"Predictive Modeling of Injury Severity Utilizing Pre-hospital Trauma Triage and Mechanism of Injury Criteria for Advanced Automatic Crash Notification (AACN) Systems"

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HARBORVIEW
INJURY PREVENTION
& RESEARCH CENTER

NHTSA Priorities

- **Advanced Automatic Collision Notification (AACN)**
- Description: AACN provides early contact with emergency personnel and GPS position when a severe crash occurs. Examine potential benefits and triage capabilities of AACN and **EMS connection to get serious injuries to a Level 1 trauma hospital**. Determine whether a rulemaking is warranted.

The NEW ENGLAND JOURNAL of MEDICINE

SPECIAL ARTICLE

A National Evaluation of the Effect of Trauma-Center Care on Mortality

Ellen J. MacKenzie, Ph.D., Frederick P. Rivara, M.D., M.P.H., Gregory J. Jurkovich, M.D., Avery B. Nathens, M.D., Ph.D., Katherine P. Frey, M.P.H., Brian L. Egleston, M.P.P., David S. Salkever, Ph.D., and Daniel O. Scharfstein, Sc.D.

ABSTRACT

BACKGROUND

Hospitals have difficulty justifying the expense of maintaining trauma centers without strong evidence of their effectiveness. To address this gap, we examined differences in mortality between level 1 trauma centers and hospitals without a trauma center.

METHODS

Mortality outcomes were compared among patients treated in 18 hospitals with a level 1 trauma center and 51 hospitals without a trauma center (non–trauma centers) located in 14 states. Patients 18 to 84 years old with a moderate-to-severe injury were eligible. Complete data were obtained for 1104 patients who died in the

From the Johns Hopkins Bloomberg School of Public Health, Center for Injury Research and Policy, Baltimore (E.J.M., K.P.F., B.L.E., D.S.S., D.O.S.); and the University of Washington School of Medicine, Harborview Injury Prevention and Research Center, Seattle (F.P.R., G.J.J., A.B.N.). Address reprint requests to Dr. MacKenzie at Johns Hopkins Bloomberg School of Public Health, 624 N. Broadway, Rm. 554, Baltimore, MD 21205-1996, or at emackenz@jhsph.edu.

Research conducted at Harborview Injury Prevention and Research Center

If you are severely injured, care at a Level I trauma center lowers the risk of death by 25%.

McKenzie, Rivara, Jurkovich…
NEJM, 2006

NHTSA AACN Activities

Outline

1. Overview
2. NHTSA and NHTSA/CDC AACN Work
3. EDR Rule and Analysis
4. Injury Prediction Algorithms
5. AACN Scorecard/Next Steps

Getting from Crash to Trauma Center

- Finding the car
- Notifying 9-1-1
- Appropriate EMS response
  - Getting the right people there
- Triage
  - Getting the **right patient** to the **right** hospital
- Care and transport
- Designated trauma centers
- Consistent communication essential

Current Need for Crash Notification Systems and GPS locations – CIREN case studies

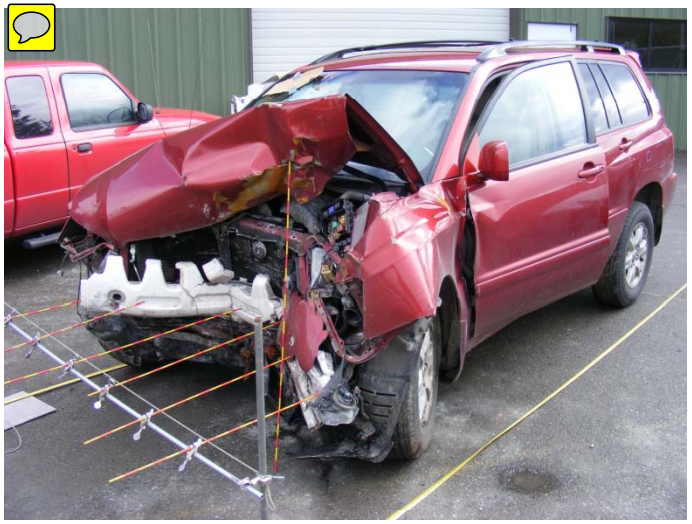
-Driver found after 8 days, departed roadway down into roadside ravine

-Survived with critical injuries after very long treatment at the trauma center

-Would have benefited greatly from initial EMS response

Need for Crash Notification Systems for Notification and GPS locations – CIREN case studies

An elderly couple struck a tree late evening and rotated into ditch out of site



- Couple not found until next morning and passenger had died and driver was critically injured

-Injuries appeared survivable if EMS response was initiated

Background
NHTSA/CDC AACN Work

CDC

MMWR™

Morbidity and Mortality Weekly Report

www.cdc.gov/mmwr

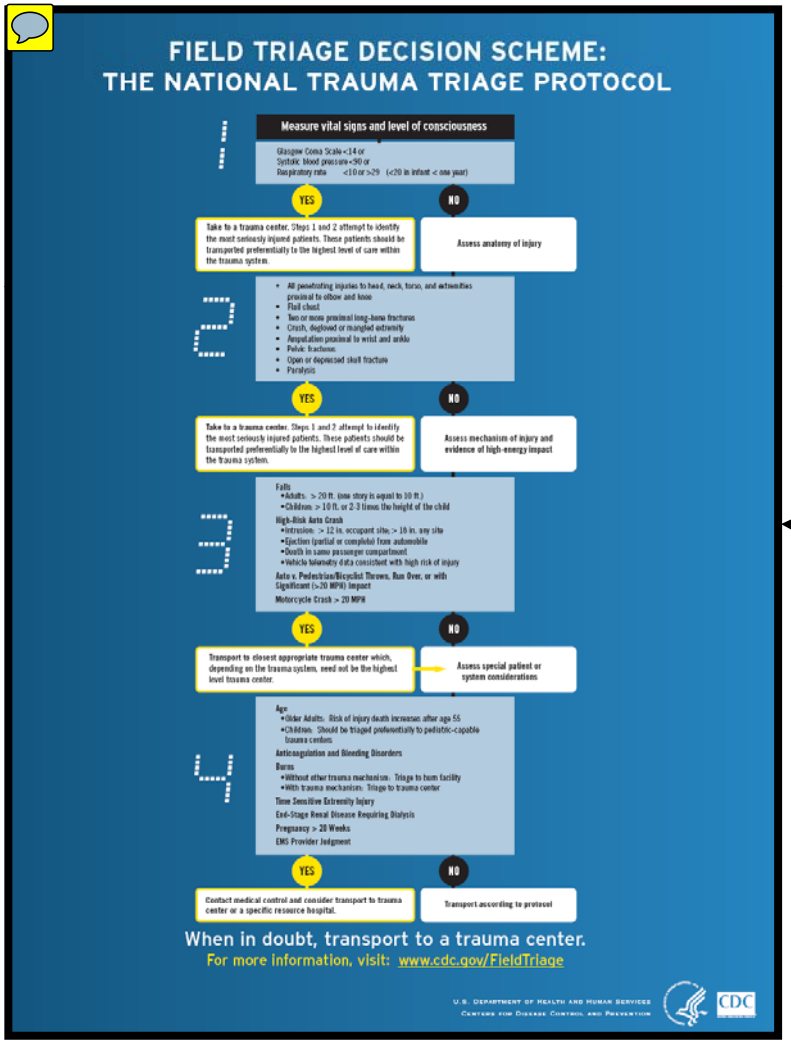
Recommendations and Reports — January 23, 2009 / Vol. 58 / No. RR-1

Guidelines for Field Triage of Injured Patients

Recommendations of the National Expert Panel on Field Triage

DEPARTMENT OF HEALTH AND HUMAN SERVICES
CENTERS FOR DISEASE CONTROL AND PREVENTION

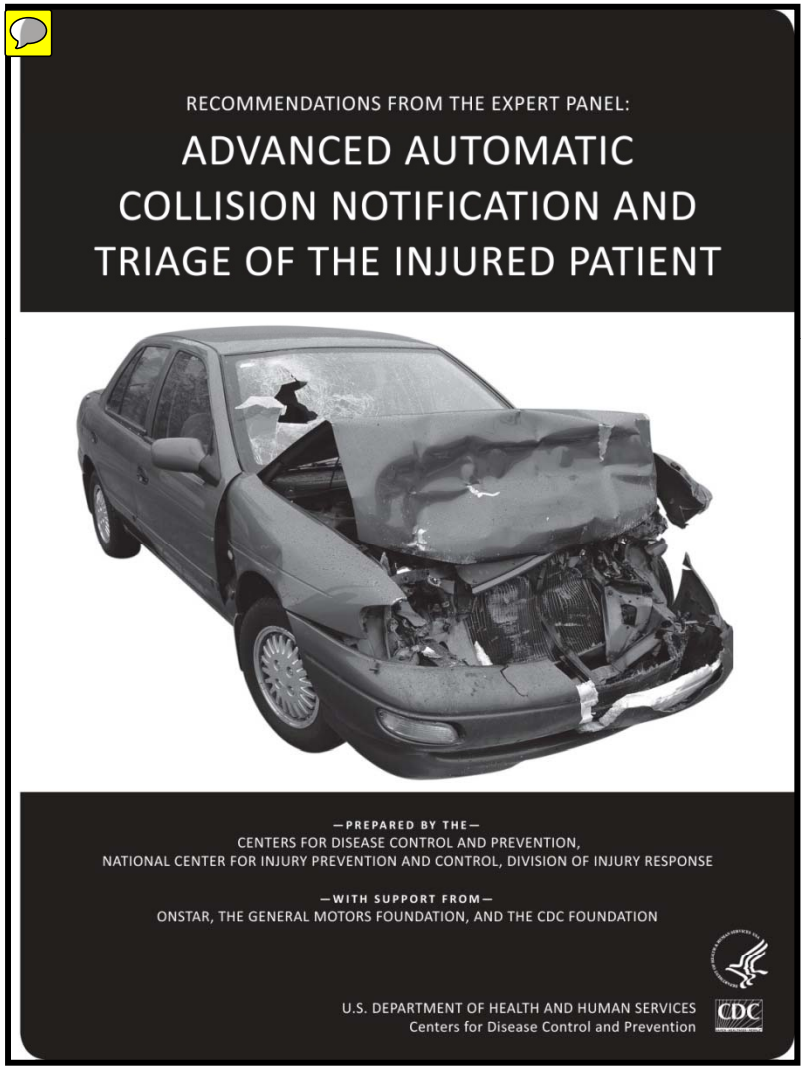
NHTSA/CDC AACN Work



Field Triage Decision Scheme

"Vehicle telematics consistent with high risk of injury"

