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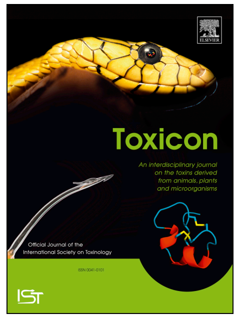

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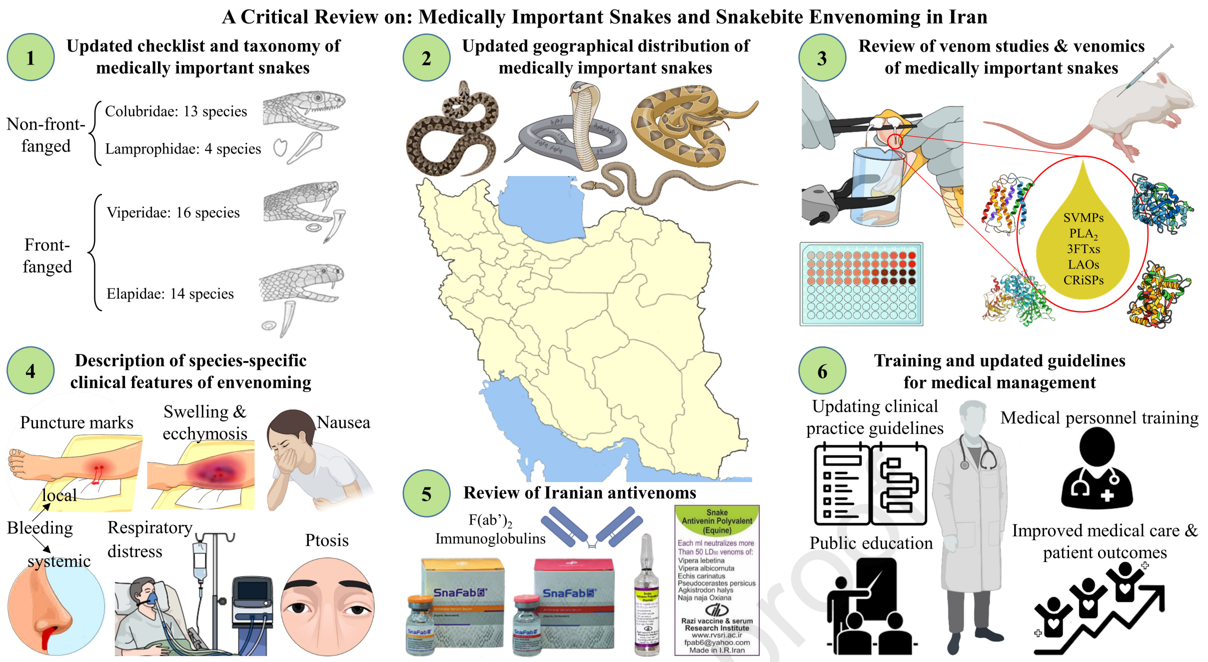
A Critical Review on: Medically Important Snakes and Snakebite Envenoming in Iran
1 Updated checklist and taxonomy of medically important snakes
Non-front-fanged
Colubridae: 13 species
Lamprophidae: 4 species
Front-fanged
Viperidae: 16 species
Elapidae: 14 species
2 Updated geographical distribution of medically important snakes
3 Review of venom studies & venomics of medically important snakes
SVMPs
PLA2
3FTxs
LAOs
CRiSPs
4 Description of species-specific clinical features of envenoming
Puncture marks
Swelling & ecchymosis
Nausea
local
Bleeding
systemic
Respiratory distress
Ptosis
5 Review of Iranian antivenoms
F(ab')2
Immunoglobulins
SnaFab
Snake Antivenin Polyvalent (Equine)
Razi vaccine & serum Research Institute
6 Training and updated guidelines for medical management
Updating clinical practice guidelines
Medical personnel training
Public education
Improved medical care & patient outcomes

