

A future with no MVC patients? Impact of autonomous vehicles on orthopaedic trauma may be slow and steady

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Abstract

Introduction: Orthopaedic trauma results in significant patient morbidity. Autonomous vehicle (AV) companies have invested over \$100 billion in product development. Successful AVs are projected to reduce motor vehicle collision (MVC)-related injuries by 94%. The purpose of this study was to estimate the timing and magnitude of AV impact on orthopaedic trauma volume.

Methods: ICD 9 codes consistent with acetabulum (OTA 62), pelvis (OTA 61), hip (OTA 31), femur (OTA 32–33), tibia (OTA 41–43), ankle (OTA 44), and calcaneus (OTA 82) fractures and the proportion of cases caused by MVC were taken from the National Trauma Databank (NTDB) 2009–2016. Regression was performed on estimates of market penetration for autonomous vehicles taken from the literature.

Results: For NTDB years 2009 to 2016, 300,233 of 987,610 fractures of interest were the result of MVC (30.4%). However, the percentage of MVC mechanism of injury ranged from 9% to 53% depending on fracture type. Regression of estimates of AV market penetration predicted an increase of 2.2% market share per year. In the next 15 years we project 22% market penetration resulting in a 6% reduction in orthopaedic lower extremity trauma volume.

Conclusion: Adoption of AVs will result in a projected 8% reduction in MVC-related orthopaedic trauma-related injuries over a 15-year period. Although this represents a significant reduction in morbidity, the advent of AVs will not eliminate the need for robust orthopaedic trauma programs. The gradual rate of injury reduction will allow hospitals to adapt and reallocate resources accordingly.

Keywords: acetabulum, automobile, autonomous vehicle, pelvis, pilon, plateau, safety, technology, trauma

1. Introduction

When IBM’s “Deep Blue” chess algorithm beat the world’s top chess player in 1997, predictions of smarter-than-human computers were rampant. However, it took nearly 15 years before IBM’s “Watson” was able to win Jeopardy in 2012.^[1]

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Although Watson’s natural language processing technology is now taken for granted on our smartphones; Alexa, Siri, and Google Assistant are far from replacing human to human interaction, activity performance, and decision-making. However, specific domains once thought untouchable are mastered by artificial intelligence (AI) every year. AI has become superhuman in facial recognition, strategic gaming, and photorealistic style transformation. Now AI companies are focusing on autonomous vehicles (AVs).

Waymo, Tesla, Uber, Ford’s Argo AI, Chevy’s Cruise Automation, Amazon’s Aurora Innovations, Apple’s project Titan, Intel, and Mobile Eye in partnership with Chrysler, BMW, Nissan, and VW are all developing autonomous vehicles.^[2] Together they have invested over \$100 billion with the intention that driving will be one of the next domains in which computers can consistently outperform humans.^[3] Many expect that the computerized mastery of driving will lead to a dramatic reduction in motor vehicle collisions, citing a national highway transportation safety administration (NHTSA) report that 94% of MVCs are the result of human error.^[4] This estimate has yet to be supported with any real-world data or closely scrutinized as an accurate representation of the proportion of injuries that would actually be avoided by autonomous vehicles.

If the projected reduction in MVCs as a result of AVs comes to fruition, it would have a tremendous positive impact on society. Among those impacts would be a reduction in complex orthopaedic trauma. The purpose of this study was to estimate the timing and magnitude of AV impact on lower extremity orthopaedic trauma volume.

2. Methods

Estimates of autonomous vehicle arrival, market penetration, and reduction in MVCs were taken from literature, periodicals, industry websites, and manufacturer’s statements. The ratio of cases caused by MVC was taken from the 2009 to 2016 NTDB. Injuries caused by MVC or pedestrian or bicycle struck by motor vehicle were considered MVC related. MVC-related injuries were considered avoidable by AVs. Motorcycle, ATV, and bicycle collisions were not considered avoidable by AVs even when a motor vehicle was involved in the incident.