NHTSA/CDC AACN Work



Advanced Automatic Crash Notification

- Critical information helpful to dispatch, respond and triage an injured occupant to final destination
  - Velocity change of vehicle
  - Principle Direction of Force
  - Seat belt usage
  - Crash with multiple impacts
  - Vehicle type
  - Voice (GCS proxy)
- Information can be collected in vehicle EDR for transmission

Event Data Recorders (EDRs)

- NHTSA published a final rule on August 28, 2006 regulating Event Data Recorders (EDR)
- Effective date of rule is Sept. 1, 2012

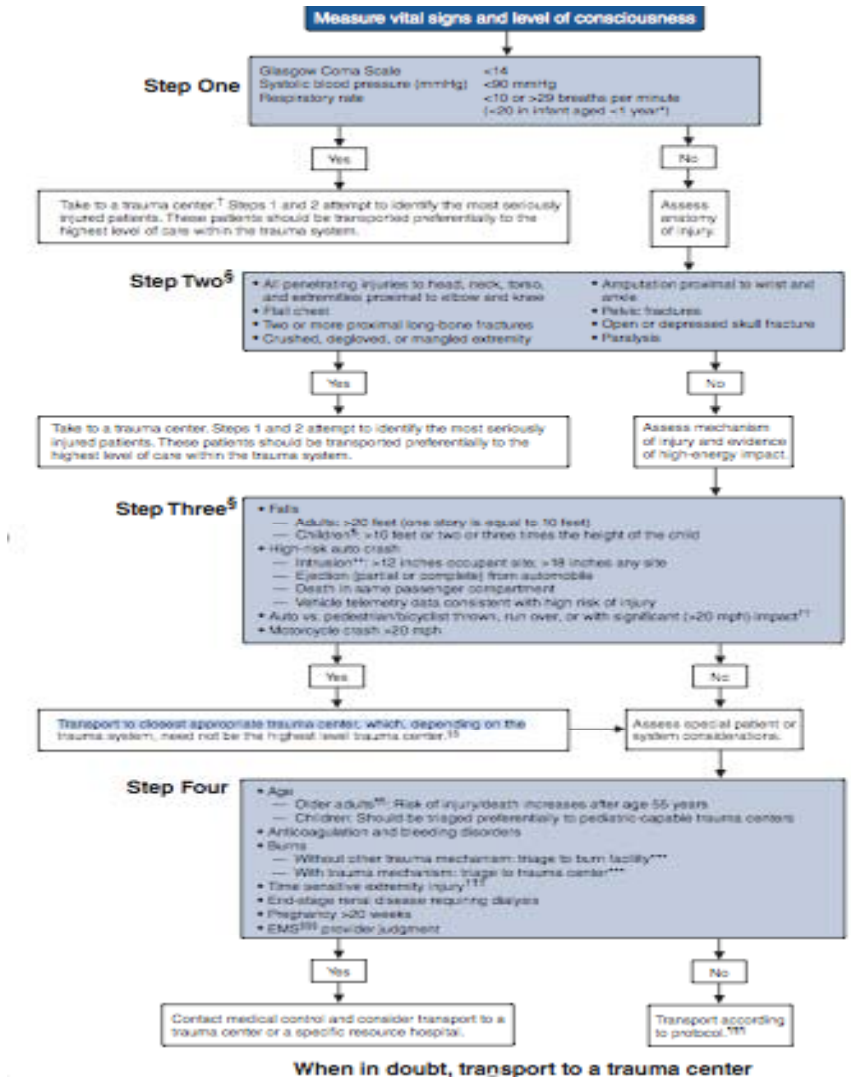
AACN : Next Steps

- AACN data can be used to predict injury severity, conveyed to EMS services and trauma centers, and integrated into the field triage process.
- CDC and NHTSA
  - Working together to create awareness
  - Meeting with industry to solicit cooperation
  - Determining course of action relative to Expert Panel Recommendations
  - Determining benefits

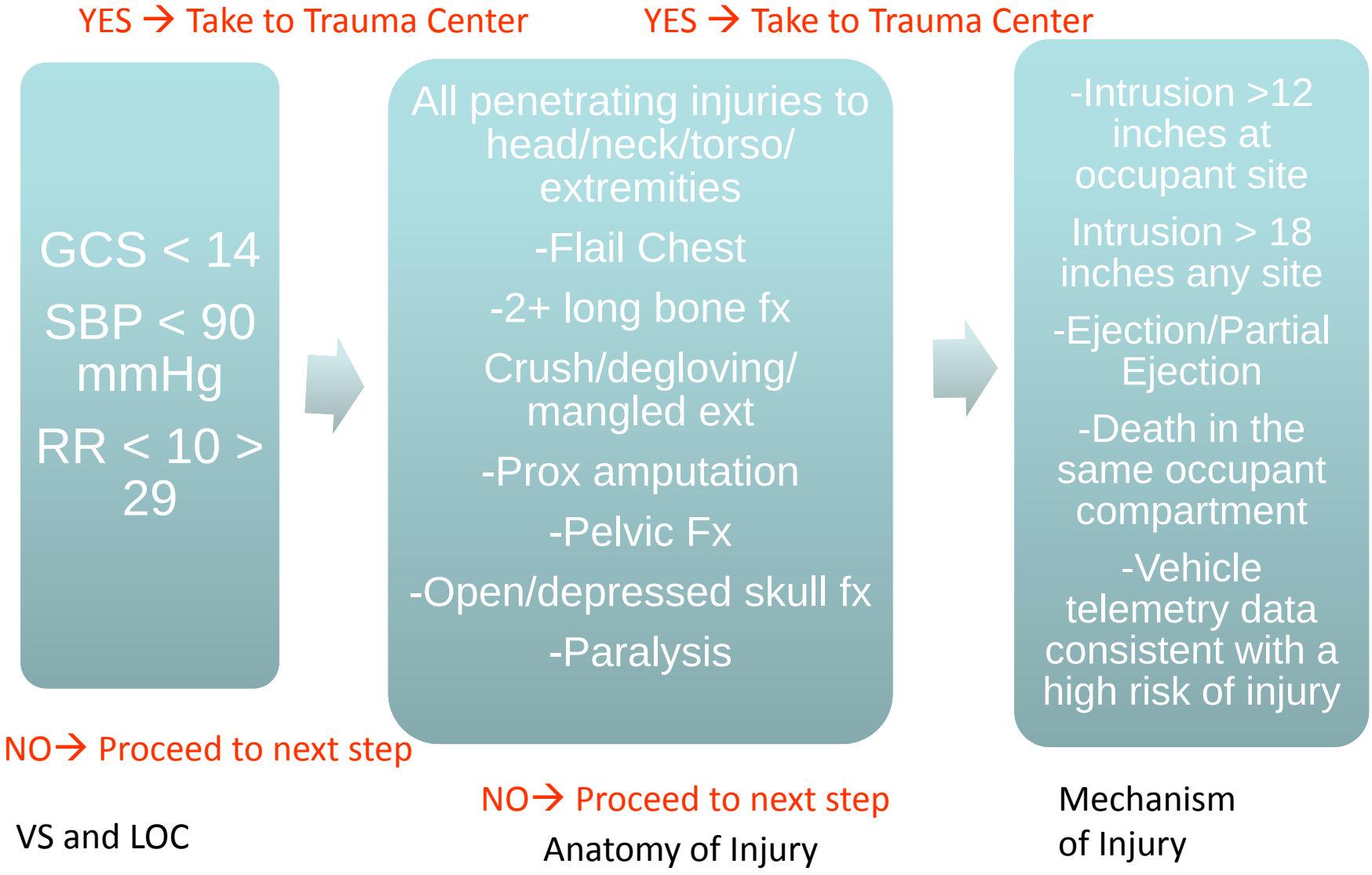
AACN

- Shows promise in improving outcomes in severely injured crash patients by:
  - Predicting the likelihood of serious injury
  - Decreasing response time
  - Assisting with field triage decisions
  - Decreasing time to trauma center
  - Decreasing death and disability

Triage Steps to Determine Transport to Level 1 Trauma Center



Current CDC GUIDELINES



Background: Evidence for 2006 Guidelines

- 1995: South Carolina EMS registry data
  - 66 (16.1%) of 411 patients meeting mechanism-of-injury criteria had ISS of >15
  - 262 (63.7%) with ISS > 15 had mechanism of injury as the sole indication (i.e., with no physiologic or anatomic criteria)
  - MOI: Adding MOI criteria increased sensitivity for identifying severely injured patients

Norcross ED, Ford DW, Cooper ME, Zone-Smith L, Byrne TK, Yarbrough DR. Application of American College of Surgeons' field triage guidelines by pre-hospital personnel. J Am Coll Surg 1995;181:539–44.

Background: Evidence for 2006 Guidelines

- 1997: Prospective study of 3,147 trauma patients
  - mechanism-of-injury criteria alone had a sensitivity of 70% for identifying patients with ISS of >16
  - Criteria: Ejection, occupant death, extrication time > 20 min

Bond RJ, Kortbeek JB, Preshaw RM. Field trauma triage: combining mechanism of injury with the prehospital index for an improved trauma triage tool. J Trauma 1997;43:283–7.

