

The nature of the windscreen mounting is a factor which requires further study. This is directly relevant to legislation which demands a high level of windscreen retention. The justification for such legislation has not been established and it may well be that adhesive bonding is diminishing the actual safety performance of laminated windscreens.

With the adoption of thinner inner plies on conventional laminated windscreens it will be of interest to examine whether such a change will produce measureable benefits in real world collisions.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support by a number of individuals at Triplex Safety Glass Co. Limited and the financial assistance provided for this work by Pilkington Brothers Limited, also the co-operation from the Police forces, insurance companies, hospitals and recovery garages throughout the country. Our thanks especially go to the late Professor Gissane and to Dr. J.P. Bull and Miss B. Roberts at Birmingham Accident Hospital and to Dr. P.R. Acland who all assisted in collecting the injury information.

The support of all other members of the Accident Research Unit is also gratefully acknowledged, and in particular Zoe Whale who worked on much of the data collection.

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