Linear regression was used to project the adoption of autonomous vehicles. These projections were carried through the case proportions using the formula below.

$$C_{future}(y) = C_{Current}P_{MVC}A \frac{1-(f(y))}{1} + C_{Current}P_{MVC}U + C_{Current}P_{Other}$$

Where: C_{future} : future case level
 y : year
 $C_{Current}$: Current case level
 P_{MVC} : Proportion of cases caused by MVC
 A : Proportion of cases affected by AV
 $f(y) = 0.0223y - 45.16$ is the future percentage of cars that are autonomous according to the function determined by regression of AV arrival and market penetration estimates.
 U : proportion of cases unaffected by AV
 P_{other} : Proportion of cases by other mechanisms

Independent samples t tests were used for continuous and ordinal variables, with values less than 0.001 considered to represent a statistically significant difference. A Pearson Chi-Square test less than 0.001 was considered to represent a significant difference in categorical variables. Linear regression was used to project the adoption of autonomous vehicles. Binary logistic regressions were used to calculate odds ratios. Multivariate binary logistic regression was attempted for all significant variables. All analysis was performed in SPSS version 25 (IBM Corp. Released 2018. IBM SPSS Statistics for Macintosh, Version 25.0. Armonk, NY: IBM Corp).

3. Results

3.1. Estimate of AV arrival and market penetration

Statements from 5 automotive manufacturers with projected year of release of autonomous vehicles were included in the regression and these points were taken as 1% market penetration in the year predicted. Articles from 10 sources printed between 2015 and 2019 were found with predictions for AV market penetration at various time points. The mean year of predicted arrival was 2023 ± 3.6 years. The mean prediction for advanced market penetration was 88% ± 13.3% by the year 2051 ± 11.7 years (Table 1).

Linear regression of all estimates of market penetration by year revealed an R squared of 0.66 for the equation $y = 0.0223x - 45.158$ where y is the percent market penetration and x is the year. This correlates with a 2.2% increase in market share per

Table 1
Estimate of arrival date and market penetration of autonomous vehicles (AV)

Author	Study year	Arrival year	Lower bound estimate		Middle		Upper bound estimate	
			Year	AV market penetration	By year	AV market penetration	By year	AV market penetration
Bansal ¹	2016		2045	24%			2045	87%
Bernhart ²	2016	2021			2030	27%		
Kok ³	2017	2020					2030	95%
KPMG ⁴	2015	2025			2030	25%		
Litman ⁵	2015	2020s			2040	40%	2060	99%
Lavasani ⁶	2016	2025					2059	75%
McKinsey ⁷	2016	2022			2030	15%		
Simpson ⁸	2019		2045	20%			2045	95%
Shin ⁹	2019	2032	2030	15%	2040	40%	2060	65%
Stevens ¹⁰	2016				2040	50%	2060	100%
GM cruise automation ¹¹	2019	2020						
Tesla	2019	2020						
Ford Argo AI ¹²		2021						
Nissan Microsoft ¹³	2019	2025						
Daimler BMW ¹⁴	2019	2024						
Mean	2017	2023					2051	88%
Std Dev	1.6	3.6	8.7	4.5%	5.5	12.7%	11.7	13.3%

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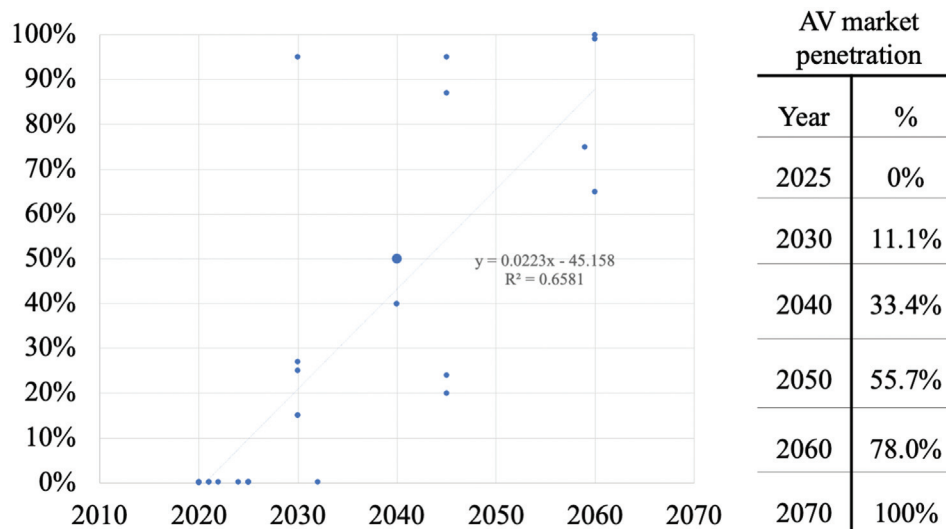


Figure 1. Projected AV adoption by regression of estimates from literature. AV, autonomous vehicles.

year starting from the year 2025. This would yield a theoretical date of 100% market penetration occurring in 2070 (Fig. 1).