Predicting Trauma Center Need using the Mechanism of Injury Criteria

- Prospective observational study: 3 Level 1 Trauma Centers
- Adult injured patient (all ISS included)
- EMS interviewed upon ED arrival
- Patients who met step 1 or step 2 were excluded
- Used 1999 Field Triage Guideline Criteria
- Patients were followed to hospital discharge
- Definition: NEED TRAUMA CENTER:
  - Surgery (non-orthopedic) within 24 hours of ED arrival
  - Death prior to discharge
  - Admission to the ICU
- Data was analyzed by calculating sensitivity, specificity, likelihood ratios, and ROC curves

Lerner EB, Shah MN, Swor R, Cushman J, Guse C, Brasel K, Blatt A, Jurkovich GJ: Predicting Trauma Center Need using the Mechanism of Injury Criteria. Prehospital Emergency Care 2011; 15:518-525

Results:

- 11,892 interviews conducted (9,483 patients Mechanism only) Likelihood Ratios

Criteria	TC NEED	ISS > 15
Death of an occupant	6.8 (2.7-16.7)	5.5 (2.2-13.6)
Extrication> 20min	5.1 (3.2-8.1)	3.7 (2.2-6.0)
Intrusion > 12 inches	4.2 (2.9-5.9)	3.2 (2.2-4.6)
Ejection	3.2 (1.3-8.2)	7.1 (3.6-14.1)
Deformity >20 inches	2.5 (1.9-3.2)	2.2 (1.7-2.8)
Speed > 40mph	2.0 (1.7-2.4)	1.8 (1.5-2.1)
Rollover	1.0 (0.7-1.5)	1.2 (0.9-1.7)

Comparison of CDC Guidelines 1999 to 2006

1999	CRITERIA	2006
x	Ejection	x
x	Death in Same Compartment	x
x	Intrusion > 12 inches	Changed: >12" on pt side and >18" any side
x	Deformity > 20 inches	removed
Not included	Vehicle Telemetry Data consistent with a high risk of injury	x
x	Extrication time > 20 minutes	removed
x	Initial Speed > 40 mph	removed
x	Rollover	removed

Lerner EB, Shah MN, Swor R, Cushman J, Guse C, Brasel K, Blatt A, Jurkovich GJ: Comparison of the 1999 and 2006 Trauma Triage Guidelines: Where do the Patients Go?

HIPRC/CIREN Research Project:

Validation of Pre-Hospital Triage Mechanism of Injury Criteria

NASS analysis
2006 Mechanism Criteria
Sequential analysis of algorithm

RESULTS

	ISS > 9		ISS > 15	
Criteria	**PPV %**	**NPV%**	**PPV %**	**NPV%**
Step 1	26.1	96.7	21	98.8
Step 2	92.9	97.1	48.5	99
Step 3	22	97.9	9.7	99.4
Step 4	3.6	98.1	1.4	99.4
Intrusion 30	36.2	96.4	21.9	98.5
Intrusion 46	32.1	96.3	20.5	98.4
Death in Vehicle	59.6	96.4	47.4	98.9
Ejection	35.6	96.4	22.4	98.5

Seattle CIREN Research Goal:

Develop predictive models for AACN with telemetry data using the triage rules

GCS < 14

SBP < 90 mmHg

RR < 10 > 29

-All penetrating injuries to head/neck/torso/or extremities

-Flail Chest

-2+ long bone fx

Crush/degloving/mangled ext

-Prox amputation

-Pelvic Fx

-Open/depressed skull fx

-Paralysis

-Intrusion >12 inches at occupant site

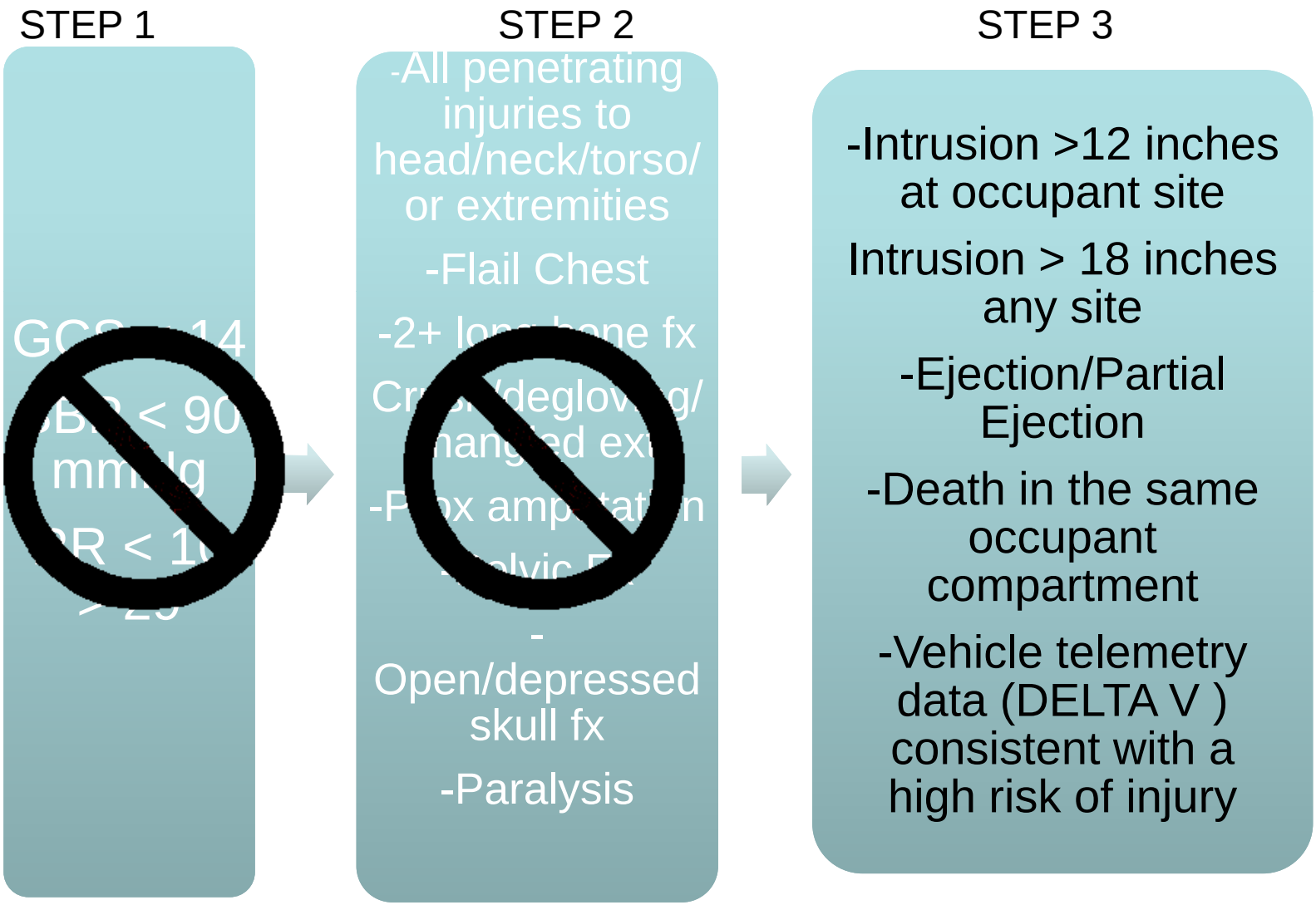
Intrusion > 18 inches any site

-Ejection/Partial Ejection

-Death in the same occupant compartment

-Vehicle telemetry data consistent with a high risk of injury

Analysis focused on Step 3 data that could be utilized for AACN



Methods

- Conducted analysis utilizing NASS data to assess Step 3 mechanism criteria as a predictor of injury severity.
- Use CIREN case studies to illustrate the potential benefits of Step 3 to predict injury severity.

Data Analysis

- Selected all vehicles with model year 2000 and later from the 1999-2009 NASS/CDS data
- To correct for biases from missing data, we imputed missing data 20 times using a system of multivariate imputation by chained equations (MICE) as implemented in Stata

Rue T, Thompson HJ, Rivara FP, Mackenzie EJ, Jurkovich GJ. Managing the Common Problem of Missing Data in Trauma Studies. Journal of Nursing Schollarship. (2008) 40:4, 373-378

Elliot MR, et al. Appropriate analysis of CIREN data: Using NASS-CDS to reduce bioas in estimation of injury risk factors in passenger vehicle crashes. Accid Anal Prev. (2009)

Results

Component	Odds of ISS >= 16	95% C.I.
Magnitude of intrusion 30 cm at site	18.9	(14.0, 25.5)
Magnitude of intrusion 46 cm anywhere in passenger compartment	16.7	(10.6, 26.2)
Ejected from vehicle	47.5	(35.6, 63.4)
High dV (40+ kph)	13.1	(9.98, 17.2)
Rollover (3+ quarter turns)	10.4	(7.2, 15.2)
Death in vehicle	111.7	(84.1, 148.4)
Any step 3 criterion	29.4	(22.4, 38.7)
Any step 3 criterion (minus death in vehicle)	23.3	(18.3, 29.7)

- 30cm/12” intrusion at seated position is a statistically superior predictor over DV and rollover.

Death in vehicle is the strongest predictor, but unlikely to be captured by AACN.

