

Traumatic amputations caused by drone attacks in the local population in Gaza: a retrospective cross-sectional study



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Summary

Background Little data exist to describe the use and medical consequences of drone strikes on civilian populations in war and conflict zones. Gaza is a landstrip within the Palestinian territories and the home of 2 million people. The median age in Gaza is 17·2 years and almost half of the population is below the age of 14 years. We studied the prevalence and severity of extremity amputation injuries caused by drone strikes compared with those caused by other explosive weapons among patients with amputations attending the main physical prosthesis and rehabilitation centre in Gaza.

Methods In this retrospective cross-sectional study, we recruited patients from the Artificial Limb and Polio Centre (ALPC) in Gaza city in the Gaza strip with conflict-related traumatic extremity amputations. Patients were eligible if they had one or more amputations sustained during a military incursion in Gaza during 2006–16 and had an available patient record. Each patient completed a self-reporting questionnaire of the time and mechanism of injury, subsequent surgeries, comorbidities, and their socioeconomic status, and we collected each patient's medical history, recorded the anatomical location of their amputation or amputations, and interviewed each patient to obtain a detailed description of the incursion or incursions that led to their amputation injury. We classified the severity of amputations and number of subsequent surgeries on ordinal scales and then we determined the associations between these outcomes and the mechanism of explosive weapon delivery (drone strike vs other) using ordinal logistical regression.

Findings We collected data on 254 patients from APLC who had sustained an amputation injury. Of these patients, 234 (92%) were male and 43 (17%) were aged 18 years or younger at the time of injury. The age of participants was representative of the Gaza population, with a median age at inclusion was 28 years (IQR 23–33), and the median age at the time of injury was 23 years (IQR 20–29). 136 (54%) amputation injuries were caused by explosive weapons delivered by drone strikes, with explosives delivered by tanks being the next most common source of amputation injury (28 [11%]). Adjusted for age and sex, drone-delivered weapons caused significantly more severe injuries than explosives delivered by other mechanisms (eg, military jet airplanes, helicopters, tank shelling, and naval artillery; odds ratio [OR] 2·50, 95% CI 1·52–4·11; $p=0\cdot0003$). Compared with all other types of weapons, the patients whose injuries were caused by drone strikes needed significantly more subsequent surgical operations to treat their amputation injuries than those injured by other weapons (OR 1·93, 1·19–3·14; $p=0\cdot008$).

Interpretation Drone strikes were the most commonly reported cause of amputation injury in our study population and were associated with more severe injuries and more additional surgeries than injuries caused by other explosive weapons. Limitations of our study include the self-reported nature of the mechanism of injury and number of subsequent surgeries and selection bias from not incorporating amputation injuries from individuals who died immediately or due to complications. The increasing use of drones needs to be addressed, rather than passively accepted, by the international community. This study fills a gap in our knowledge of the civilian consequences of modern warfare and we believe it is also relevant to the growing populations that are being exposed to drone warfare and for health-care personnel treating these people.

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Introduction

Serious explosive injuries from a variety of weapons can cause traumatic extremity amputations, often needing immediate lifesaving surgery.¹ The use of remote-controlled, unmanned aerial vehicles (UAE or drones) is increasing in present-day armed conflicts, both for surveillance and as weapon carriers.² Few studies have assessed the medical consequences of drone-delivered explosive weapons (drone strikes) during armed conflicts and war.

The Palestinian population in the Gaza Strip has experienced four major Israeli military incursions over the past decade (2006, 2008–09, 2012, and 2014). Various military weapons have killed around 4000 Palestinians and injured more than 17000 during 2006–14, mostly civilians.² During the military incursion Operation Cast Lead (2008–09), 42 drone strikes killed 87 civilians.³ Amnesty International documented 48 civilian deaths from drone strikes during the same period but suggested the actual numbers to be much higher than those

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For the Israeli Information Center for Human Rights in the Occupied Territories Statistics webpage see <http://www.btselem.org/statistics>

Research in context

Evidence before this study

Civilians who have traumatic extremity amputation injuries during modern warfare seem to be increasingly caused by explosive weapons delivered by unmanned aerial vehicles, also known as drones. The magnitude and consequences of such injuries in affected populations are poorly described and understood. We searched PubMed, MEDLINE, Embase, and Google Scholar from database inception to May, 2014, for publications in English and Norwegian using the search terms “drone*”, “drones*”, “drone strikes*”, “modern warfare*”, “Traumatic amputation(s)*”, “Gaza*”, “Israel*”, “Palestine*”, “military incursions”, “war-related amputations*”, “amputees*”, and “amputations*”. We found a paucity of peer-reviewed literature on these topics and could not find any peer-reviewed studies of traumatic amputations among civilians caused by drone strikes. We studied the prevalence and consequences of traumatic extremity amputations, including amputation severity and additional surgeries needed, among Palestinians in the Gaza Strip after drone strikes and compared these with amputations caused by other weapons.