Literature comparing rates of MVC from real-world crash databases in cars with advanced driver assistance (ADAS) features showed up to 27% MVC reduction and 20% injury reductions for cars equipped with forward collision warning (FCW),^[5] up to 38% reduction in injuries for cars equipped with automatic emergency braking (AEB),^[6] and up to a 41% reduction in MVCs for cars equipped with both FCW and AEB.^[7] Analysis of large crash databases has also shown reductions in crashes of 14% for blind spot monitoring (BSM),^[8] 18% for lane departure warning (LDW),^[9] and 30% for LDW with lane keeping assist (LKA).^[10] In contrast, literature reviewing crash data from autonomous vehicles on the road have shown a marked increase in rate of MVC compared to traditional vehicles without any evidence of improvement.^[11] Evaluating the types of MVCs that involve AVs reveals they are predominantly low-speed crashes that largely go unreported in traditional vehicles^[12] and most are in intersections or involve being rear ended.^[13] Despite the data on current immature AV systems, predictions of reductions in MVCs in AVs are consistently above 90%^[14] (Table 2).

3.2. National Trauma Databank

International Classification of Disease – 9th Edition (ICD-9) codes corresponding with major lower extremity trauma including pelvic, acetabular, femur, tibia, and calcaneal fractures were extracted from the 2009 to 2016 NTDB resulting in 988,248 records with injuries of interest, 987,610 having complete records. MVC (23.5%) combined with bicycle struck by motor vehicle (0.2%) and pedestrians struck by motor vehicle (6.6%) were combined as MVC-related injuries and comprised 30.4% of all injuries. However, fall (41.5%) was the most common mechanism of injury. Motorcycle crash (8.8%), high-energy fall (8.7%), and pedestrian struck by vehicle (7.5%) were also common (Table 3). Patients injured in an MVC were more likely to be male (58.5% vs 50.9%, $P < 0.001$) have open fractures (13.5% vs 10.0%, $P < 0.001$), blood EtOH above the legal limit at the time of injury (13.0% vs 4.9%, $P < 0.001$), and illegal drug

use confirmed by test at the time of injury (13.0% vs 4.8%, $P < 0.001$). Patients injured in an MVC are more likely to be treated at university-affiliated teaching hospitals (57.2% vs 44.2%, $P < 0.001$). Patients injured in an MVC were more likely to have fractures of the acetabulum (15.3% vs 5.9%, $P < 0.001$), and pelvis (26.2% vs 16.2%, $P < 0.001$). In the NTDB, MVC was the mechanism for 53.1% of acetabulum fractures, 41.4% of pelvis fractures, 9.2% of hip fractures, 33.8% of femur fractures, 36.5% of tibia fractures, 20.7% of bi- or trimalleolar ankle fractures, and 39.0% of calcaneus fractures (Table 3). Projected reduction in MVCs with 33% market penetration of AVs by 2040 would result in 16% reduction in acetabulum, 13% reduction in pelvis, 3% reduction in hip, 10% reduction in femur, 11% reduction in tibia, 6% reduction in bi- or trimalleolar ankle, and 12% reduction in calcaneus fracture surgeries (Fig. 2).

4. Discussion

Predictions of AI completely changing industries are common.^[14] These estimates usually focus on industries such as manufacturing and trucking.^[15] Orthopaedic trauma stands to benefit from reductions in motor vehicle crashes secondary to improved safety of autonomous vehicles. Despite a paucity of data, it is important to start the discussion on the scale and timing of the impact of autonomous vehicles orthopaedic trauma patients. Our regression of estimates of AV arrival and market penetration taken from the literature show that estimates are largely conservative: on average predicting 33% of cars on the road being AVs by 2040. This relatively slow progression suggests that orthopaedic trauma programs will have time to adapt and adjust. Changes in injury patterns will be slow and steady.