Methods:

ISS score			
	Severe >16	Not Severe <16	
Meets step 3 criteria	A	B	PPV: A/A+B
Does not meet step 3 criteria	C	D	NPV: D/D+C
	Sens: A/A+C	Spec: D/B+D	

Results

Step 3 Criteria by ISS

- % of ISS >= 16 meeting Step 3 criteria (Sensitivity of Step 3): 65.6%
- % meeting Step 3 criteria with ISS >= 16 (Positive Predictive Value of Step 3): 13.8%
- % not meeting Step 3 criteria with ISS >= 16: 0.55%

	Step 3 -No	Step 3 -Yes
ISS < 16	92.4%	6.1%
ISS >= 16	0.5%	1.0%

Results

Step 3 Criteria (minus death in vehicle) by ISS

- % of ISS >= 16 meeting Step 3 criteria (minus death in vehicle) (Sensitivity): 60.1%
- % meeting Step 3 criteria (minus death in vehicle) with ISS >= 16 (PPV): 13.1%

	Step 3 -	Step 3 +
ISS < 16	92.5%	6.0%
ISS >= 16	0.6%	0.9%

Results: Current Triage Patterns

- % meeting Step 3 criteria going to Level 1 trauma center: 43.8%
- % meeting Step 3 (minus death in vehicle) going to Level 1 trauma center: 43.7%
- % of ISS >= 16 going to Level 1 trauma center: 63.1%

Utilizing Step 3 Mechanism of Injury today with CIREN data

- Implementing AACN will take time to fully implement

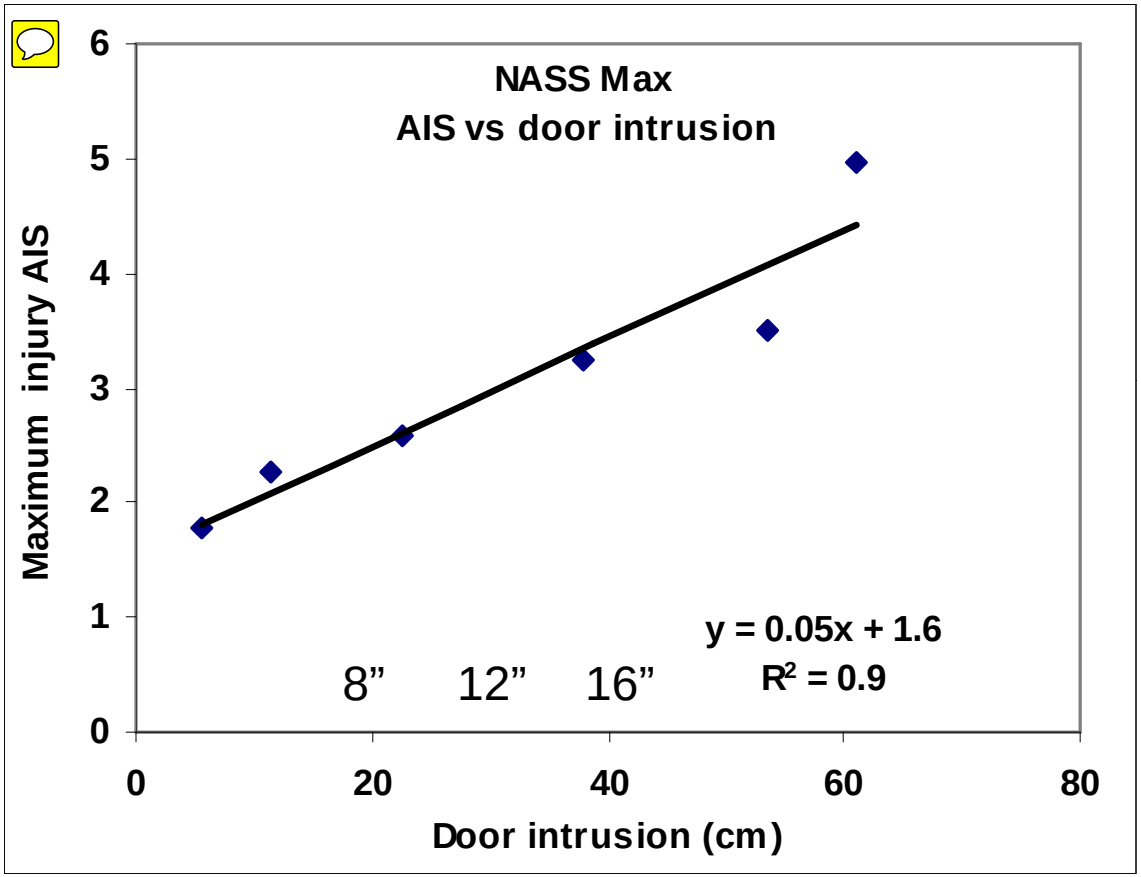
- Seattle CIREN team has trained trauma care providers to begin using the intrusion injury predictors on scene and transmitting digital images to level trauma center

Critical Clues at Crash

One can determine an injury mechanism based on the following:

- Restraint status (most important)
  - witness, first responder, locked open, belt burns
- Identify Seated Location
- Occupant compartment intrusion at patient location of 12” or more
- **Intrusion = Injury!!**

Results – NASS MAIS v Door intrusion

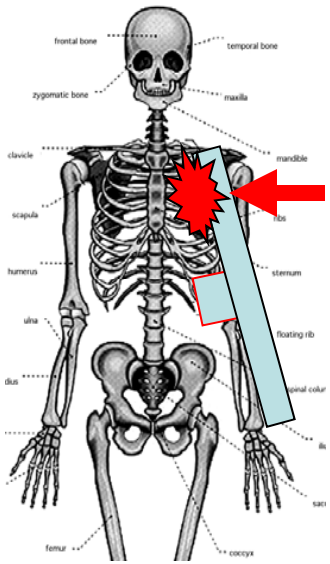


Tencer A., Kaufman R., Mack C., Mock C. Factors affecting pelvic and thoracic forces in near-side impact crashes: a study of US-NCAP, NASS, and CIREN data. Accident Analysis and Prevention - 37 (2005) 287-293.

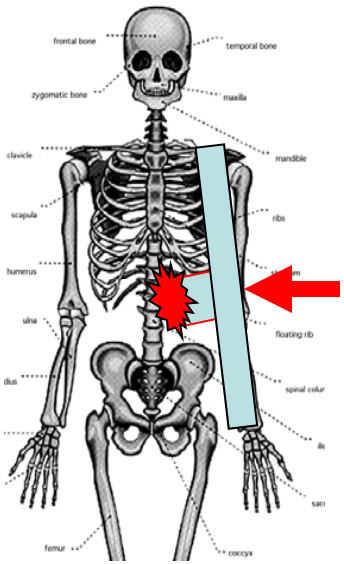
Lateral Impact Mechanism

Intrusion = Injury

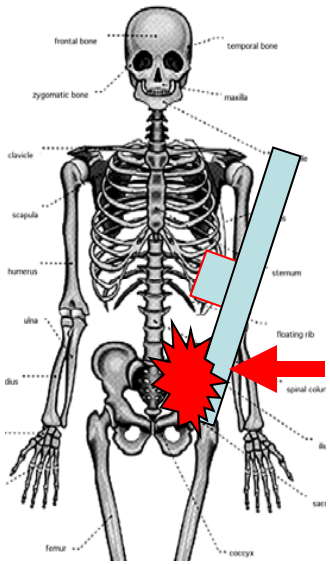
Thorax



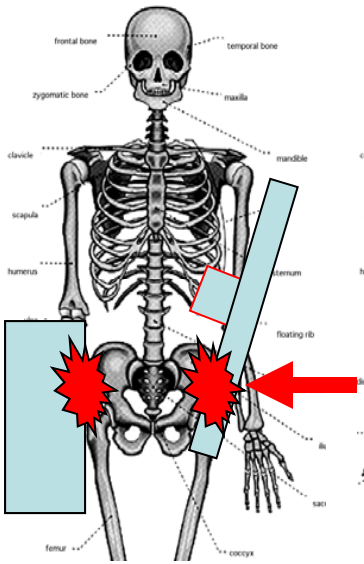
Abdominal



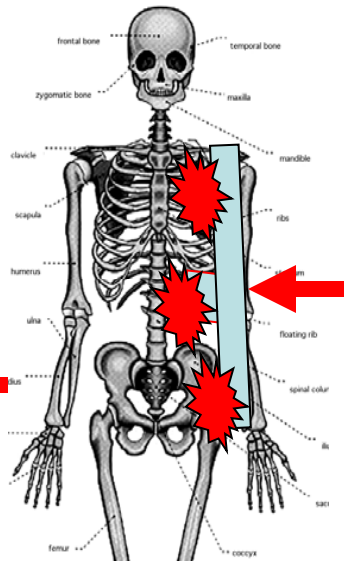
Lateral Pelvis



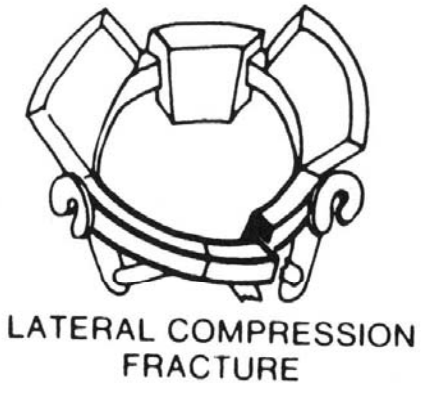
Bilateral Pelvis



Combination



12” of Door Intrusion



AIS 3 Pelvis Fracture to Driver

Intrusion = Injury

12” upper door panel intrusion

Think Thorax!! - AIS 3 Chest Injuries

12” of Instrument Panel Intrusion
AIS 3 Lower Extremity Fractures

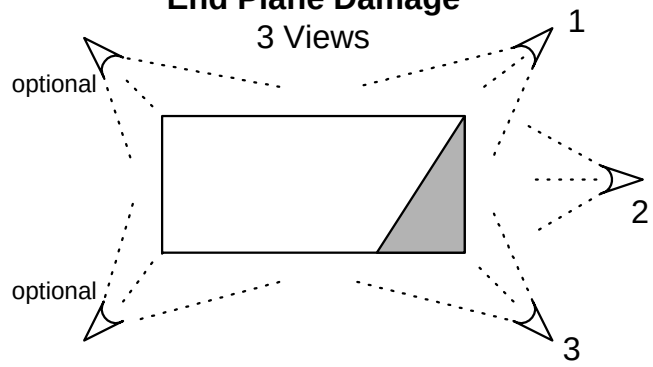
Vehicle Documentation

- First responders document crash vehicles using digital cameras

- Trained medics, trauma staff, law enforcement to interpret intrusion mechanism

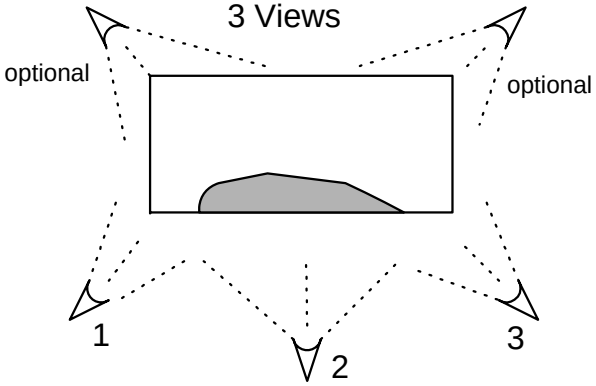
Photography guidelines

End Plane Damage
3 Views



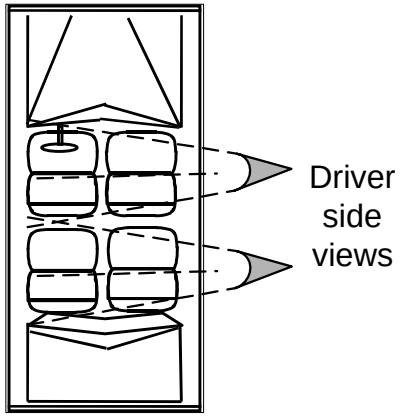
Corner oblique views include both planes

