Assessment of the effect of snakebite on health and socioeconomic factors using a One Health perspective in the Terai region of Nepal: a cross-sectional study

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Summary

Background Snakebite envenoming has a substantial health and socioeconomic effect in rural communities. However, there are insufficient epidemiological and animal data, which prevents accurate assessment on the effects of snakebite. We aimed to assess the health and socioeconomic effect of snakebite using a One Health perspective.

Methods In this cross-sectional survey-based study, we assessed the health and socioeconomic effects of snakebite data using a multicluster survey that was previously done as part of the SNAKE-BYTE project in the Terai region, Nepal. Health effect was measured in terms of disability-adjusted life years (DALYs). Livelihood losses encompassed out-of-pocket health-care expenditures, losses of productivity due to days off work, and the losses due to mortality and treatment costs in domestic animals. Mortality losses in domestic animals were also estimated as animal loss equivalents, and overall human and animal health effect expressed using modified DALYs for zoonotic disease (zDALYs).

Findings We estimate an annual snakebite burden of 200 799 DALYs (95% CI 103 137–357 805), mostly due to mortality in children and women. Snakebite is estimated to lead to US$2·8 million in yearly livelihood losses associated with human and animal cases. Overall, we estimate a yearly human and animal health burden of 202 595 zDALYs (104 300–360 284).

Interpretation These findings present robust evidence on the extent of snakebite's health and socioeconomic effect and emphasise the need for a One Health perspective. The results also stress how improved data collection at the community level is crucial for improved assessments of its effect.

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Introduction

Snakebite envenoming is a neglected tropical disease (NTD) that is a major public health problem. It causes high mortality and morbidity in people, mainly due to acute injury and permanent sequelae,[1] and has substantial financial consequences associated with its clinical management and wage losses due to absenteeism.[2–4] Similar to other NTDs, snakebite affects mostly low-income communities, contributing to the exacerbation of the poverty–disease cycle.[2,3,5,6] In the 2021–30 NTD Roadmap, WHO urged the need to improve the robust and comprehensive evidence on the health and socioeconomic effect of snakebite in endemic countries.[7]

In Nepal, snakebite envenoming has a high incidence and mortality rate.[8] Several highly venomous species of snakes are found in the Terai region. Elapid snakes, notably the Indian spectacled cobra (*Naja naja*) and the common krait (*Bungarus caeruleus*), cause most of the morbidity and mortality related to snake envenoming in Nepal.[9,10] Elapid envenoming is characterised by a progressive neuromuscular paralysis that leads to respiratory failure and death, if untreated. Local tissue necrosis is a frequent complication of envenomation caused by particular species (eg, *Naja* species), which is often associated with long-term sequelae such as chronic wounds and amputation.

Although recurrently overlooked, snakebite also causes mortality and morbidity in domestic animals, with high mortality in livestock.[11] Cases in domestic animals could translate into livelihood losses for the households that depend on those animals for food, revenue, and support for other economic activities. These losses could be particularly damaging to smallholder farmers, who make up most farmers in Nepal.[12] Snakebite can thus result in negative health and socioeconomic effects due to losses incurred by human and domestic animal cases.[13]

The assessment of this double cross-sectoral socioeconomic effect requires a One Health perspective to frame the issue. One Health is an approach based on multisectoral collaboration principles and transdisciplinarity that capture health interconnection across species and systems. For zoonoses, namely for neglected parasitic zoonoses, a holistic One Health approach can be essential to inform cost-effectiveness studies for

Research in context

Evidence before this study

Snakebite is a highly endemic and important medical problem in Nepal that affects the most economically disadvantaged. In the southeastern region of Nepal, a community-based study found a substantial livelihood effect for the affected households, with a mean working incapacity period of 2 weeks and important out-of-pocket expenses. Estimates of the health and socioeconomic effect from other endemic countries echo these results and show the substantial burden of snakebite on affected families, especially for venomous snakebite cases. Studies have focused on the human health dimensions of snakebite; however, its health and socioeconomic consequences could be even higher if snakebite cases in domestic animals and subsequent livelihood losses for households are added.