Previous automotive safety technologies have led to changes in fracture patterns. The introduction of seatbelts led to increased MVC survival rates and therefore more need for fracture treatment.^[16] Initial research suggested seatbelts led to increased injury to the lumbar spine,^[17] and thorax.^[18] Airbags further reduced central injuries while paradoxically increasing distal upper^[19] and lower extremity injuries.^[20] It is likely that current changes in complex case volume^[21] are related to increased market penetration of safety equipment such as standard air bags,

Table 2**Estimate of ADAS and AV technology on reduction of MVCs**

Author	Year	Category	Technology	MVC reduction	Injury reduction	Fatality reduction
Cicchino JB ¹⁵	2017	ADAS	FCW	27%	20%	
Cicchino JB	2017	ADAS	AEB	43%	45%	
Cicchino JB	2017	ADAS	FCW and AEB	50%	56%	
Cicchino JB ¹⁶	2018	ADAS	LDW	18%	24%	86%
Cicchino JB	2018 (2)	ADAS	BSM	14%		
Fildes B ¹⁷	2015	ADAS	AEB	38%		
Isaksson-Hellman I ¹⁸	2012	ADAS	AEB	23%		
Ohlin M ¹⁹	2017	ADAS	AEB		57%*	
Rizzi M ²⁰	2015	ADAS	FCW and AEB	35–41%		
Sternlund S ²¹	2017	ADAS	LDW/LKA	30%		
Blanco M ²²	2016	AV	AV	61%		
Boggs A ²³	2019	AV	AV			
Evans L ²⁴	1996	AV	AV	{90%}		{94%}
Favarò FM ²⁵	2017	AV	AV	1089% (Increase)		
Morando MM ²⁶	2018	AV	AV	{29–64%}		
Papadoulis A ²⁷	2019	AV	AV	{90–94%}		
Schoettle B ²⁸	2015	AV	Av	384% (increase)	10%	
Virdi N ²⁹	2019	AV	AV	{48–100%}		

ADAS = advanced driver assistance, AEB = autonomous emergency braking, AV = autonomous vehicle, BSM = blind spot monitoring, FCW = forward collision warning, LDW = lane departure warning, LKA = lane keeping assist.

* Bicycle injuries.

{ } brackets denote predictions all other numbers are reports of data.

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Table 3**Mechanisms associated with lower extremity trauma**

	Total	Acetabulum	Pelvis	Hip	Femur	Tibia	Bi/TriMal	Calc
MVC	987,610	86,558	58,424	20,454	44,636	46,190	11,325	11,246
Bicycle Struck by MV	23.5%	46.4%	30.8%	7.9%	28.5%	23.1%	17.2%	36.0%
Pedestrian Struck by MV	0.2%	0.2%	0.3%	0.1%	0.2%	0.4%	0.1%	0.1%
MVC related*	6.6%	6.5%	10.4%	1.2%	5.1%	12.9%	3.4%	2.9%
MCC [‡]	30.4%	53.1%	41.4%	9.2%	33.8%	36.5%	20.7%	39.0%
Other Bicycle [†]	8.8%	10.2%	9.6%	2.5%	10.6%	14.9%	5.8%	9.7%
Other Pedestrian [†]	1.3%	1.9%	1.6%	1.1%	0.9%	1.5%	1.1%	0.3%
High Energy Fall	0.9%	0.8%	1.3%	0.2%	0.7%	1.5%	0.5%	0.6%
Fall	8.7%	7.9%	9.2%	6.5%	6.0%	9.8%	13.5%	23.2%
GSW	41.5%	20.4%	29.2%	76.8%	34.4%	22.9%	50.8%	19.2%
Other penetrating	2.7%	1.6%	3.0%	1.2%	5.6%	3.2%	0.1%	2.6%
Crush	0.1%	0.0%	0.1%	0.0%	0.2%	0.3%	0.1%	0.5%
Other blunt	0.3%	0.3%	0.4%	0.1%	0.2%	0.4%	0.2%	0.6%
Other	2.6%	1.9%	2.1%	1.1%	3.5%	4.9%	3.0%	2.1%
	2.7%	2.1%	2.1%	1.4%	4.0%	4.2%	4.0%	2.3%

* MVC-related mechanisms thought to be affected by future AV included MVC, Ped, and bicycle struck by motor vehicles (MV).

[†] Other pedestrian and other bicycle include those struck by any non-highway vehicle including train, ATV, etc.

[‡] MCC included off road vehicles.