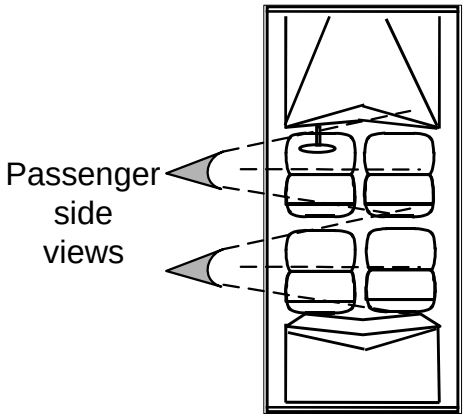
Side Plane Damage
3 Views



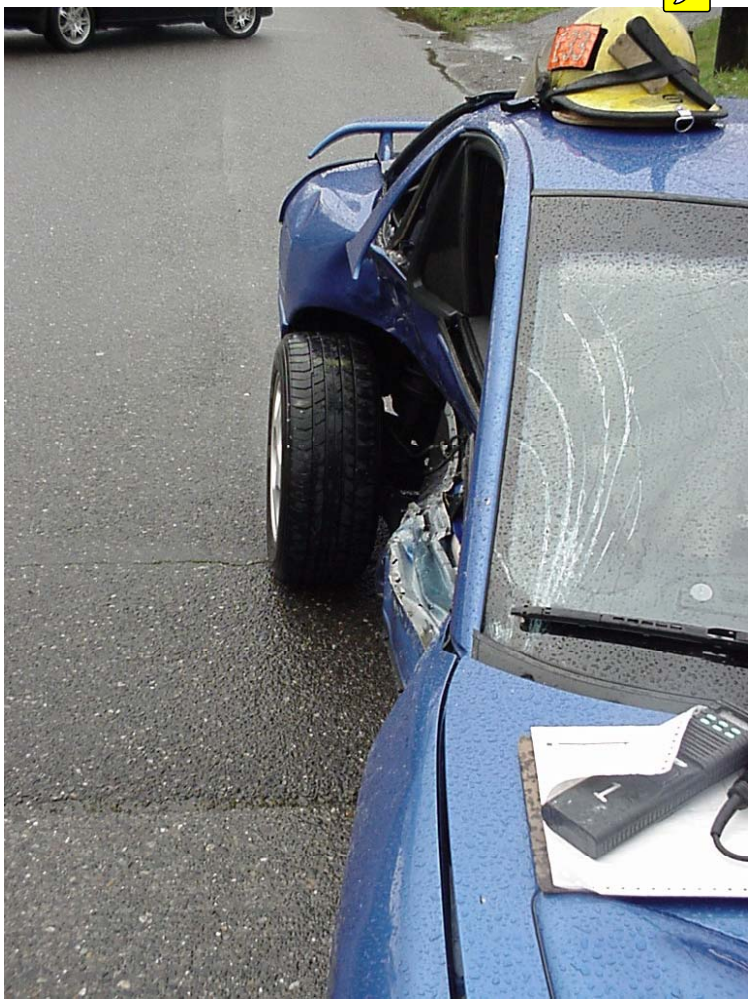
Corner oblique views include both planes

Occupant seated locations
Photo from opposite side





Front Right Passenger Critically Injured




ONE
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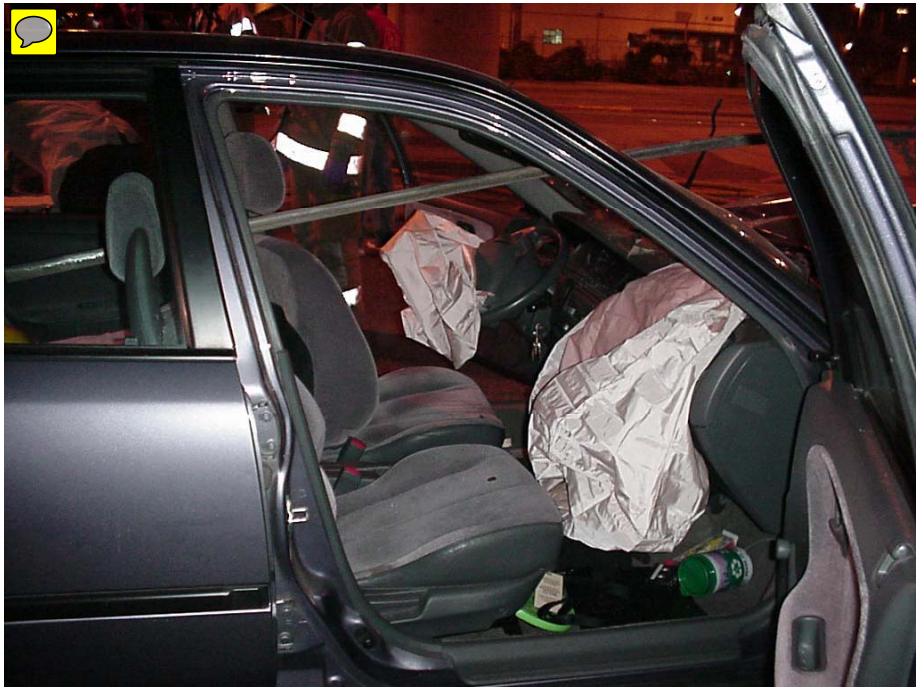
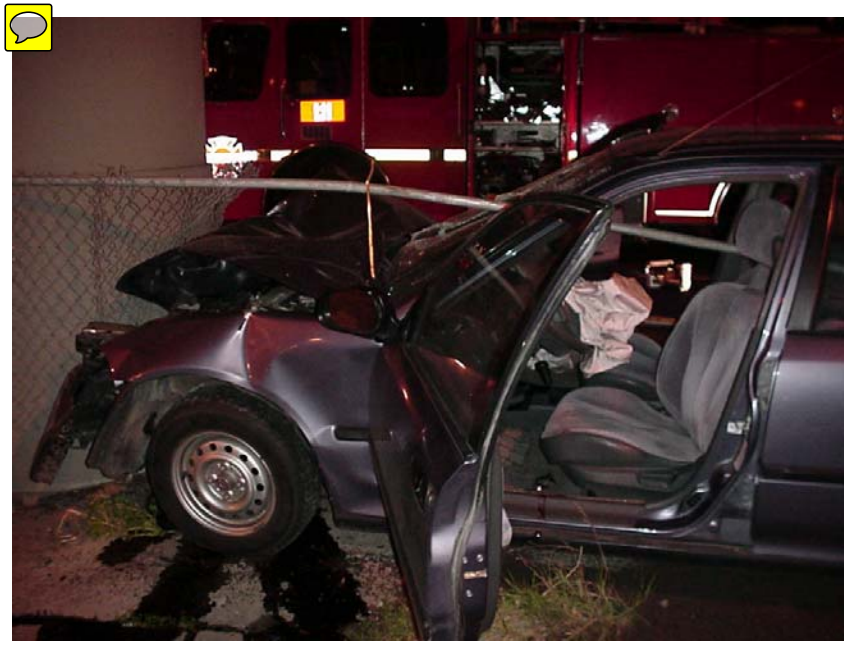
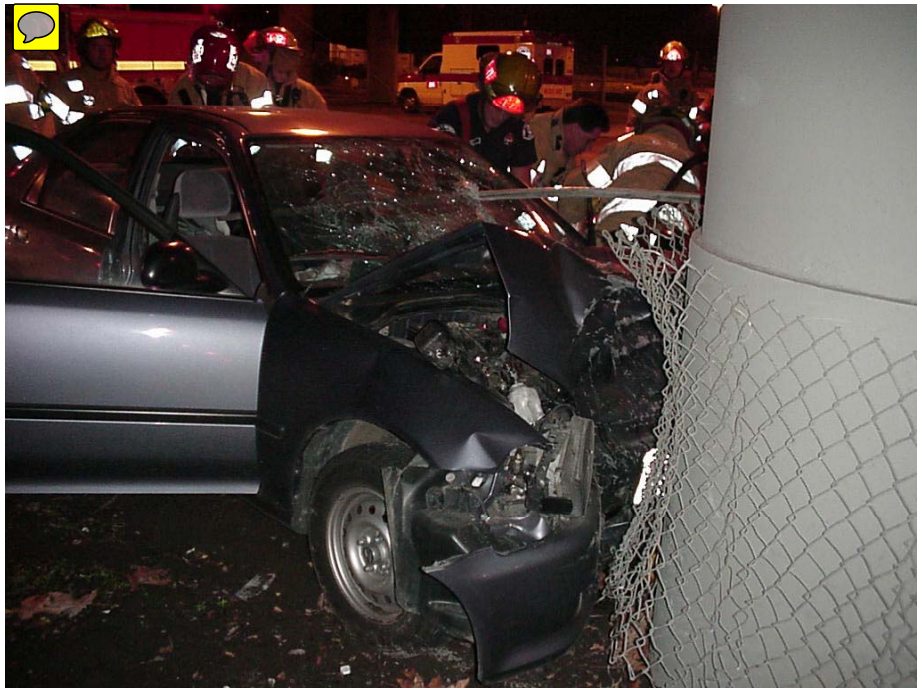
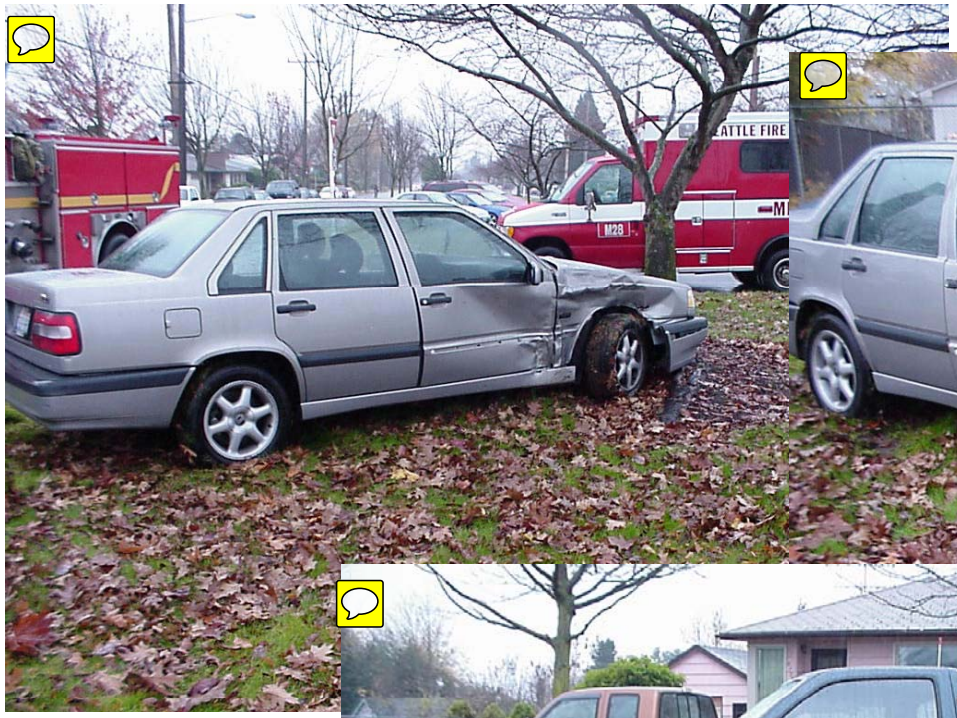