Added value of this study

Our study aimed to assess the health and socioeconomic effect of snakebite in the Terai region of Nepal using a One Health perspective. We used primary data collected through a multicluster random survey covering human and domestic animals cases of snakebite, to assess the health effect associated with premature death and ill-health sequelae, losses associated with direct and indirect medical expenses resultant of bites and productivity losses, and losses linked to the death of domestic animals and expenses in animal health care. To our knowledge, this study is the first to quantify the health and socioeconomic effects of snakebite using a One Health perspective. We found a substantial health effect, with a high annual burden that was mostly associated with mortality among children and women. We also found that snakebite cases in domestic animals contribute to substantial livelihood losses, emphasising the importance of a One Health approach to snakebite.

Implications of all the available evidence

Epidemiological data from community-based studies estimating the extent of the health burden and the socioeconomic effect of snakebite remain uncommon. Hindering these assessments is the insufficient amount of high-quality data due to long-standing underreporting, underdiagnosis, and inadequate surveillance of snakebite. This lack of data contributes to an incomplete understanding of the overall effect of snakebite and the perpetuation of a cycle of neglect. Additionally, the economic effect of snakebite cases on domestic animals has not been considered in studies so far; hence, there is little consideration of its overall effect on livelihood. Our results show the extent to which snakebite has a detrimental effect on the lives of the affected communities in the Terai region, raise awareness of a crucial yet underreported public health and animal health problem, and inform snakebite interventions in Nepal and other endemic countries. By highlighting the importance of primary data to inform effect estimates, this work also supports the broader call for strengthening data collection efforts on snakebite. Finally, the analytical methods used in this study can be used in other endemic countries, and for other neglected tropical diseases with implications for human and animal health, which aligns with the call for a more integrated approach and collaborative actions proposed by WHO in the 2021–30 NTD Roadmap.

interventions and policy making. This approach has previously estimated negative outcomes of disease, reduced productivity in livestock caused by disease, and negative effects on the wellbeing and productivity in people.[14,15] In 2018, the modified disability-adjusted life years for zoonotic disease (zDALYs) metric has combined the societal burden of diseases and health threats that affect humans and domestic animals, within the DALY framework.[16] For snakebite, such a holistic perspective of health and socioeconomic effects has not been applied to date. In this study, we assess the health and socioeconomic effect of snakebite in the region Terai of Nepal, a snakebite endemic region, using a One Health approach.

Methods

Study design and participants

In this cross-sectional study, we used our previously proposed framework[13] to identify pathways for the effect of snakebite using a One Health perspective in the Terai region of Nepal. Accordingly, three main effects were considered: (1) direct health effect associated with human cases, including premature death and ill-health sequelae, (2) losses due to out-of-pocket health-care expenses and productivity losses associated with human cases, and (3) losses linked to the death, health sequelae, and morbidity impairing the productivity of domestic animals and expenses in animal health care.

See Online for appendix

Primary data was collected through a multicluster randomised survey that was conducted as part of the SNAKE-BYTE project, which enrolled 63 454 participants living in 13 879 households in 249 clusters in the Terai region between Nov 30, 2018, and May 7, 2019.[17] The questionnaire focused on snakebite and covered a range of questions, including questions on health burden for humans and animals and the socioeconomic effect, the result of these questions are reported here. Northern parts of Nepal comprising the high hills and Himalayas were excluded from the survey because snakebite is reported to be absent. Sampling was performed using cluster sampling and spatial random sampling of households based on satellite imagery. Selected households were surveyed without restrictions, if written informed consent was given, except if access to the household in the field was not possible (eg, a fenced household). The details on the data collected per loss stream considered in this assessment are detailed in the appendix (p 1).

The study was approved by the Nepal Health Research Council (registration number 585/2018), and the

Commission Cantonale d'Ethique de la Recherche Scientifique in Geneva, Switzerland (registry number 2018-01331).

Procedures

The burden of snakebite was assessed using DALYs.[18] Envenoming and non-envenoming snakebite were considered in this assessment. A non-envenoming event was considered as a bite by a non-venomous snake or a bite by a venomous snake without injection of venom. Health outcomes considered for envenoming were death, amputation, blindness, hand or arm impairment, walking impairment, wound treatment, and stress, nightmares or phobia to return to the location of the bite. For non-envenoming snakebite, health outcomes considered were hand or arm impairment, walking impairment, wound treatment, and stress, nightmares, or phobia to return to the location of the bite.