Medically important snakes and snakebite envenoming in Iran

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ABSTRACT

Snakebite is a common health condition in Iran with a diverse snake fauna, especially in tropical southern and mountainous western areas of the country with plethora of snake species. The list of medically important snakes, circumstances and effects of their bite, and necessary medical care require critical appraisal and should be updated regularly. This study aims to review and map the distributions of medically important snake species of Iran, re-evaluate their taxonomy, review their venomics, describe the clinical effects of envenoming, and discuss medical management and treatment, including the use of antivenom. Nearly 350 published articles and 26 textbooks with information on venomous and mildly venomous snake species and snakebites of Iran, were reviewed, many in Persian (Farsi) language, making them relatively inaccessible to an international readership. This has resulted in a revised updated list of Iran's medically important snake species, with taxonomic revisions of some, compilation of their morphological features, remapping of their geographical distributions, and description of species-specific clinical effects of envenoming. Moreover, the antivenom manufactured in Iran is discussed, together with treatment protocols that have been developed for the hospital management of envenomed patients.

Keywords: Iran; Elapidae; Hydrophiini; Viperidae; Snakebites; Antivenoms

1. INTRODUCTION

Paradoxically, snake [mɑːr in Persian (Farsi) language] has epitomized both "vivification/ vitality/agility/well-being/productivity" and "annihilation/cunning/treason" in Persian culture and literature (Afshari & Monzavi, 2016b; Rasmi, 2016). "Bimar", Persian for "patient", is a word compounded of "bi (= without)" and "mar"; denoting a living entity that has lost its vitality/well-being (bimar = without well-being) (Afshari & Monzavi, 2016b). Rooted in old Persian, and perhaps through mutual understanding and cultural exchange, these concepts may have contributed to an ancient Greek symbol, the "Rod of Asclepius", a serpent-entwined staff, representing health and healing. In addition, in historical remains and architecture of Persian territory, the snake is depicted with reverence, as signifying life, fertility, and blessings conferred on nature and the environment (Kazemi Shishavan & Maleki, 2018; Rasmi, 2016; Taheri, 2015).

Iran (literally means the land of Aryan people) covers an area of 1,648,195 square kilometers, bordering Armenia, Azerbaijan, and Turkmenistan in the north, Afghanistan and Pakistan in the east, and Iraq and Turkey in the west, and associated maritime boundaries with Kuwait, Iraq, Saudi Arabia, Bahrain, Oman, Qatar, and the United Arab Emirates across the Persian Gulf and the Sea (or Gulf) of Oman (also known as Sea of Makran) (**Fig. 1**). Iran is separated from the arid lowland areas of Iraq by the high Zagros Mountains, more than 4,000 m in altitude, and from the Caucasus and Turkmenistan's arid sandy deserts in the north and northeast, by the higher Alborz Mountains, at more than 5,500 m. The country's 31 provinces have widely varying climates (**Fig. 1**). Average annual rainfall is rarely more than 40 mm in some parts of central and southern Iran, but exceeds 600 mm in some western and northern regions. The faunal diversity of Iran is influenced by its geographical position interconnecting the Palearctic, Ethiopian and Oriental regions (Dehghani et al., 2014b; Hosseinzadeh et al., 2014; Jowkar et al., 2016). Iran's vast biological diversity and tropical/subtropical, and semi-arid climate, have provided an ideal habitat, in which many species of snakes and other reptiles have evolved. This has exposed Iranians to the potential health-related dangers of encounters with these creatures throughout history. Ancient Indo-Iranian (Aryan) healers and physicians practiced various and sometimes strange methods of treating snakebite~~s~~ victims, although some of them, contemporary with Thrita or Trita (the earliest known Aryan physician and producer of antidotes and remedies, in about 3000 BCE) (Ambartsumian, 2001; Dadashi Arani & Mastali Parsa, 2020; Jayne, 1919; Nayernouri, 2015), were said to have had a good knowledge of antidotal remedies for snakebites (Kaviani Pooya, 2010; Najmabadi, 1992; Saameie, 2020). More recently, the world-renowned Iranian physicians, Zakaria Razi (Abu Bakr al-Razi or Rhazes, 854-932 A.D.) and Ibn Sina (Avicenna, 980-1037 A.D.), advanced the knowledge on snakebites and envenoming management. At a time when the "snake stone" was one of the foundations of traditional snakebite treatment, Razi was among the few who questioned its usefulness. Through careful observation and scrutiny, he ultimately discredited its effectiveness (A'alam, 2000; Pymm, 2017). He used pressure bandaging above the bite site and a kind of snakebite antidote (*Teriaq-e Afa'ei*) to treat the patients and he believed that the internal temperature of the patient should be increased using grape wine or naked lady lily (Rezaei-Orimi et al., 2022). Avicenna in his monumental masterpiece, *The Canon of Medicine*, provided classified diagnostic descriptions of bites of different venomous animals. He listed 30 different snakes and ranked them according to 3 classes based on lethality to humans. His therapeutic directives were based mainly on preventing venom's entering the bloodstream, i.e., by washing the wound, incision of the bite site and amputation of the bitten limb (for severe cases), and on the use of various herbal remedies depending on the snake species involved (Rezaei-Orimi et al., 2019).