Added value of this study

We found that drone strikes are the most prevalent weapon-delivery mechanism that causes traumatic amputations in Palestinian patients with amputation injuries who attended a central rehabilitation clinic in Gaza. This finding challenges the idea that drone-delivered explosives are more precise and lead to less civilian casualties and so-called collateral damage than other weapons used in modern warfare. The participants who reported having been injured by drone strikes had more severe, proximal amputations and needed more surgical revisions after the initial amputation than those who had been injured by conventional explosive weapons.

Implications of all the available evidence

Our findings support that drone strikes substantially affect civilians living in areas of armed conflicts, and that restrictive formal rules for the use of armed drones and a clear humanitarian legal framework should be generated to restrict the use of these weapons on civilians.

reported.⁴ The human rights organisation Al Mezan reported that 513 people were killed by drone strikes during the same period.⁵ The variation between the number of reported drone strikes and the number of casualties attributed to drone strikes could indicate either methodological problems or the secrecy of military drone programmes, or both.⁶ Israeli authorities state that the Israeli Defence Forces used precision-guided aerial strikes to “minimise potential civilian casualties” during the 2014 military incursion on Gaza.⁷ The secrecy surrounding military drone programmes and variable estimates of civilian casualties is not limited to Gaza. The reported number of civilian casualties after US military drone strikes in Pakistan in 2015 varies from 158 to 2600.⁸ Therefore, further studies are needed to clarify civilian consequences of drone strikes.

The paucity of information regarding civilian consequences of military drone strikes restricts understanding of the impact of these weapons, and narrows the discourse on military attack drones that is pertinent to international law and human rights. We studied drone strikes as the cause of traumatic extremity amputations in a local population in Gaza. We aimed to compare the severity of amputation injuries caused by drone strikes with those caused by other weapons in a population with traumatic amputations attending physical rehabilitation in Gaza.

Methods

Study participants

On the basis of a previous feasibility study (Heszlein-Lossius H, masters thesis, unpublished) in the Gaza strip, of 91 patients from Gaza’s main physical

rehabilitation centre and prosthesis workshop, the Artificial Limb and Polio Centre (ALPC),⁹ we completed a retrospective cross-sectional study, for which we invited all patients attending ALPC during the study period and all participants from the previous feasibility study to participate. Inclusion criteria were one or more amputations sustained in Gaza during a military incursion or incursions during 2006–16 and an available patient record. Exclusion criteria were if the amputation injury was not caused by a military incursion and if the amputation injury was from before 2006.

The study was approved in Norway by the Regional Ethical Committee (2016/1265/REK nord); in Gaza by the local health authorities, the board of Al-Shifa Hospital, and the Director of the ALPC. The Palestinian Ministry of Health approved the study through the Helsinki ethics approval committee in Gaza. All included patients gave written informed consent following detailed explanation in Arabic of the study objectives and procedures. No economical compensation was offered to the patients except for covering their costs of transportation from home to the clinic. We did the clinical examinations and interviews at the ALPC in Gaza City. All patients were informed that they could withdraw their consent and leave the study at any time.

Data collection

The participants completed a self-reporting questionnaire without any investigator instruction before a physical examination. Participants reported the date of injury, age at time of injury, age at time of questionnaire, diseases or injuries, comorbidities, use of rehabilitation and artificial limbs, physiotherapy, their socioeconomic status (ie,

living and working status, number of people in household, number of people economically dependent on patient, level of education), and number of surgeries since injury. We made no documentation of any military activities. All the written material we used was in Arabic and the questions were read aloud by one of the Palestinian investigators (YA-B, SS, or NS) for participants who were illiterate.

An experienced physician (YA-B, SS, or NS) then collected their medical history; did a clinical examination, including measuring their heart rate, blood pressure, height, and weight, and registered the results of heart and lung auscultation, examination of the abdomen, and any heart palpitations; and examined and photographed their amputation stump or stumps. Each patient was then interviewed and the mechanisms of injury was explored.

In the interview, each patient gave detailed descriptions of the incursion or incursions that caused their traumatic amputation or amputations. The interviews were done one to one with a local clinician who had been coached in how to conduct the interview beforehand. By use of a pre-prepared list of questions, the interviewers asked the participants to describe in detail where they were at the time of the incursion, other witnesses, sounds, sights, and concomitant destruction of cars and buildings. We recorded the reported mechanism of weapon delivery (eg, tank, helicopter, jet fighter, naval gunship, drone). The patients and local clinicians were not told that injuries from drone strikes were specifically of interest.