Incidence rates of each health outcome considered in the DALY estimation, calculated as a cross-sectional prevalence of snakebite in the past 12 months, were sourced from the results of the 2021 SNAKE-BYTE survey.[8] In this survey, among the 63 909 participants from 249 villages surveyed, 167 people with snakebite were identified, of whom 81 (49%) had envenomed snakebite and 13 people had died (case fatality ratio 7·8%). There were 261·6 snakebites per 100 000 population per year (95% CI 224·8–304·5), 126·7 envenoming snakebites per 100 000 population per year (102·0–157·5), and 20·5 deaths from snakebite per 100 000 population per year (12·0–35·1). Based on this incidence, there were an estimated 37 661 people who had been bitten by a snake (32 362–43 836) and 2949 deaths (1728–5053) in the Terai region per year.[8]

The disability weights used were sourced from the 2013 Global Burden of Disease study[19] and fitted to β distributions. When the disability weight for a specific health outcome was not available, a disability weight from an outcome with similar health effects was used. Life expectancy estimates for the years of life lost (YLL) components were obtained from the 2000–11 WHO methods and data sources for the Global Burden of Disease estimates.[20] Life expectancy for the years of life lost due to disability (YLD) was obtained from the WHO Global Health Observatory data repository for Nepal.[21] Estimations of the duration of illness were based on clinical expert opinion (by GA and FC). Age weighting and discounting were not applied. Total YLD, YLL, and DALYs for envenoming, non-envenoming, and overall snakebite were calculated using a stochastic model, with 20 000 iterations, in the DALY Calculator[22] using R (version version 4.0.1). Details of the data inputs used to populate the burden estimates are presented in the appendix (pp 2–3).

The median out-of-pocket expenditure was estimated using data from the survey for self-reported expenses incurred with antivenom, traditional healers and medicine, self-treatment and pharmacy, visits from family and carers, food during hospitalisation, religious and cultural rituals, and other unspecified costs. Data were stratified according to the clinical characteristics of the snakebite (ie, non-envenoming, mild, and severe envenoming).[8] Survey respondents were also asked about coping strategies, including whether a loan was needed, and if the ability to work had been affected either partially or fully. If so, respondents were asked about the length of time off work for the victim and carers to evaluate productivity losses. To estimate the total annual socio-economic effect of snakebite in the Terai region, the median expense per victim and the proportion of victims that incurred that cost, the productivity losses and the proportion of respondents reporting as having lost income were multiplied by the estimated overall incidence of snakebite found on the SNAKE-BYTE survey.[8]

Only confirmed and probable snakebite cases in domestic animals were included in the assessment, as per the case definition in the appendix (p 6). Losses considered were those associated with cases in cattle, buffalos, goats, and poultry. Snakebite cases in companion animals such as dogs and cats were reported in the survey[8] but were not included in this assessment because of methodological constraints in the quantification of their monetary value.

At the household level, losses linked to cases in domestic animals were estimated considering responses to the survey. For the Terai region estimate, stochastic distributions were fitted for producer-level prices to estimate the overall annual losses, using data from the survey and agricultural statistics to model uncertainty on these parameters (appendix p 4). Only mortality effects were considered, as there were no recoveries with subsequent production losses reported in the survey. No salvage value for the carcass or any animal by-products was considered as fatally envenomed domestic animals from surveyed households were buried. For each animal type, the producer-level prices were multiplied by the incidence of confirmed and probable cases standardised to the domestic animal's population of the Terai region, using a stochastic model. The incidence values for snakebite in domestic animals were those found on the survey[8]—ie, an annual incidence ranging from 41·6 to 202·4 animal cases per 100 000 depending on the animal type, translating into 38 616 animal cases (95% CI 32 020–46 570) per year in the Terai region. Annual overall costs of animal health care for the region were derived by multiplying estimated household losses by the percentage of respondents reporting those costs and the incidence per animal type. The overall Terai yearly effect associated with cases in domestic animals was then estimated considering mortality losses and animal health-care costs.

The health burden due to human and animal cases of snakebite was summarised using zDALYs.[16] Domestic animal losses due to mortality were converted from US dollars into animal loss equivalents (ALE) considering

a gross national income per capita for Nepal of US$960.[23] The results of the DALY estimation were added to the ALE results to calculate zDALY.

