I. ABSTRACT

This paper reviews many findings from the medical literature regarding injuries to belt restrained adult occupants of motor vehicles. The review is limited to a subset of that literature in which restraint system contact forces were associated with the injury. Thus, injuries caused solely by internal loadings or by contacts with objects other than the lap or lap/shoulder restraint systems were generally excluded. Head and extremity injuries are therefore not discussed for either lap-only or lap-shoulder belt systems, nor are thoracic injuries considered for lap belt only systems. The injury rates seen in a recent decade of FARS (Fatality Analysis Reporting System) data for front outboard occupants of fatal frontal crashes are noted for comparison.

II. INTRODUCTION - HISTORICAL REVIEW OF OCCUPANT PROTECTION SYSTEMS

Motor vehicle accidents have grown to be a major cause of death and injury since the first known crash-related occupant fatality occurred in 1895. Fortunately, statistics indicate that the death rate in terms of fatalities per 100 million vehicle miles traveled has declined from a peak of 24.1 in 1921 to the present 1.7 (NHTSA, NCSA, 1997). The recent steady reduction in the fatality rate has been the result of a combination of a variety of factors including vehicle crash safety, engineering developments, and improved roadway design among others. Unquestionably, the most important motor vehicle crash safety innovation which contributed to that reduction has been the installation and proper use of seat belts.

The aircraft type lap belt was first incorporated into passenger car design by the Nash-Kelvinator Corporation in September 1949 with the introduction of the reclining front seat, but these belts were not widely used (Johannessen, 1984). The safety benefit afforded to users of these aircraft-type seat belts was confirmed by the Cornell Aeronautical Laboratories report issued in 1953 (Automotive Engineering, 1996). The American Medical Association was so convinced of the injury/death reduction potentials that in 1954 the Association voted to support the installation of lap belts in all automobiles (Consumer Reports, 1998). Ford Motor Company introduced the lifeguard safety package with its 1956 models which offered front and rear lap belts (Automotive Engineering, 1996). Chrysler Corporation also included lap belts as an option on some models in 1955 (Automotive Engineering, 1996; Chrysler Corporation, 1955). Chevrolet introduced the first lap/shoulder safety belts in 1957 (Automotive Engineering, 1996). Most U.S. automobile manufacturers provided lap belts as standard equipment at the front outboard seating positions in 1964 (Johannessen, 1984), and at the rear outboard seating positions for the 1968 model year (FHWA, 1967).
By 1/1/68, Federal Motor Vehicle Safety Standard 208 required lap and shoulder belts on all U.S. passenger cars. In 1974, a lap/shoulder seat belt (with non-detachable shoulder strap) in its basic form was required in all front outboard seating positions. Unfortunately, usage of belt systems remained quite low in the U.S. until the mid-1980's (NHTSA, 1998; Warner, 1997).

Passenger car restraint systems continued to evolve, with the phase-in of automatic occupant protection for front seat occupants in the form of either: (1) automatic seat belts, or (2) the combination of airbags and manual lap/shoulder belts beginning with the 1987 model year, and the installation of lap/shoulder belts for outboard rear seat occupants in cars manufactured on or after December 11, 1989 (NHTSA, 1984; 1989).

III. THE PERSPECTIVE ON THE MEDICAL LITERATURE OF BELT RELATED INJURIES.

Although few papers provide any reliable estimates of crash severity, many of the belt related injuries described in the medical literature surely have occurred in very severe crashes. They cannot be rationally related to any quantification of accident severity; neither can the information provided be used for inferences for overall injury rate or for estimates of belt effectiveness.

A useful source of information on belt effectiveness and injury rate in severe crashes in the United States is present in FARS, a census of almost every fatal crash in the United States since 1975, drawn from state police and death records. Although no quantitative severity information is presented, the FARS census is certainly representative of crashes within the upper levels of crash severity. The FARS census of front outboard occupants in severe fatal frontal crashes (initial force direction 11, 12 and 1 o'clock) was examined for the decade beginning in 1986, when U.S. mandatory belt use laws began to take effect and usage rates began to increase sharply in the U.S. (Warner, 1997).