The physician who did the examination used a simple anatomical sketch to draw the level of the amputation or amputations. Immediately after each interview, each photo of an amputation stump was given a unique identification number and a photocopy was kept at the ALPC with the patient's files. We classified the amputations using common terms for extremity amputations—ie, above or below the extremity joints.¹⁰ We categorised types and combinations of extremity amputations by generating an ordinal scale that classified the amputations in increasing order of severity on the basis of proximity to the torso and number of affected limbs. The ordinal scale was as follows: 1 indicated a finger, toe, hand, or foot; 2 indicated below the knee or below the elbow; 3 indicated above the knee or above the elbow; and 4 indicated a bilateral amputation or an amputation in both lower and upper extremities, or a unilateral amputation at hip or shoulder level.

To analyse how different types of weapons affected the need for additional surgical treatment, we classified the total number of self-reported surgical operations after the trauma on an ordinal scale. We had to collapse the categories to fulfil the ordinal regression assumption of adequate cell count, and so the scale used in our calculations was as follows: 1 was one surgery; 2 was two to three surgeries; 3 was four to five surgeries; and 4 was six to nine surgeries; and 5 was ten or more surgeries.

Four different major military incursions took place in Gaza from December, 2006, to August, 2014. We classified conflict time on the basis of the official recorded dates of each military operation. We defined times of cease-fire on the basis of the periods between each of the four major military incursions. The dates of injury for each patient were matched with periods of conflict or cease-fire.

Around the four major documented incursions several minor incursions have occurred, and so we included six periods in our definition of conflict time, based on dates used by Israeli authorities:^{11–14} from June 27, 2006, to Nov 11, 2006 (two operations overlapped, with one not officially declared over and another starting on Nov 1, 2006); from Feb 28, 2008, to March 3, 2008; from Dec 27, 2008, to Jan 17, 2009; from Nov 14, 2012, to Nov 21, 2012; and from July 7, 2014, to Aug 26, 2014.

Outcomes

Our primary objectives were to determine the prevalence and severity of extremity amputations caused by drone strikes compared with those caused by other explosive weapons among amputees attending the main physical prosthesis and rehabilitation centre in Gaza. We determined the severity of amputation injuries using two outcomes: proximity of the amputation to the torso, and the number of subsequent surgeries to date.

Statistical analysis

We report descriptive statistics as mean and SD for normal distributions. Skewed variables were log-transformed before multivariate analysis. For non-normal data, we report the median and IQR. Frequencies are reported as percentages. A p value of less than 0.05 was considered statistically significant.

We created an alluvial diagram to visualise complex associations between categorical variables. We used multivariate ordinal logistical regression to investigate the association between mechanism of injury, amputation severity, and number of subsequent surgeries adjusted for age and sex. We used Monte Carlo simulations (n=1000) of the estimates we obtained from the multivariate ordinal regression analysis to obtain easily interpretable probability estimates. Briefly, the probability of being injured via drone strike versus other explosive weapon was simulated across the ordinal severity score for amputations. The difference in probability was then calculated from the simulations, with a 95% CI for drones strikes versus other explosive weapons for each ordinal category. The number of additional surgeries and the severity of the amputation are related outcomes. Post hoc, we generated a probability based Venn diagram of the outcomes and drone strikes using cutoffs that were the closest to dividing the study population in equal binary categories (≥ 6 surgeries vs ≤ 5 surgeries, amputation at knee or elbow and higher vs more distal). We excluded gunshot injuries from our comparative analyses with drone strikes because guns have less potential to cause amputation injuries than

Patients (n=254)	
Sex	
Male	234 (92%)
Female	20 (8%)
Age at inclusion, years	28 (23–33)
Age at injury, years	23 (20–29)
Aged ≤18 years at injury	43 (17%)
Refugee status*	154 (57%)
Immediate amputation	215 (86%)
Surgical attempt at salvage	24 (10%)
Surgeries after amputation	
0–1	44 (17%)
2–3	63 (25%)
4–5	47 (19%)
6–9	44 (17%)
≥10	53 (21%)
Missing data	3 (1%)†

Data are n (%) and median (IQR). *Patrilineal descendants of refugees from the establishment of the Israeli state in 1948. †Three patients did not answer this question on the questionnaire.