Outcomes

The primary outcome for this study was the health and socioeconomic effect of snakebite in the Terai region of Nepal using a One Health perspective, expressed as DALYs, zDALYs and livelihood losses due to human and animal cases.

Role of the funding source

The funder had no role in study design, data collection, data analysis, data interpretation, writing of the report, or the decision to submit for publication.

Results

In total, 200 799 DALYs (95% CI 103 138–357 805) are associated with snakebite in the Terai region every year, 5·3 DALYs per snakebite case. The mean annual estimated DALYs for snakebite envenoming is 200 795 (103 137–357 794), corresponding to 1869 DALYs per 100 000 population (960–3330). Of the total DALYs for envenoming, we estimate a mean of 193 564 YLL (101 308–340 401) and 1800 YLL per 100 000 population (900–3000). Of the total YLL, 76·7% were due to envenoming in women and girls and 60·3% were due to cases in people aged 5–14 years. The YLLs per fatal case is 65·6.

The mean annual YLD associated with envenoming is estimated to be 7231 YLD (95% CI 1829–17 393) and 67 YLD per 100 000 population (17–162), of which disability associated with walking impairment contribute the most (47%). Additionally, 68·7% of the total YLD are estimated to be accrued in women and girls. The mean DALYs due to non-envenoming bites is 4 (1–11).

136 (90·6%) of 150 survey respondents reported having incurred out-of-pocket health-care expenditure following a snakebite (table 1). The median total out-of-pocket expenditure per snakebite was $27·2 (IQR 15·4–58·6). For severe envenoming, the reported median out-of-pocket expenditure was $63·5 (34·0–99·9). 133 (88·7%) of 150 respondents have paid these expenses in cash.

Concerning productivity losses, 44 (23·3%) of the respondents reported having to partly or fully stop working. The median period off work reported was one week. The median total loss reported due to absenteeism was $22·7 [9·1–45·4]. In 40% of the cases, at least one family member reported absenteeism, with a median length of 3 days (IQR 2–12; table 2). The median income loss reported was $18·2 (9·1–45·4). Accordingly, overall household losses due to health-care costs and productivity ascend to $67·7.

At the Terai level, the annual estimate for out-of-pocket health-care expenditure was $693 563. The estimated annual lost income due to productivity losses was $390 623, with the total yearly overall losses associated with human cases estimated to be $1·08 million.

87 (93·5%) of 93 households with cases of snakebite in domestic animals reported livelihood losses. Of those, 20 (22·9%) provided an estimate of their losses in our survey. The median reported loss due to mortality of domestic animals at the household level was $90·8 (IQR 36·3–213·3). At the Terai level, losses associated with domestic animal cases are estimated to be $1·72 million (95% CI 1 115 005–2 380 016). These losses correspond to 1796 ALE (1162–2479) for all domestic animal types considered, 16·7 ALE per 100 000 population (10·8–23·1). The results by animal types considered in our estimates are detailed in the appendix (p 7). Additionally, 29 (31·2%) of 93 respondents reported treatment expenses for cattle and buffalo. At the Terai level, yearly treatment costs are estimated to be $58 051 in total.

Overall, snakebite in humans and domestic animals is estimated to lead to annual losses of $2·8 million in the Terai region of Nepal. We estimate the combined

	Households reporting costs (n=150)	Reported expenditures and losses (US$)
Overall out-of-pocket expenditure for snakebite	136 (91%)	27·2 (15·4–58·6)
Transport to health-care facility	81 (54%)	4·5 (2·7–11·8)
Medical expenses: in a health facility setting	81 (54%)	9·1 (4·5–27·2)
Medical expenses: on antivenom	26 (17%)	9·1 (4·5–18·1)
Medical expenses: traditional healers	50 (33%)	9·1 (4·5–13·6)
Medical expenses: in self-treatment or pharmacy	61 (41%)	4·5 (4·5–9·1)
Visits from family	69 (46%)	9·1 (4·5–9·1)
Help and carers	44 (29%)	4·5 (1·8–5·0)
Food during hospitalisation	79 (53%)	4·5 (4·5–9·1)
Religious or cultural rituals	17 (11%)	4·5 (2·7–13·6)
Other unspecified costs	42 (28%)	7·3 (4·5–9·1)
Total out-of-pocket expenditure for severe envenoming cases	..	63·5 (34·0–99·9)

Expenditures and losses are reported at median (IQR).