During those ten years of FARS, over 270,000 occupants of fatal crashes were coded to have been unrestrained, lap-only or lap/shoulder belted, and restrained but type of “restraint unknown”. The “restraint unknown”, “child restraint” cases, and “unknown if restrained” cases are omitted from Table 1, which classifies the remaining cases as to fatal injury rates.

<table>
<thead>
<tr>
<th>Occupants</th>
<th>&quot;K&quot; Injury</th>
<th>&quot;K&quot; Injury Rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Unrestrained&quot;</td>
<td>129,327</td>
<td>70,553</td>
</tr>
<tr>
<td>&quot;Lap/Only&quot;</td>
<td>4,617</td>
<td>1,117</td>
</tr>
<tr>
<td>&quot;Lap/Shoulder&quot;</td>
<td>81,461</td>
<td>20,561</td>
</tr>
<tr>
<td>Total</td>
<td>215,405</td>
<td>92,231</td>
</tr>
</tbody>
</table>

Table 1. Injury Rates vs. Coded Restraint Type
Front Outboard Seat Occupants in Severe Frontal Crashes

Belt usage estimates for all occupants in the U.S. averaged about 40% over that decade. Fatal injury rates to belt users averaged about 25% in these severe crashes, regardless of the belt system used. The data leads to two important findings relating to these very severe frontal crashes. First, restraint usage is definitely helpful in prevention of fatalities and many severe injuries, even at the higher end of crash severity. Secondly, at these high severity levels lap-only and lap/shoulder belts appear to offer about the same level of injury reduction to front outboard occupants; distinctions in fatal injury rates between lap-only and lap/shoulder belts are not apparent at the severity levels represented by the FARS census data.
This finding of about the same injury rate to lap only and lap-shoulder belted outboard occupants of FARS frontal crashes has also been seen to be true for rear outboard seating positions (Warner, 1997; Padmanaban, 1998). This result is surprising when viewed against the background of conventional wisdom and many studies which have provided estimates of restraint system effectiveness. It should be kept in mind that like many of the severe injuries described in the following sections, the FARS data generally represent the higher end of the crash severity spectrum. The performance advantages of lap and lap-shoulder belts when used properly are unquestionable for low and moderate crash severities, and in many examples of severe crashes. Clearly, extreme impact distributions and structural intrusions are involved in many fatal frontal crashes, rendering any restraint system less effective.

The protective benefit afforded to users of all types of occupant restraint systems is well known and has been extensively documented. Several general injury reduction principles can be identified with restraint system design. Belt systems are expected to: (1) limit or mitigate to the extent practicable occupant interior contacts, (2) prevent occupant ejection, (3) extend the deceleration force distance of a collision by coupling the occupant with the crush characteristics of the vehicle (4) apply crash forces to the anatomically strongest portions of the human anatomy, and (5) be convenient and comfortable for the user.

Restraint system performance is often criticized by a perceived “failure” to prevent injuries under all accident circumstances and severities. As with any other form of technology, advancements or improvements are all too often prospectively lauded at the expense of earlier designs which were of value but were replaced by systems which held promise of greater benefit. Nowhere has this become more obvious than in the area of restraint system design. A recent example is demonstrative. In 1977, it was claimed that the implementation of driver airbag systems alone would save 96,000 lives per decade using a nominal projection (NHTSA, 1977). That estimate was incorrect by a large factor. In actuality, only approximately 1,700 lives have been saved in the decade 1986-1996 (NIITS, 1997).

As belt system usage increased, terms like “seat-belt injuries” have come into wide circulation in the medical literature. This review examines many case reports which compare the types of injuries reduced by use of belt systems versus those injuries “caused” by the various belt systems used. The reader should be aware that, in general, the injuries in such studies arise from accidents in the higher severity range, and in some cases from improper seat belt use. The instances of no or minor injury consequences sustained by occupants using identical restraints systems in similar crashes are usually not reported. Further, the patients which comprise the majority of these “seat belt injury” reports in all probability, would have suffered serious or perhaps fatal injury if they had not been wearing seat belts. It is often forgotten that seat belts per se are not hazardous. Further, the issue of “causation” of certain types of injuries is the consequence of a variety of additional factors that can not be related to a specific type of restraint system to the exclusion of all others.