Table 1: Patient demographic and clinical characteristics

	During declared military incursions (n=159)	Between declared military incursions (n=95)	Overall (n=254)
Drone strike*	100 (63%)	36 (38%)	136 (54%)
Helicopter (Apache)	6 (4%)	0	6 (2%)
Aircraft (manned)	8 (5%)	1 (1%)	9 (4%)
Artillery shell	6 (4%)	1 (1%)	7 (3%)
Cannon shell	7 (4%)	2 (2%)	9 (4%)
Naval shell	1 (<1%)	2 (2%)	3 (1%)
Other shelling injury†	3 (2%)	4 (4%)	7 (3%)
Tank shell	19 (12%)	9 (9%)	28 (11%)
Unexploded ordnance‡	1 (<1%)	22 (23%)	23 (9%)
Landmine	0	2 (2%)	2 (1%)
Gunshot wound‡	0	12 (13%)	12 (5%)
Friendly fire§	1 (<1%)	1 (1%)	2 (1%)
Unknown	7 (4%)	3 (3%)	10 (4%)

Data are n (%). *Weapons delivered from an unmanned armed airplane. †Other shelling; the patient only reported shelling but did not specify. ‡Not included in multivariate analyses. §Palestinian rockets fired from Gaza into Israel.

Table 2: Mechanism and time of traumatic amputation injuries

drone strikes do, hence our comparative analyses include only explosive or shelling injuries.

We analysed data using STATA 15 (version 15), with graphical displays from RAW Graphs, and post-hoc simulations by the STATA package moreClarify.

Results

Between June 25, 2014, and Dec 30, 2016, we recruited 254 patients from the ALPC in Gaza city, of whom 90 took part in the previous feasibility study (one of 91 participants

took part in the previous study declined to participate). Most of the participants were male, with a median age of 28 years (IQR 23–33) at the time of inclusion, and a median age of 23 years (20–29) at the time of the amputation trauma (table 1). 43 (17%) participants were children (ie, 18 years or younger).

136 (54%) participants reported that drone strikes had caused their amputations, of whom eight (6%) were female, and 14 (10%) were children, equivalent to 40% of 19 female patients and 33% of 43 children who participated (table 2; figure 1). 28 (11%) patients were injured by weapons delivered by tanks. 23 (9%) patients had amputation injuries caused by unexploded ordnances (weapons that explode long after being deployed). For two (1%) patients, their amputation injuries were caused by Palestinian rockets fired from Gaza aimed at Israel (ie, friendly fire).

By ordinal logistic regression, drone strikes caused more proximal amputation injuries that needed more surgeries than other explosive weapons did, adjusted for age and sex (OR 2.50, 95% CI 1.52 to 4.11; $p < 0.0003$; table 3). After estimation of the results by ordinal logistic regression, Monte Carlo simulation showed that when an amputation injury was caused by a drone strike the amputation trauma is 8% more likely to fall into a higher severity category than if it was caused by another explosive weapon (OR 2.50, 95% CI 1.52–4.11; figure 2).

By ordinal logistic regression, patients with amputations caused by drone strikes needed significantly more surgeries after the initial trauma compared with those who had amputation injuries caused by other weapons (OR adjusted for age and sex 1.93, 95% CI 1.19–3.14; $p = 0.008$; table 4). 53 (21%) patients needed ten or more surgical operations after their initial injury. Of these patients, 37 (70%) had an amputation injury caused by explosive weapons during drone strikes. Notably, the number of surgeries after amputation injury and the severity of the amputations are related outcomes (figure 3).

Drone strikes caused amputation injuries both during periods of cease-fire and during declared military incursions. Of 136 amputation injuries caused by drone strikes reported, 100 (74%) were during military incursions and 36 (26%) were during periods of cease-fire (table 2). Amputation injuries caused by unexploded ordnances (23 [9%] of 254 injuries) mainly occurred between declared military incursions, and amputation injuries caused by explosive weapons delivered by helicopters (six [2%] of 254) only occurred during declared military incursions. For the other shelling injuries, they caused amputation injuries both during and between declared incursions.

Discussion

In this cross-sectional study of traumatic amputees attending a physical rehabilitation centre in Gaza, we found drone strikes were associated with more proximal amputations that needed more surgical operations after initial life-saving emergency surgery than traumatic