Table 1: **Socioeconomic losses following a snakebite in the Terai region of Nepal**

	Productivity loss
Patient	
Length of work time lost (days)	7 (7–21)
Total income reported (US$)	22·7 (9·1–45·4)
Family or carer	
Work absenteeism due to snakebite (days)	3 (2–12)
Income losses due to snakebite (US$)	18·2 (9·1–45·4)

Data are median (IQR).

Table 2: **Productivity losses for the patient and the patient's family or carers following a snakebite in the Terai region of Nepal**

human and animal health burden of snakebite to be 202 595 zDALYs (95% CI 104 300–360 284), 1885 zDALYs per 100 000 population (971–3353).

Discussion

We assessed the effect of snakebite in the Terai region of Nepal using a One Health perspective that encompasses health and socioeconomic losses associated with snakebites of people and domestic animals. To our knowledge, this study presents the first One Health estimate of snakebite's effect on health and socioeconomics. This assessment was done using primary data from a large-scale household survey and produced estimates for disease burden, out-of-pocket expenditure in health care, productivity losses for people who had been bitten and their families, and losses associated with cases in domestic animals. Our results confirm that snakebite is an important problem in the Terai region that affects livelihood and DALYs, which are mostly associated with envenoming in women, high paediatric mortality, and losses in domestic animals.

We estimated that snakebite is responsible for 200 799 DALYs per year in the Terai region, a figure 14-times higher than the 14 447 DALYs due to venomous animal contact estimated by the Institute for Health Metrics and Evaluation for Nepal in 2019, and 16-times higher for the YLL estimates. Our estimates are also higher than those for Sri Lanka, where a burden of 0·5–0·7 DALYs per 100 000 population was reported.[24] The high mortality found in our study among children aged 5–14 years and women largely explains these results. The high estimate of YLLs per fatal case is consistent with the fact that most deaths are among children aged 5–14 years. The YLL estimate for children aged 5–14 years is 23-times higher than the Institute for Health Metrics and Evaluation estimates for under people aged 20 years or younger. The distribution of the DALYs per age group in Sri Lanka also reveals a different stratification of burden, with the 5–14 years age group contributing to only 5·3–5·6% of the DALYs.[24] Estimates using spatiotemporal models at the provincial level showing a higher incidence for Sri Lanka could further affect the country's snakebite burden estimates.[25]

However, the comparison with other burden of disease estimates needs to be cautious as methodological differences and population structure, particularly with regards to age, can partly contribute to these differences. We have not used age-weighting and discounting, as per the current standard in the assessment of the burden of disease. A methodology that does not use age-weighting and discounting, however, might lead to a substantial increase in the absolute number of DALYs lost and a relative increase in the share of DALYs among infants and older people here. Similarly, we have also used the global life expectancy table for the YLL calculation, which leads to higher YLLs, particularly for the earlier fringes of the age range. The high YLL associated with snakebite in younger people needs to also be interpreted within the population structure of Nepal, which has a young average median age of the population. Still, our results converge with previous studies from Nepal[26–31] and India,[32] which have reported a substantial number of cases in children and young adults, possibly because older children are more likely to participate in outdoor activities than infants.

The results of our study show that the burden of snakebite in the Terai is higher among women and girls, highlighting a gender dimension to snakebite in Nepal and the need for further research into how this can be important in the prevention and treatment of snakebite. Differences in health-care seeking behaviours for women and men in Nepal could be a contributing factor to this result.[33] An analysis of accessibility to health care for snakebite within the SNAKE-BYTE project will help clarify this aspect.

Our results show that the YLD component of burden represents a smaller ratio of the total burden of snakebite than the YLL, as also seen in west Africa,[34] but contrasts with a higher ratio estimated for Sri Lanka.[24] Along with methodological differences, national and regional discrepancies in the YLD to YLL ratio can result from geographical differences in the diversity of venomous snakes, the health effects of snakebites in the area, and the availability of and access to antivenom and health care. Our study provides an estimate of YLD including data from multiple health outcomes associated with envenoming and non-envenoming snakebites. By contrast, previous studies considered only amputation or used a single disability weight to assess the overall health outcomes associated with snakebite.