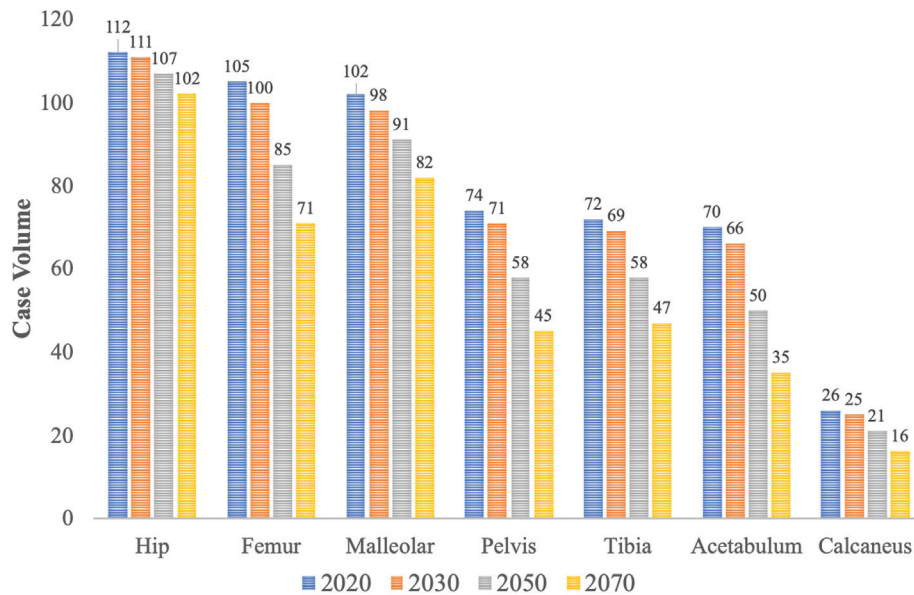


Figure 2. Projected changes in case volume per year for orthopaedic trauma fellows from 2020 to 2070.

crumple zones, antilock brakes and traction control, lane departure warning, and blind spot monitoring.^[22] It can be extrapolated that similar changes in case volume may occur with increased market penetration of AVs in the upcoming years.

No rigorous estimates of the percentage of MVCs that could be avoided by AVs were found in the literature. Nor was any analysis of the types of MVCs that will be affected by AVs available. To date, no AV company has demonstrated reduced injuries as a result of decreased collisions in autonomous vehicles. Only Tesla claims a 10 times reduction in collision rate, having demonstrated that its cars on autopilot travel on average 4.7 million miles between MVCs while traditional vehicles travel 479,000 miles between accidents.^[23] Waymo and other AV companies tout safety improvements while pointing out the correlation of reported “disengagements” with the difficulty of the driving environment.^[24] This is important as injury patterns from highway crashes are not the same as those from city streets. Nearly all safety estimates analyzed were derived from a national highway transportation safety statistic that 94% of accidents are caused by avoidable human errors such as texting and driving.^[25] In reality this may be much less, and although data from studies of driver assistance features have shown significant decreases in morbidity and mortality, studies of current AV performance are limited (Table 2). There have not been previous estimates of the impact of AVs on trauma presentation injury patterns nor surgical case volumes.

Analysis of the NTDB revealed that less than one-third of major pelvic and lower extremity cases are caused by MVCs. The fractures most affected by AVs would be the ones caused most often by MVCs. Namely, pelvic and acetabular fractures are projected to decrease while hip and ankle fractures would largely be unaffected. In addition, the aging of the US population associated with the baby boomers is expected to lead to a doubling of hip fractures by 2050.^[26] The reduction in pelvic and acetabular trauma projected by our model combined with this increase in hip fractures mean that hip fractures could make up one-third of all trauma cases by 2050.

There are several limitations of this study as it attempts to project currently unproven technology into the future. It fails to

model the above-mentioned increases in periprosthetic, hip, and other fragility fractures due to aging population. Furthermore, the NTDB did not allow classification of fracture severity; therefore, we are unable to determine the changes in more complex fracture patterns. The study uses a linear model for the timeline of adoption patterns because it best fit the estimates from the literature; however, technologies are often adopted in an exponential fashion. Furthermore, all data in this study refers to European countries or the United States; therefore, this analysis likely does not generalize to all countries. These weaknesses mean that the magnitude and timing of the impact in this paper will be inaccurate. However, the authors believe it is a starting point for a conversation about the impact that AVs may have on our training and practices.

5. Conclusion

If changes in pelvic and lower extremity case volumes and distribution due to adoption of autonomous vehicles do materialize, it will likely be slow and steady. Furthermore, 70% of pelvic and lower extremity trauma cases are not caused by MVC and will therefore remain unaffected. Our analysis projects that 6% of cases will be affected in the next 15 years and only 24% of cases are likely to be eliminated over 50 years.

AV LE Trauma Supplemental Digital Content, <http://links.lww.com/OTA/A19>

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