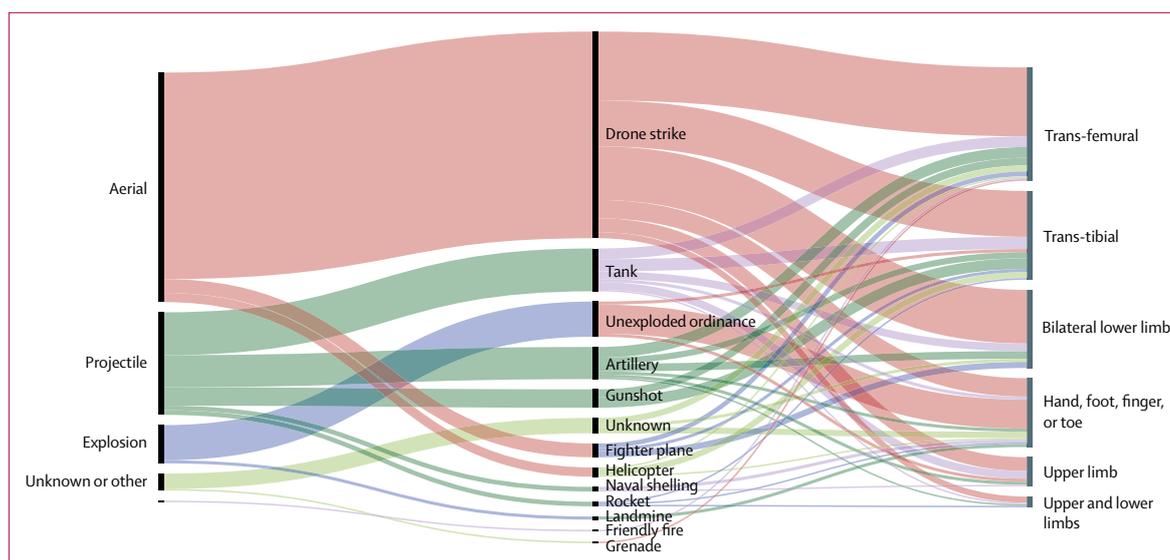


Figure 1: Alluvial diagram of mechanism of weapon delivery and type of amputation

Widths of bands correspond to the frequency of the mechanism of injury and the frequency of different types of amputation injuries, and the vertical axis is organised with the most prevalent injuries and mechanisms of delivery at the top. Data are from all 254 Palestinian patients included in the study. Fighter plane indicates military F-16 jet airplanes, helicopter indicates military Apache attack helicopter. Unknown indicates the patient does not know which type of weapon caused their amputation injury or they did not supply the information.

amputations caused by other types of explosive weapons. To our knowledge, this is the first study to show the frequent use of armed drone strikes on the Palestinian population in Gaza and that armed drone strikes are the most frequent cause of traumatic extremity amputations in this population.

Aerial drones were developed throughout the 19th century, but were first used in close combat during the Israeli Bekaa Valley campaign in 1982.¹⁵ Armed drones were widely used during Operation Desert Storm in 1991, with unmanned aircrafts developed by a joint effort of the Israeli and US armies.¹⁵ Drones are mainly used against targets in low-income and middle-income countries and most military drone programmes are clandestine, leading to possible under-reporting of drone-inflicted injuries, in particular when drone attacks affect civilians. The predominance of young male patients with amputations in our study raises the question of whether they were combatants from the resistance forces. However, we did not validate the social status of each patient beyond the information they self-reported because of ethical and security concerns. Collecting personal information on Palestinian resistance fighters could endanger their lives, and so we considered a detailed investigation and registration to be unethical.

The predominance of male patients with amputation injuries in our study could be a result of several factors. The male patients in our study were young, with an overall median age among all participants of 23 years at time of injury. This finding is unsurprising since, as of July, 2017, the median age of Gaza's about 1795 000 inhabitants was 17·2 years, and 803 919 (45%) people were aged 14 years or

	Risk factors	Odds ratio	p value
Age*	NA	1·04 (0·52–2·07)	0·918
Sex	Male sex (n=213) vs female sex (n=19; ref)	1·69 (0·70–4·10)	0·243
Mechanism of injury†	Drone strike (n=136) vs non-drone explosive weapon (n=96; ref)	2·50 (1·52–4·11)	<0·0003*

Data in parentheses are 95% CIs. Ordinal logistic regression with injury severity as the outcome. 12 patients with gunshot wounds and ten who did not report the mechanism of injury are excluded from analyses (n=232). (ref) indicates the reference group in the analysis. *Log transformed for regression analysis. †Adjusted for age and sex.

Table 3: Risk factors for increased severity of amputation injury

younger.¹⁶ Boys comprised 87% of children killed in Palestine during the second Intifada (2000–07).¹⁷

The amputation injuries caused by drone strikes were more severe as measured by proximity to the torso and need for subsequent surgical revisions. Traumatic amputations caused by drone strikes were more frequent than those caused by other explosive weapons both during times of declared military incursion and between these incursions. More than 1000 daily raids on Gaza were reported during Operation Protective Edge from July 7, 2014, to Aug 26, 2014, with nearly 90% of attacks taking place in densely populated areas.¹⁸

Among patients admitted to Al-Shifa Hospital, Gaza during July–August, 2014,¹⁹ extremity amputations were reported to be caused by drone strikes, unexploded ordnances, tank shells, ground and naval artillery shelling, and attacks from Apache helicopters and jet fighters. In the current study, two (1%) of 254 patients reported that their amputation injuries were caused by Palestinian rockets fired from Gaza aimed at Israel (ie, friendly fire).