Modern ophiology in Iran owes an enormous debt to the late Professor Mahmoud Latifi (1929-2005), a renowned herpetologist, who devoted his life to gathering information about the snakes of Iran (**Fig. 2**). Following 24 years of painstaking expeditions (1959 to 1983) across the whole country, Latifi and his team collected 62 species from 28 genera and 8 families of venomous and non-venomous snakes. These were the basis of research articles and, notably, his classic textbook, “Snakes of Iran”, originally published in 1985 in Persian by the Iranian Department of Environment (IDE) (Latifi, 1985), and later translated into English through the support of the National Museum of Natural History, Smithsonian Institution and the Society for the Study of Amphibians and Reptiles (Latifi, 1991). The naming of *Montivipera latifii*, an endemic species of viper from the Lar valley in Mount Damavand, was fitting recognition of his endeavors. Latifi also pioneered antivenom production in Iran at the Razi Vaccine and Serum Research Institute in Karaj, supplying the country and the Middle East region for over 50 years. This program depended on the help of a network of snake catchers who brought snakes captured throughout Iran to the institute (**Fig. 2**). Another major contribution was the late Dr. Reza Farzanpay's (1934-2018) book “Ophiology” on the morphological characteristics of Iran's snakes [published in Persian, 1990] (Farzanpay, 1990). Dr. Farzanpay was best known for his work on scorpions and scorpion antivenoms at the Razi Institute. Zoological studies and conservation of wildlife, including snakes, in Iran are also indebted to the late Eskandar Firouz (1926-2020), a pioneering environmentalist and conservationist, who was the founding director of the IDE and a cofounder of the Convention on Wetlands of International Importance, also known as the Ramsar Convention (1971). In 1977, he was elected president of the International Union for Conservation of Nature and Natural Resources (IUCN). His book “The Complete Fauna of Iran” (2005) is an essential reference for anyone interested in the vertebrate fauna of Asia and the Middle East (Firouz, 2005) (**Fig. 2**).

Worldwide, the survival of snakes is threatened by human intrusion into their environment, global climatic change, and excessive collecting, for commercial reasons such as the sale of their body parts for food and medicines, venoms and skin (Almasieh et al., 2019; Ansari, 2020; Dehghani et al., 2014a; Jowkar et al., 2016; Reading et al., 2010; Yousefi et al., 2019). This is why so many snake species are now in the IUCN's red list of threatened species (Betts et al., 2020). Therefore, accurate and up-to-date information about the geographical distribution and preferred habitats of different snake species is needed to conserve them and their ecosystems, and to make the human inhabitants of these regions aware of the risk of venomous snakebites (Yousefi et al., 2020). Determination of precise geographical distributions of venomous snake species is also important for developing preventive interventions to reduce human-snake encounters, and to improve medical services to make antivenom and other medical resources more readily available (Warrell, 2016). The list of medically-important snakes of Iran has not been critically reevaluated since the publication of Latifi's book in 1985 (Latifi, 1991, 1985). The present study has reviewed all relevant publications concerning the geographical distribution, morphology, taxonomy, venom composition, clinical effects of envenoming, and clinical significance of Iran's medically important snakes (i.e., front-fanged venomous, and non-front-fanged mildly-venomous snakes, both potentially dangerous to human health). Locally developed protocols for medical management of envenomed patients are also assessed in the light of international advances in clinical toxinology.