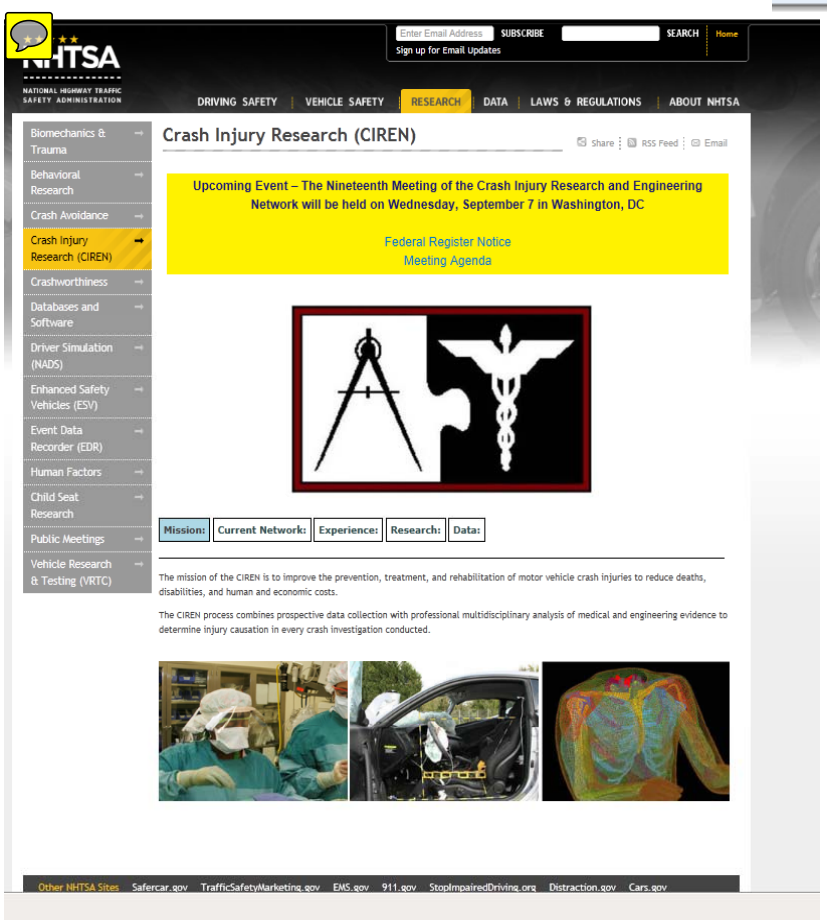


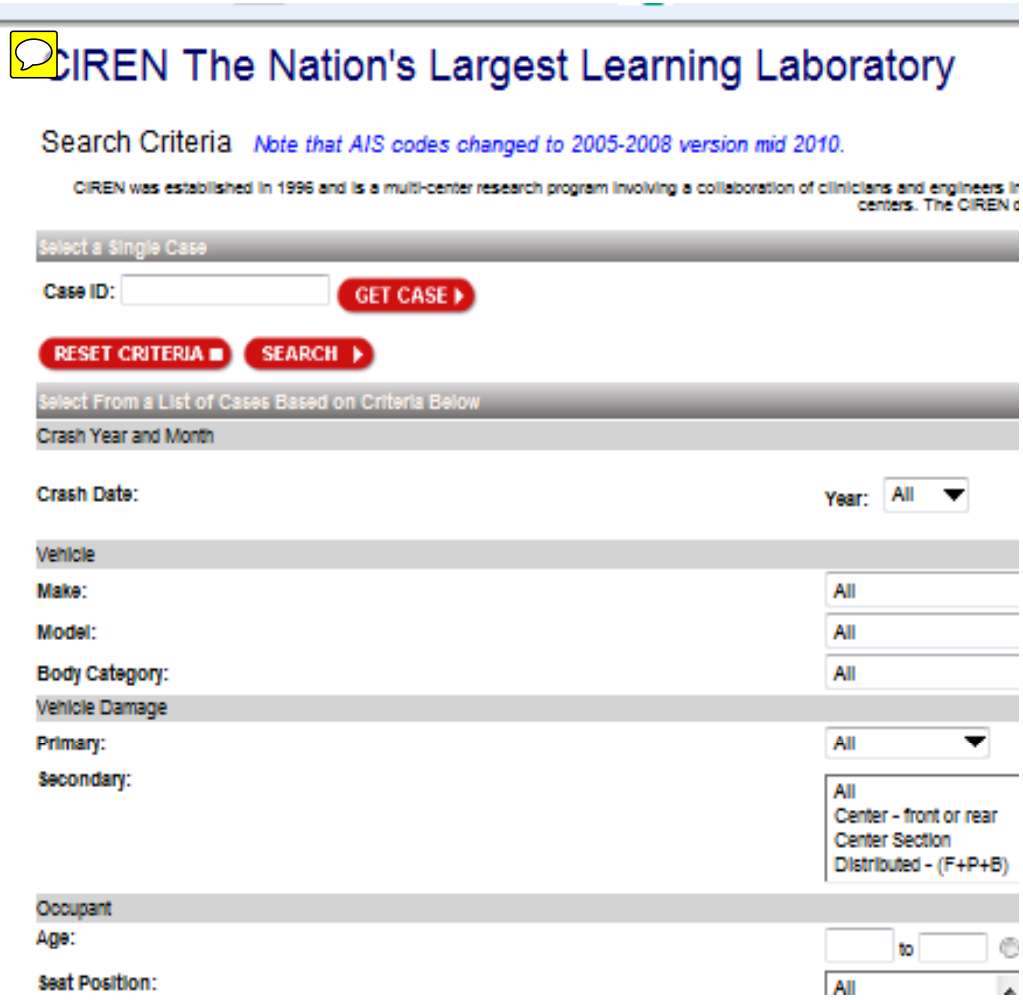

M28


E13

Digital images utilized or even emailed to server at trauma centers

Direct trauma care providers and first responders to utilize CIREN NHTSA web page for on-line training
-Query CIREN electronic cases and review CIREN presentations





CIREN case viewer to assess injury causations and triage rules

CIREN Case Viewer
Case Number: 160117780

New Case Search | Last Case List | Text and Images Only | Print Friendly Version of Case | Print Friendly Version of Current View | Download XML Source | Download XML Schema

Case Overview
- **CIREN Summary**
- CIREN Occupant
- Crash Summary
- Vehicle 1

Crash Overview - Summary

CIREN Summary

Crash Date	06/2004
Gender	Male
Age	57 years
Fate	Not Fatal
ISS	17
MAIS	3

Admissions

Disposition From Acute Hospitalization	HOSPITAL TRANSFER (NOT TRAUMA OR PEDS)
Total Length of Acute Stay	51 days 11 hrs 7 mins
Total ICU Days	22

Medical

Height	175 cms (69 in)
Weight	86 kgs (190 lbs)

Safety Systems

Seat Location	First Left
Occupant Role	Driver
Airbag(s) Status	(1)Air bag available;
Airbag Location(s)	(1)Steering Wheel Hub;
Airbag Deployment(s)	(1)Deployed during crash (as a result of impact);
Seatbelt Availability	Lap and shoulder belt
Seatbelt Lap Position	Snug and low across hips
Seatbelt Shoulder Position	Snugly across the collarbone and over shoulder