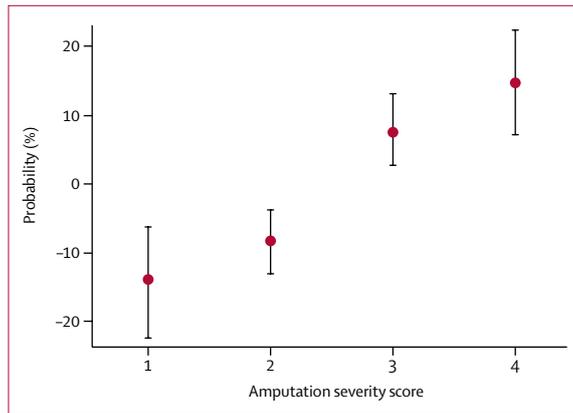


Figure 2: Difference in probability of drone strike versus other weapons by severity of extremity amputation

Datapoints are the difference in probability estimates, whiskers are 95% CIs of simulated probabilities. Data are from all participants excluding 12 with gunshot wounds and ten who had an unknown or missing mechanism of injury (n=232). The severity of amputations is classified on an ordinal scale (1 indicates finger, toe, hand, or foot; 2 indicates below the knee or elbow; 3 indicates above the knee or elbow; and 4 indicates a bilateral amputation, amputation in both the lower and upper extremities, or a unilateral amputation at hip or shoulder level).

	Risk factors	Odds ratio	p value
Age*	NA	0.39 (0.19–0.78)	0.008
Sex	Male sex (n=213) vs female sex (n=19; ref)	0.94 (0.40–2.19)	0.882
Mechanism of injury†	Drone strike (n=136) vs non-drone explosive weapon (n=96; ref)	1.93 (1.19–3.14)	0.008

Data in parentheses are 95% CIs. Ordinal regression with the number of operations as the outcome. 12 participants with gunshot wounds were not included, ten who not report the mechanism of injury, and three who had an unknown number of operations were not included in these analyses (n=229). (ref) indicates the reference group in the analysis. *Log transformed for regression analysis. †Adjusted for age and sex.

Table 4: Risk factors for multiple operations after initial amputation injury (n=229)

More patients with proximal or multiple amputations, or both, are now able to survive such war injuries than ever before because of advances in primary and secondary trauma resuscitation,²⁰ but to survive they often needs several surgical revisions. As we reported in a separate study using the same cohort,²¹ more than 1300 surgeries were done among the 254 patients we studied. Patients who had an amputation injury caused by a drone strike had significantly more surgical revisions than those injured by other explosive weapons. Thus, drone strikes caused amputations that added substantially to the almost insurmountable burdens on the already overstretched local health-care system in Gaza.²² This burden is aggravated by the military siege and blockade of Gaza that has lasted more than 10 years and that continues to result in insufficient medical and power supplies, a lack of clean water, and unsafe working conditions for health-care personnel, among other consequences.^{23,24}

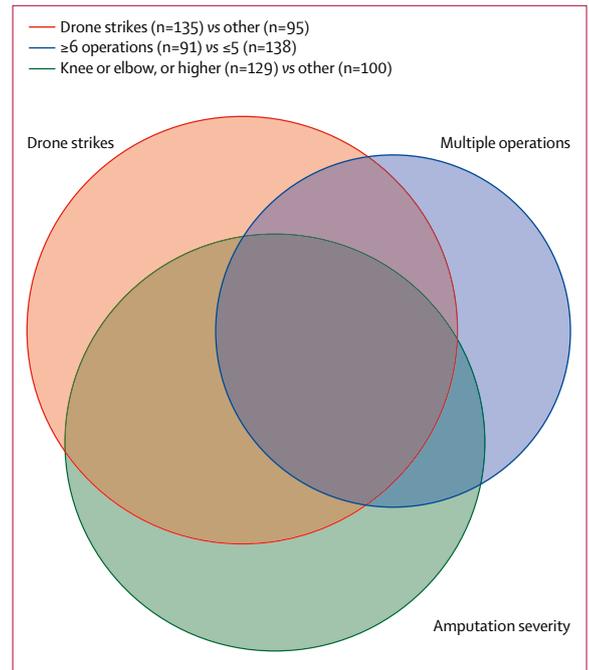


Figure 3: Proportional association between amputation severity, number of surgeries, and drone strikes as the mechanism of injury

Proportional associations between amputation injuries that are proximal to the torso, more than six operations after the initial trauma, and drone strike as the mechanism of injury. Figure based on 136 amputees with injuries caused by drone strikes.

Our findings are in accordance with previous reports from Pakistan and Afghanistan where drone-based weapon systems are a major threat to civilian lives and health.^{25,26} A study²⁷ on the effects of drone strikes on politics found that the use of drones will increase violence on both sides of a conflict. Our finding of a high prevalence of drone-related amputations compared with amputations caused by other explosive weapons challenges the claim that armed drones minimise so-called collateral damage.²⁸ On the contrary, we found that attacks by armed drones were associated with extensive traumatic injuries among Palestinians in Gaza, and that the injuries were of significantly higher severity, and added substantially to an already overstretched local health-care system than the injuries caused by other explosive weapons.