2. METHODS

A systematic review was performed using keywords including, "SNAKE", "SNAKEBITE", "ENVENOMING", "ENVENOMATION", "ANTIVENOM" and "IRAN"; as well as "species names" of snakes currently known to be part of herpetofauna of Iran, based on two reliable resources (Latifi, 1991, 1985; Safaei-Mahroo et al., 2015). Articles and scientific documents available up to the end of 2022 were explored in peer-reviewed biological and biomedical journals, as well as eminent indexing databases including Web of Science, PubMed, Scopus and Google Scholar. In addition, articles in Persian were retrieved from Iranian online repositories of scientific literature including the Scientific Information Database (SID) and IranDoc. Original studies of clinical findings of envenoming or LD_{50} studies of venom of snake species occurring in Iran, including studies not performed by Iranian scientists or those carried out in adjacent or neighboring countries, were also reviewed and reliable data extracted. A total of 2897 articles were identified, and after removal of 797 duplicates, the abstracts of the remaining titles were evaluated; and accordingly, 1768 irrelevant documents and those not meeting the required criteria were removed. Within the study objectives, 347 documents (including 186 studies from Iran and 161 articles about publications involving Iran's snake species occurring in other geographic regions) were finally determined to be eligible for review and were subjected to deeper scrutiny and analyses (**Fig. 3**). Ten Iranian clinical and environmental toxicology textbooks and compendia on Iranian herpetofauna, as well as sixteen international toxicology and toxinology textbooks were also reviewed for relevant information on Iranian snakes and snakebites (Afshari & Monzavi, 2016a; Balali-Mood & Shariat, 1999; Dehghani, 2010; Farzanpay, 1990; Firouz, 2005; Latifi, 1991, 1985; Mozaffari et al., 2016; Nabipour, 2012; Rajabizadeh, 2018; Zare Mirakabadi & Teymurzadeh, 2009). An Iranian website focusing on ecological information including Iran's wilderness deserts (https://www.irandeserts.com), which is directed by an expert team of scientists and interested volunteers, was accessed to retrieve relevant photos and information on the geographical biotopes of Iranian snakes. The http://reptile-database.reptarium.cz/, https://www.iucnredlist.org and https://www.inaturalist.org databases were also accessed to find relevant photos, taxonomic information and global conservation status of the Iranian snake species. Reports and guidelines endorsed by the World Health Organization (WHO), available on the WHO website (www.who.int/snakebites/resources), were also reviewed. Following consensus of all authors, retrieved materials that were deemed authentic were further interpreted, and compiled with tables, representative images of medically important snakes of Iran and their geographical distributions in regionalized distribution maps along with their global conservation status (based on IUCN).