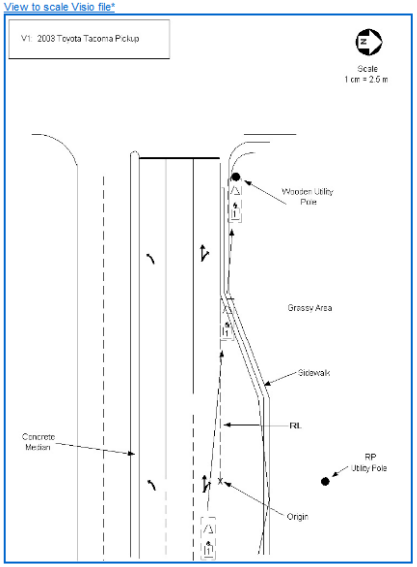
Crash Details

Category	
Object	Nonbreakaway pole or post(>10 cm but <= 30 cm in diameter)
Force Direction	0 degrees
Clock Direction	12
CDC Summary	FCEN03
Total Delta V	Unknown mph

Vehicle

Model Year	2004
Make	TOYOTA
Model	TACOMA

View to scale Visio file*



Crash Summary

Injury Causation

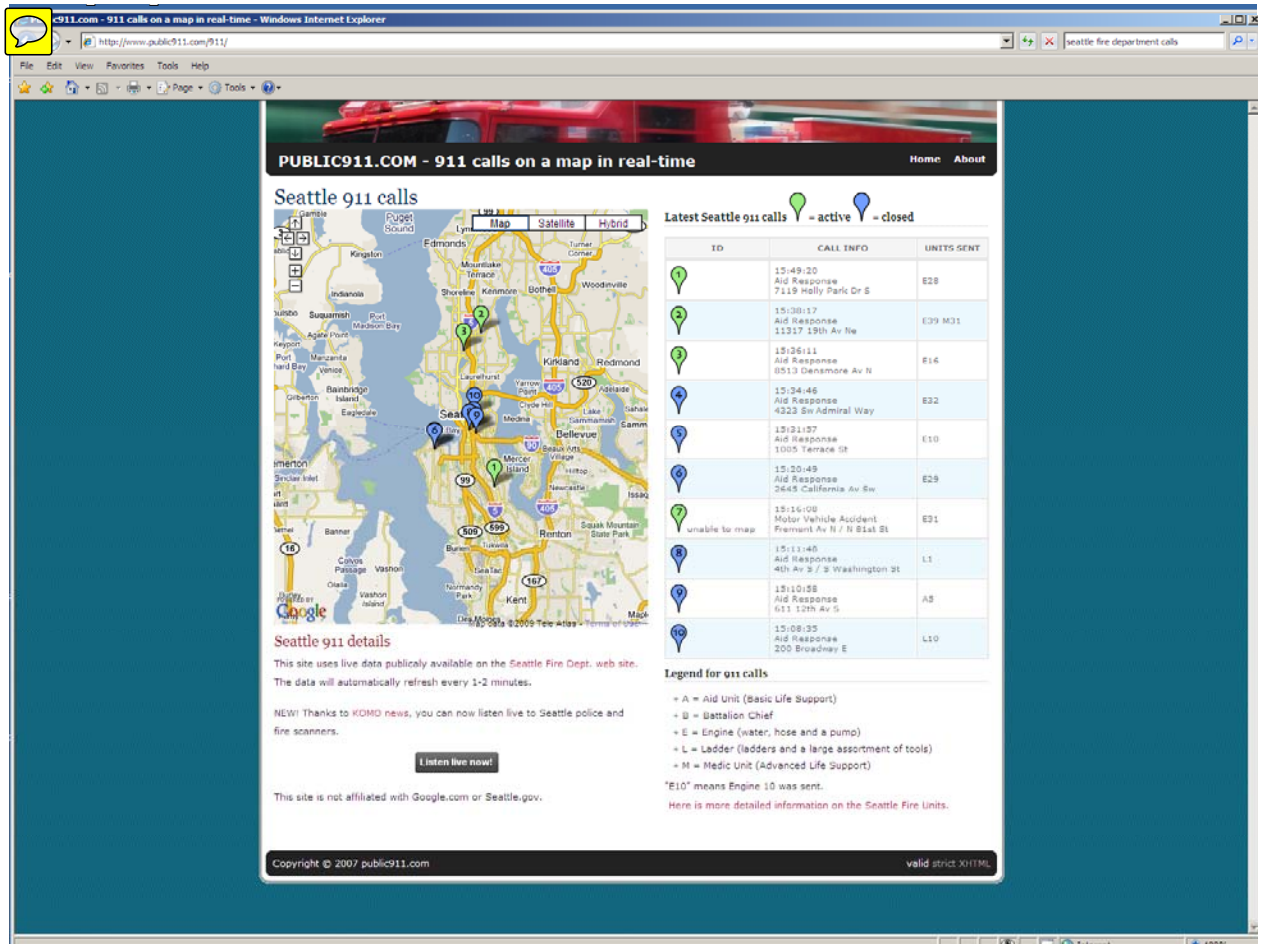
This 57-year-old male case occupant was the driver of a 2004 Toyota Tacoma that was involved in a head-on collision with a wooden utility pole. The case vehicle ran off the right side of the roadway due to the driving being ill, causing the case vehicle to drive up onto the curb and the sidewalk where it struck a wooden utility pole head-on. The case occupant utilized the available 3-point lap and shoulder belt and the available driver front air bag deployed. Upon impact the shoulder portion of the seatbelt limited the chest's forward movement. The forces exerted by the seatbelt on the rib cage caused the sternal contusion, sternal fracture and right-sided rib fracture. The lap portion of the seatbelt is the source of the contusions to the hips. His arms also moved forward where they impacted the instrument panel on both sides of the steering wheel causing the forearm contusion and abrasion on the right and bilateral hand contusions. The left arm possibly struck the door panel causing the left forearm contusion. The straightening of the spine during the crash in combination with the belt use caused spinal column compression which resulted in the lumbar compression fracture. Upon impact the instrument panel and toe pan intruded in the occupant's compartment at the same time as the case occupant's knees moved forward where they struck the knee bolster causing the left patella dislocation and meniscus tear as well as the right knee abrasion. This contact also resulted in axial loading of the left tibia and fibula causing the tibial plateau fracture. The forces exerted on the ankles from the intruding toe pan caused bilateral ankle dislocation with fractures of the left malleolus and talus and fractures of the right distal tibia, fibula and lateral malleolus.

Injury Summary

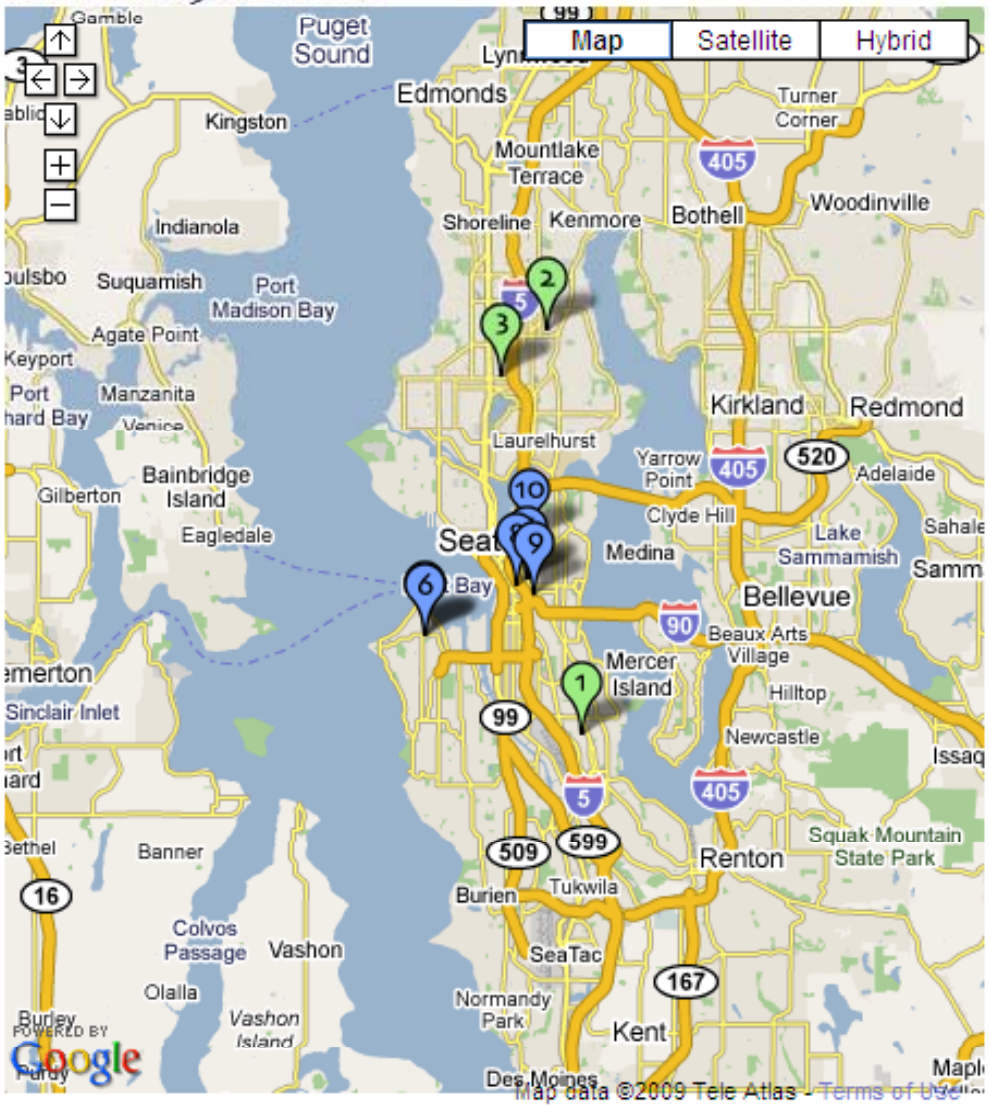
AIS Code	AIS Name	Aspect	Injury Source	Confidence	Rank
8534083	Tibia fracture condyles open/displaced/comminuted	Left;	Knee bolster	Certain	1
8534183	Tibia fracture posterior malleolus open/displaced/comminuted	Left;	Floor (including toe pan)	Certain	2
8516143	Fibula fracture, bimalleolar or trimalleolar, open/displaced/comminuted	Right;	Floor (including toe pan)	Certain	3
8516102	Fibula fracture lateral malleous open/displaced/comminuted	Right;	Floor (including toe pan)	Certain	4
8508222	Knee meniscus tear	Left;	Knee bolster	Certain	5
8502142	Ankle (Tarsus) Joint dislocation without involving articular cartilage	Right;	Floor (including toe pan)	Certain	6
8502142	Ankle (Tarsus) Joint dislocation without involving articular cartilage	Left;	Floor (including toe pan)	Certain	6
8532002	Talus fracture	Left;	Floor (including toe pan)	Certain	7
4502202	Rib cage fracture 2-3 ribs any location (OIS Grade I, II or III)	R Rib 4; R Rib 5;	Belt restraint webbing/buckle	Certain	8
4508042	Sternum, fracture [OIS II, III]Sternum fracture (OIS Grade II or III)	Central;	Belt restraint webbing/buckle	Certain	9
6506322	Vertebra, lumbar spine, fracture with or without dislocation but no cord involvement, vertebral body (""burst"" fracture), minor compression (<=20% loss of anterior height)Lumbar Spine fracture vertebral body minor compression	Inferior/Lower; L5;	Belt restraint webbing/buckle	Probable	10
8508102	Knee dislocation without involving articular cartilage	Left;	Knee bolster	Certain	11
4904021	Chest Skin contusion (OIS Grade I)	Central;	Belt restraint webbing/buckle	Certain	12
7904021	Upper Extremity Skin contusion	Left; Forearm;	Left side interior surface, excluding hardware or armrests	Possible	13
7904021	Upper Extremity Skin contusion	Right; Forearm;	Center instrument panel and below	Probable	14
7904021	Upper Extremity Skin contusion	Left; Hand/Digits;	Left instrument panel and below	Probable	15
7904021	Upper Extremity Skin contusion	Right; Hand/Digits;	Center instrument panel and below	Probable	15
5904021	Abdomen Skin contusion	Whole Region;	Belt restraint webbing/buckle	Certain	16
7902021	Upper Extremity Skin abrasion	Right; Forearm;	Center instrument panel and below	Probable	17
8902021	Lower Extremity Skin abrasion	Right; Knee;	Knee bolster	Certain	18