This study has several limitations. We did not include injury patterns in patients who had died due to their amputation injury, either immediately or due to early complications such as sepsis. Thus, selection bias could have occurred due to immediate and in-hospital mortality for people with the most severe injuries. The ALPC rehabilitation centre is the only institution in Gaza where patients are fitted with artificial limbs and are given subsequent rehabilitation and training, and so all hospitals and primary care centres in the area refer patients with traumatic amputations to the ALPC. It is also free of charge for all patients, avoiding selection bias

due to patients' financial situation. Thus, although we included all patients with conflict-related amputation injuries at the ALPC during the study period, and hence have a representative sample of Gaza amputees, we cannot be sure that all people who had an amputation injury (eg, minor finger amputations) are referred to the centre, and so our study has unavoidable inclusion bias. Although few alternatives exist in countries with few registries, the use of self-reported data in our survey overall has weaknesses. For instance, although Palestinians in Gaza have long-standing experience with military incursions and can usually accurately differentiate between commonly used weapon carriers, weapon types, and explosives, we relied on the judgment and ability of each included patient to classify the type of weapon and weapon-delivery system that caused their amputation injury, and so some human error could have occurred.

Another limitation is that we did not validate the social and military status of each patient beyond the information they self-reported. The high predominance of male participants with amputations in this study raises the question of possible non-civilian status. We believe that a detailed investigation of the personal information of potential Palestinian resistance fighters could endanger their lives, and hence regarded the collection of further personal details beyond the information supplied by participants to the local investigators to be unethical.

Compared with other methods of weapons delivery, drone strikes caused the most traumatic amputations in surviving Palestinian citizens from 2006–16 during Israeli military incursions and periods of cease-fire in Gaza. Explosive weapons delivered by military drones inflicted more severe injuries in survivors than non-drone delivered weapons did. Our study shows the need for a specific legal framework for remote-controlled, human-directed weaponised drones that are used as carriers of attack weapons.

Contributors

HH-L contributed to study design, data collection, entry, and analysis, interpretation of the results, the primary draft of the manuscript, editing of the manuscript, and the literature search. YA-B, SS, and NS contributed to study design, patient recruitment, data collection and transfer, and revision of the manuscript. LMG contributed to the statistical analysis, interpretation of the results, design of the figures, and editing and revision of the manuscript. MFG contributed to the original research idea, the study design, interpretation of the results, and editing and revision of the manuscript. All authors approved the final version of the manuscript.

Declaration of interests

We declare no competing interests.

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References

- 1 Brown KV, Clasper JC. The changing pattern of amputations. *J R Army Med Corps* 2013; **159**: 300–03.