A proper engineering approach to injury analysis includes many physical and biomechanical factors influencing restraint system/occupant injury performance. It is difficult to assess the importance of these factors in the absence of an in-depth investigation of many crash factors not available to most medical authors. Among these are vehicle factors relating to crash severity and engineering factors such as seat design (geometry,
structure, seat and interior trim). Other aspects of restraint performance include restraint design features such as anchorage geometry, webbing areas, webbing material elongation, force limiting energy absorbing devices, retractor behavior, and pretensioners. Also important are factors of occupant anatomy and crash tolerance such as stature, weight, age, gender, obesity and pre-existing health conditions. Further, usage variables can be pivotal to successful belt performance: anatomical positioning, pre-impact position, and belt slack being very important.

In contrast to a multi-disciplinary approach which could possibly discern many of these factors, most medical articles in this area simply contain assessments of the medical condition of patients seen in hospital emergency rooms with little or no information regarding the crash severity, the vehicle, and its restraint. While these reports are potentially of great value to a physician who may attempt to treat a similar injury in other cases, they offer little useful information to one who is interested in restraint effectiveness evaluation or design.

Seat belts (or any of many other injury reduction devices taken singly or together) do not constitute a panacea for all crash injuries. Used properly, they are a highly valuable and essential contribution to injury reduction. However, the fact that certain injuries are associated with each kind of restraint system in severe crashes must be kept in the context of the multiple injuries they help us to avoid.

IV. “INJURY TYPES” AND RESTRAINT SYSTEM DESIGNS

Since the first use of the term “seat belt syndrome” (Garrett, 1962), it has been employed extensively to describe those injuries associated with the restraining effect of both lap and lap/shoulder restraint systems (Asbun, 1990; Bibliography No. 62). Generally, those injuries are claimed to be the result of decelerative forces being directed through the restraint system webbing to the underlying anatomical structures (Pansky, 1984). The reviewed medical bibliography does not purport to be all-inclusive, comprising each and every publication on these injury types. Rather, it is meant, rather to provide a starting point from which more exhaustive research can commence for those interested in these injuries.

Injuries of various types are frequently associated with a particular type of restraint system. Lap belts have been variously reported as being the “cause” of lumbar spine fractures and various abdominal injuries. As will be seen, many of the cases reported as “lap belt injuries” come from medical case histories from the 1960’s and 1970’s.

Careful review of the papers indicates that similar injuries to these body regions have been documented in occupants using lap and occupants using lap/shoulder belt systems, again without controlling for accident severity. The literature reviewed is readily divided regarding injured skeletal and soft tissue systems as shown in figures 1 and 2 (Pansky, 1984; Pike, 1990):

- cervical spine/neck
- thoracic spine
- lumbar spine
- thorax and contents
- abdomen contents

Figure 1. Topography of Abdomen and Thorax
Table 2 identifies the specific citations for each region. Figure 3 (adapted from NHTSA, 1992) demonstrates the frequency distribution by region of numbers of citations reviewed. Table 3 gives a summary of reviewed citations regarding the 5 areas.

The authors were surprised to note that there were a greater number of citations relating to lap/shoulder belts than to lap belts in every anatomical region but one. Early citations were understandably linked predominantly to lap-belt-related injuries. These have been mistakenly cited out of context in some litigation situations as proof that addition of a shoulder belt would have prevented a specific injury. As is seen, this is not generally the case.

Some of the occupant injuries are reported as consequential injuries, resulting from contacts with the interior of the vehicle or other objects (Bibliography Nos. 18, 24, 33, 46, 52, 60, 120, 128, 129 refer to lap belt related cervical spine injuries among others). These are beyond the scope of this study.