All Seattle Fire Calls on the Web

- Potential link of digital images to responses



Seattle 911 calls



Seattle 911 details

This site uses live data publicaly available on the Seattle Fire Dept. web site.

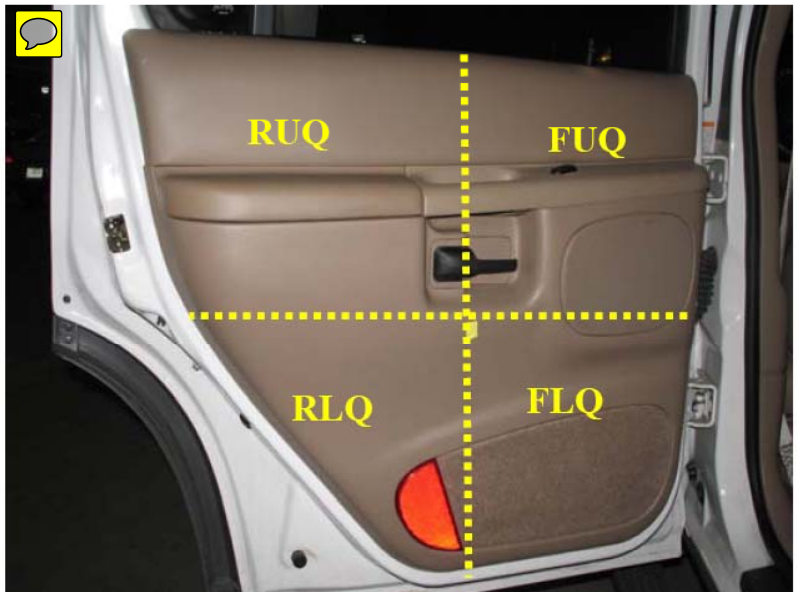
The data will automatically refresh every 1-2 minutes.

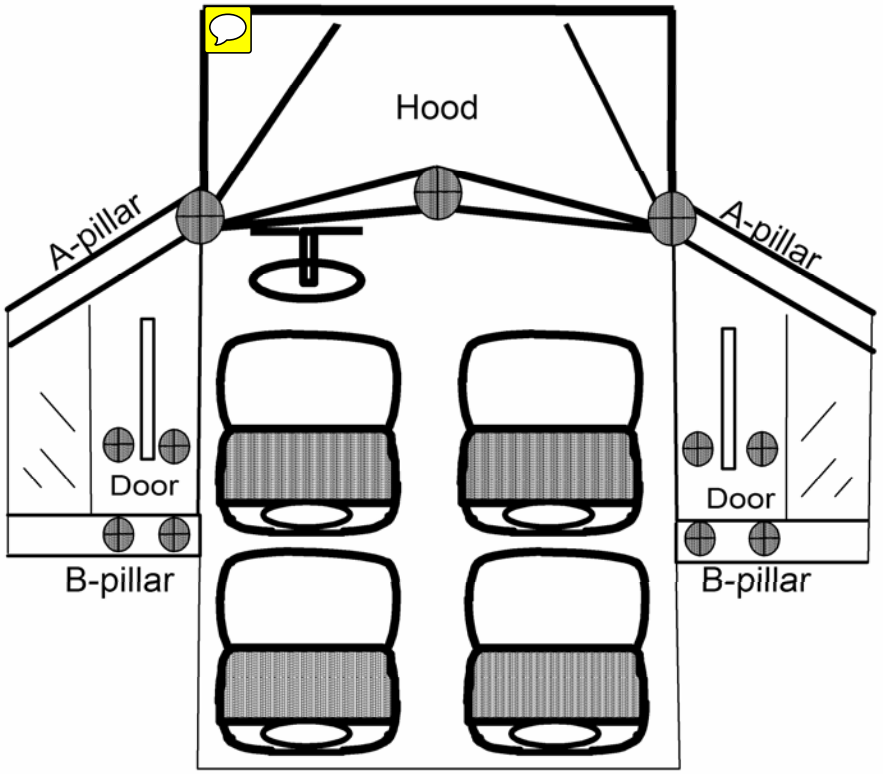
Latest Seattle 911 calls = active = closed

ID	CALL INFO	UNITS SENT
1	15:49:20 Aid Response 7119 Holly Park Dr S	E28
2	15:38:17 Aid Response 11317 19th Av Ne	E39 M31
3	15:36:11 Aid Response 9513 Densmore Av N	E16
4	15:34:46 Aid Response 4323 Sw Admiral Way	E32
5	15:31:57 Aid Response 1005 Terrace St	E10
6	15:20:49 Aid Response 2645 California Av Sw	E29
7 unable to map	15:16:08 Motor Vehicle Accident Fremont Av N / N 81st St	E31
8	15:11:48 Aid Response 4th Av S / S Washington St	L1
9	15:10:58 Aid Response 611 12th Av S	A5
10	15:08:35 Aid Response 200 Broadway E	L10

Legend for 911 calls

Integrate AACN with Intrusion Sensors





CIREN helped to implement door quadrant intrusion measurement documentation for both CDS/NASS and CIREN

Washington State Collision Reporting

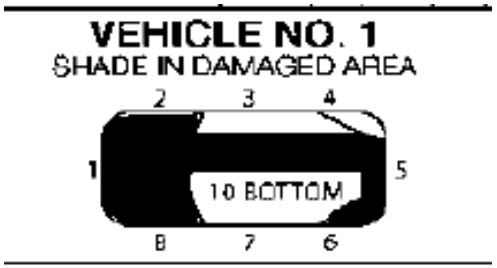
Seattle CIREN assisting in the addition of new elements for the redesign of the officer collision report form:

- Identify vehicles towed due to damage *(vehicle level)*
- Intrusion (12 inches) into vehicle compartment at occupant level (seated position)
- Transport status and facility for each occupant

Washington State Collision Reporting

Seattle CIREN assisting in the addition of new elements for the redesign of the officer collision report form:

- Existing 10 point drawing; No shading, Use numeric system
  - Indicate most severely damaged areas of vehicle (up to 3 choices)
  - For each of 3 possible choices, determine if vehicle damage is “Minor” or “Major” (greater or less than 18” of crush)



Washington State Collision Reporting

Seattle CIREN assisting in the addition of new elements for the redesign of the officer collision report form:

- All collision reports are currently submitted at most jurisdictions electronically (E-reports) in 48 hours.
- Data elements exist to further evaluate triage rules and potentially use CDS stratification rules to evaluate ALL crashes

Conclusions

- Step 3 Mechanism of Injury criteria alone predict 65.6% of severely injured patients requiring a need for level one trauma center
- 30cm/12” of component intrusion at the occupant seated position is a statistically superior predictor over Delta V and rollover.
- Death in vehicle is the strongest predictor, but unlikely to be captured by AACN.

Next Steps

- Utilize this database to evaluate current AACN algorithms (OnStar, URGENCY, BMW)
- Add occupant factors that may strengthen the prediction of injury (age, gender, GCS based on voice)

Future

- Begin to assess how to integrate intrusion sensors to compliment current AACN systems
- AACN will take time to integrate
  - Create EMS training programs
    - On- scene recognition of Step 3 mechanism criteria
    - Utilize digital photography documentation in the triage of patients on-scene or even remotely
- Implement Step 3 data into all police crash reporting systems for further analysis to examine all crashes

Thank you