- 2 Kontodimos A. Lethal use of armed drones and the 'war on terror': legality under international law. Master's thesis, University of Tilburg, 2017. <http://arno.uvt.nl/show.cgi?fid=142388> (accessed Sep 24, 2018).
- 3 United Nations Human Rights Council. The United Nations independent commission of inquiry of the 2014 Gaza conflict. United Nations General Assembly, 2015. <https://www.ohchr.org/en/hrbodies/hrc/coigazaconflict/pages/reportcoigaza.aspx> (accessed Aug 1, 2018).
- 4 Garlasco M, Abrahams F, van Esveld B, Akram F, Li D. Precisely wrong: Gaza civilians killed by Israeli drone-launched missiles. Human Rights Watch, 2009. <https://www.hrw.org/report/2009/06/30/precisely-wrong/gaza-civilians-killed-israeli-drone-launched-missiles> (accessed Sept 9, 2017).
- 5 Al Mezan Centre for Human Rights and Defence for Children International—Palestine Section. Bearing the brunt again: child rights violations during Operation Cast Lead, 2009 https://d3n8a8pro7vnmx.cloudfront.net/dcipalestine/pages/1284/attachments/original/1433971286/Bearing_the_Brunt_Again_September_2009.pdf?1433971286 (accessed March 1, 2018).
- 6 Enemark C. Drones over Pakistan: secrecy, ethics, and counterinsurgency. *Asian Security* 2011; **7**: 218–37.
- 7 The 2014 Gaza conflict 7 July – 26 August 2014: factual and legal aspects. State of Israel, May, 2015. <http://www.mfa.gov.il/ProtectiveEdge/Documents/2014GazaConflictFullReport.pdf> (accessed Jan 1, 2018).
- 8 Crawford N. Update on the Human Costs of War for Afghanistan and Pakistan, 2001 to mid-2016. 2016. Providence, RI: The Watson Institute for International and Public Affairs, Brown University, August 2016. http://watson.brown.edu/costsofwar/files/cow/imce/papers/2016/War%20in%20Afghanistan%20and%20Pakistan%20UPDATE_FINAL_corrected%20date.pdf (accessed Feb 1, 2018).
- 9 In Brief: The artificial limbs & polio center: prosthetic & orthotic service. 2011. <https://www.icrc.org/eng/assets/files/2011/gaza-orthopedic-centre-icrc-2011.pdf> (accessed July 1, 2018).
- 10 Kelapatapu V. Techniques for lower extremity amputation. UpToDate, May 2 2017. <https://www.uptodate.com/contents/techniques-for-lower-extremity-amputation> (accessed Sept 1, 2018).
- 11 Institute for Palestine Studies. Israeli military operations against Gaza, 2000–2008. *J Palest Stud* 2009; **38**: 122–38.
- 12 Israeli Defence Forces. Operation Cast Lead (2008–09). <https://www.idf.il/en/minisites/wars-and-operations/operation-cast-lead-2008-09/> (accessed Sept 2, 2018).
- 13 Israeli Defence Forces. Operation Pillar of Defense (2012). <https://www.idf.il/en/minisites/wars-and-operations/operation-pillar-of-defense-2012/> (accessed Sept 2, 2018).
- 14 Israel Ministry of Foreign Affairs. The 2014 Gaza conflict: factual and legal aspects. June 14, 2015. <http://mfa.gov.il/MFA/ForeignPolicy/IsraelGaza2014/Pages/2014-Gaza-Conflict-Factual-and-Legal-Aspects.aspx> (accessed Sept 2, 2018).
- 15 Barnhart RK, Hottman SB, Marshall DM, Shappee E. Introduction to unmanned aircraft systems. New York City, NY: CRC Press, Taylor & Francis Group, 2012.
- 16 Index Mundi. Gaza Strip demographics profile 2018. Jan 20, 2018. https://www.indexmundi.com/gaza_strip/demographics_profile.html (accessed Nov 12, 2018).
- 17 United Nations Office for the Coordination of Humanitarian Affairs. OCHA Israeli-Palestinian fatalities since 2000-key trends August 2007. OCHA, Aug 31, 2007. <https://www.ochaopt.org/content/israeli-palestinian-fatalities-2000-key-trends-august-2007> (accessed Aug 17, 2017).
- 18 Ellessi K, Elmokhallalati Y, Abdo R, Asler O. The effect of the 50-day conflict in Gaza on children: a descriptive study. *Lancet* 2017; **390** (suppl 2): S11 (abstr).
- 19 Gilbert M, Skaik S. Patient flow, triage, and mortality in Al-Shifa hospital during the Israeli operation Protective Edge, 2014, in the Gaza Strip: a review of hospital record data. *Lancet* 2017; **390** (suppl 2): S26 (abstr).
- 20 Clasper J, Ramasamy A. Traumatic amputations. *Br J Pain* 2013; **7**: 67–73.
- 21 Heszelein-Lossius H, Al-Borno Y, Shaqqoura S, Skaik N, Giil LM, Gilbert M. Life after conflict-related amputation trauma: a clinical study from the Gaza Strip. *BMC Int Health Hum Rights* 2018; **18**: 34.

- 22 Abed Y, Haddaf S A. Fatalities and injuries in the 2014 Gaza conflict: a descriptive study. *Lancet* 2017; **390** (suppl 2): S4 (abstr).
- 23 Gilbert M. Brief report to UNRWA: the Gaza Health Sector as of June 2014. Tromsø: Univeristy Hopsital of North Norway, 2014 https://www.unrwa.org/sites/default/files/final_report_-_gaza_health_sector_june-july_2014_-_mads_gilbert_2.pdf (accessed Aug 10, 2017).
- 24 WHO. Gaza crisis, February 2018. Geneva: World Health Organization. https://reliefweb.int/sites/reliefweb.int/files/resources/WHO_Donor_Alert_Gaza_20_February_2018_final_.pdf (accessed June 6, 2018).
- 25 Williams BG. The CIAs covert predator drone war in Pakistan, 2004–2010: the history of an assassination campaign. *Stud Conflict Terrorism* 2010; **33**: 871–92.
- 26 UN Assistance Mission in Afghanistan. Afghanistan: mid-year report 2013 – protection of civilians in armed conflicts. Reliefweb, July 31, 2013. <https://reliefweb.int/report/afghanistan/afghanistan-mid-year-report-2013-protection-civilians-armed-conflict> (accessed Feb 1, 2018).
- 27 Abrahms M, Mireau J. Leadership matters: the effects of targeted killings on militant group tactics. *Terror Political Violence* 2017; **29**: 830–51.
- 28 Byman D. Why drones work: the case for Washington's weapon of choice. *Foreign Affairs* 2013; **92**: 32–43.