V. DISCUSSION:

Perusal of the literature cited above provides a perspective on belt-related injuries in severe frontal crashes. The lumbar spinal and abdominal injuries often identified with lap belt forces applied above the bony pelvis are severe and often catastrophic. However, they are neither unique to the lap belt nor more severe than cervical spinal and carotid artery injuries which may result from lap/shoulder belt forces in other severe exposures.

It is clear that injuries will continue to occur in severe crashes, and that some of them will result from loadings which occur during contact with restraint systems which have been designed and proven to save lives and prevent injuries over the broad spectrum of crash severities.

Table 3. Summary of Injury Citations by Type of Restraint and Body Region

<table>
<thead>
<tr>
<th>Body Region</th>
<th>Lap Belt</th>
<th>Lap/Shoulder Belt</th>
<th>Not Specified or Other Belt</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Spine/Neck</td>
<td>....</td>
<td>34</td>
<td>7</td>
</tr>
<tr>
<td>T-Spine</td>
<td>9</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>L-Spine</td>
<td>34</td>
<td>32</td>
<td>3</td>
</tr>
<tr>
<td>Thorax</td>
<td>8</td>
<td>38</td>
<td>4</td>
</tr>
<tr>
<td>Abdomen</td>
<td>26</td>
<td>70</td>
<td>17</td>
</tr>
</tbody>
</table>

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One is well advised to remember the overwhelming benefits of belt restraints in injury avoidance and mitigation while researching those relatively few cases in which injuries relating to restraint loadings, which result from the high forces generated in high-severity crashes.
Figure 2. The Spine (Pike, 1990)

<table>
<thead>
<tr>
<th>Body Region</th>
<th>Lap Belt Only</th>
<th>Lap/Shoulder Belt</th>
<th>Not Specified or Other Belt</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Spine &amp; Neck</td>
<td>0</td>
<td>12, 13, 18, 19, 24, 30, 32, 34, 35, 37, 39, 40, 41, 45, 46, 48, 52, 53, 60, 71, 86, 87, 89, 96, 116, 117, 118, 121-23, 126, 128, 129</td>
<td>34, 35, 46, 61, 85, 88, 127</td>
</tr>
<tr>
<td>T-Spine</td>
<td>18, 20, 24, 33, 38, 52, 120, 128, 129</td>
<td>6, 13, 18, 22, 24, 30, 39, 40, 48, 52, 63, 109, 116, 117, 118, 121-23, 126, 128, 129</td>
<td>0</td>
</tr>
<tr>
<td>Thorax</td>
<td>24, 33, 52, 60, 100, 120, 128, 129</td>
<td>8, 11, 23, 24, 31, 32, 33, 39, 40, 44, 52, 54, 56, 57, 58, 60, 65, 69, 70, 71, 74, 78, 84, 90, 91, 96, 99, 111, 112, 116, 117, 118, 121-23, 126, 127, 132</td>
<td>9, 10, 33, 44</td>
</tr>
<tr>
<td>Abdomen</td>
<td>1, 3, 7, 14, 18, 20, 22, 24, 26, 29, 38, 47, 52, 55, 60, 69, 75, 97, 98, 114, 119, 120, 124, 128, 129</td>
<td>1, 2, 3, 4, 7, 8, 14, 15, 16, 17, 18, 20, 21, 22, 24, 25, 26, 27, 28, 29, 31, 33, 36, 37, 38, 39, 40, 42, 43, 44, 47, 48, 49, 50, 52, 55, 56, 57, 58, 59, 60, 62, 64-70, 72, 73, 75, 76, 81, 82, 91, 92, 111, 116, 117, 118, 119, 121-23, 127, 128, 129, 131</td>
<td>5, 9, 10, 33, 43, 44, 62, 73, 75, 77, 79, 80, 83, 92, 95, 125, 127</td>
</tr>
</tbody>
</table>

Table 2. Injury Citations by Type of Restraint and Body Region
REFERENCES

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Pike, 1990

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