Our study also found that there were substantial livelihood losses associated with snakebite. Although polyvalent antivenom has been provided free of charge to all hospitals in Nepal by the Ministry of Health since 1998,[9] patients still incur in out-of-pocket costs for the remaining treatments and can pay for antivenom if the treatment centre is out of stock. When health care and productivity losses are combined, the median household livelihood loss associated with human cases of snakebite is $67·7. Severe envenoming cases had a higher financial cost than non-envenoming cases. This result aligns with previous studies describing a mean expense of $69 for snakebite survivors in the Terai.[35]

To our knowledge, the losses resulting from cases of snakebite in domestic animals that we present in this study have been estimated for the first time. We found an important effect on the livelihood for households that have been affected by snakebite in domestic animals, with a median loss of $90·8—which is an important consideration given that the average monthly earnings for rural Nepali households of $250.[36] These results provide additional evidence that snakebite can lead to an economic crisis for affected households, fuelling the NTD vicious cycle of poverty.[37] For zoonoses, this double

health and livelihood effect has been documented,[16] highlighting the importance of One Health for these assessments. When the animal health losses at the Terai found in our study are converted to ALE, allowing us to contextualise this losses within a One Health approach, our results represent a substantial effect compared with other diseases and contexts where ALE estimates are available (eg, echinococcosis, Q fever, and cysticercosis).[16] However, because of the high DALYs per 100 000 person-years, the additional effect represented by the ALE fraction in the overall zDALYs per 100 000 person-years is small representing just under 1% of the total. This contrasts with some zoonoses (eg, echinococcosis) in which the ALE is a substantive proportion of the societal burden.[16]

Our study has some limitations. First, our estimates were based on self-reporting in the survey and reliant on the recall of individuals. Therefore, it cannot be excluded that confounders might be observed on self-reported outcomes, notably the stress-related health outcomes following a snakebite used as an input for the YLD component of the DALY estimation. Second, to minimise potential response bias in the reported losses for domestic animals, we applied a stochastic model using distributions with inputs from agricultural statistics, to estimate Terai-level losses. Human population data used as an input for the estimations was based on the most recently available census data from 2011, which might not account for population changes that occurred since. Third, the sample size used for domestic animals was incidental to that of humans, therefore, regional differences in the density of domestic animals was not considered. However, our community-based survey allowed disclosing a high incidence of snakebite in domestic animals, which could be higher if suspected cases are also included. Finally, although pets were not included in the assessment, they could protect and support household activities. Our study also did not assess the psychological or emotional effect of losing domestic animals to snakebite, which could affect human health, wellbeing, and productivity. Further work focusing on the domestic animal's health consequences of snakebite and links to human health, including also a qualitative assessment, will enhance the evidence on this area.

In line with the WHO 2030 NTD Roadmap, our work highlights the multidimensional and cross-sectoral health and socioeconomic effects of snakebite and how they can be captured using a One Health perspective and primary data collected in the community. We have provided comprehensive estimates of the health and socio-economic effect of snakebite for the Terai region of Nepal and put forward a One Health methodological basis for this assessment in other snakebite endemic countries.

Contributors

SBM conceptualised the analysis, conducted the formal analysis, and wrote the first manuscript draft. FC and NR supervise the SNAKE-BYTE project and acquired the funding. RRdC and IB contributed to the conceptual development of the One Health approach to snakebite. IB, GA, and CO verified the underlying data. PT provided overall guidance on the analytical methods. SBM, IB, GA, CO, SKS, RRdC, NR, and FC were involved in the survey design. SKS coordinated the survey implementation in the field. GA and SKS trained the data collectors. GA classified snakebite cases clinically. SBM, GA and FC identified health outcomes to be considered in the burden assessment. IB, GA, CO accessed and verified the data. All authors were involved in the data interpretation and reviewed the final manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

Participant data that underlie the results reported in this Article will be made available upon reasonable request through the University of Geneva data repository, after deidentification, beginning 12 months following the publication of this Article. Requests should be directed to Nicholas Ray at nicolas.ray@unige.ch.

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