3. RESULTS

3.1. Checklist of Iranian medically important snakes

Snakebite is not uncommon in Iran, at least for some Iranians who live and work in regions inhabited by a plethora of snake species, such as the tropical southern and mountainous western areas of the country. Various species of snakes and snakebites are reported, from islands in the Persian Gulf in the South, to the northernmost regions of the country (Afshari & Monzavi, 2016b; Dehghani, 2010; Nabipour, 2012). A total of 89 species have been identified, of which 30 are venomous, seventeen are mildly-venomous (non-front-fanged species) and the remainder are considered non-venomous (Dehghani, 2010; Dehghani et al., 2014c; Ebrahimi et al., 2018; Farzanpay, 1990; Fathinia et al., 2011; Firouz, 2005; Gholamifard, 2011; Hosseinian Yousefkhani et al., 2014; Latifi, 1991, 1985; Latifi et al., 1966; Malekoutian et al., 2018; Moradi et al., 2013; Mozaffari et al., 2016; Nabipour, 2012; Nasrabadi et al., 2016; Rajabizadeh, 2013, 2018; Ramezani et al., 2011; Rastegar-Pouyani et al., 2008; Safaei-Mahroo et al., 2015; Shaykhi Ilanloo et al., 2015; Soleimanfallah et al., 2018; Zare Mirakabadi & Teymurzadeh, 2009). While some species are widely distributed throughout the country, others are restricted to limited geographic regions (**Supplementary material - Table 1S**). Potential factors influencing the distribution of Iran's common venomous snakes include rainfall seasonality, alterations in habitat suitability, and vegetation properties (Yousefi et al., 2015; Yousefi et al., 2020). Some species have shown morphological adaptations to specific geographical locations (Fathinia & Rastegar-Pouyani, 2010; Gholamifard, 2011; Gholamifard & Esmaeili, 2010; Moradi et al., 2014; Navidpour et al., 2019; Rajabizadeh et al., 2012; Rastegar-Pouyani et al., 2008; Safaei-Mahroo et al., 2015; Todehdehghan et al., 2019; Yousefi et al., 2015).

In this study, at the family and subfamily levels, we followed the classification of Pyron et al. (Pyron et al., 2013). Accordingly, the functionally venomous snake species of Iran are grouped in the families Colubridae (subfamily Colubrinae), Lamprophiidae (subfamily Psammophiinae), Elapidae and Viperidae (subfamilies Crotalinae and Viperinae). While older works have frequently recognized subfamilies within the Elapidae (especially the subfamily Hydrophiinae for the marine elapids), recent studies (Figueroa et al., 2016; Pyron et al., 2013; Wallach et al., 2017; Zaher et al., 2019) have not supported this arrangement. Therefore, the subfamilies within the Elapidae are not recognized in this manuscript.

3.1.1. Non-front-fanged snakes

For humans, bites by the majority of opisthoglyphous (non-front-fanged or rear-fanged) snakes are mainly mildly or non-venomous, and are rarely severe, even though these snakes possess venoms containing components that are often highly toxic to their natural prey (Weinstein et al., 2023b; Weinstein et al., 2013). This is largely due to the fact that the venom-delivering fangs are at the back of the maxilla with lack of venom storage reservoir, and the venom glands lack powerful compressor muscles (Modahl & Mackessy, 2019; Modahl et al., 2016; Saviola et al., 2014). Hence, except in a few documented cases, this precludes the injection of venom under high pressure and in quantities in sufficient to cause envenoming in humans, unlike the front-fanged (proteroglyphous and solenoglyphous) vipers and elapids (Araujo et al., 2018; Brandehoff et al., 2019; Dehghani et al., 2012; Weinstein et al., 2014). However, outside Iran, bites by a few opisthoglyphous species (e.g., *Dispholidus typus, Rhabdophis* spp., and *Thelotornis* spp.) can result in envenoming as dangerous as from front-fanged venomous snakes (Dashevsky et al., 2018; Junqueira-de-Azevedo et al., 2016; Weinstein et al., 2013). The mildly venomous non-front-fanged snakes of Iran belong to two families - Colubridae and Lamprophiidae (**Supplementary material - Table 1SA & Table 2S**). Their venoms contain proteins that are structurally convergent with those of front-fanged venomous snakes (Xie et al., 2022).

3.1.1.1. Colubridae

Over 40 colubrid species have been recorded in Iran, the majority of which are considered non-venomous, or whose bites are largely unstudied (Dehghani et al., 2014c; Dehghani et al., 2016a; Rastegar-Pouyani et al., 2008; Safaei-Mahroo et al., 2015). Among these, thirteen species in four genera (*Boiga, Hemorrhois, Platyceps* and *Telescopus*) are considered mildly venomous (Dehghani et al., 2016a; Moradi et al., 2021; Rastegar-Pouyani et al., 2008; Safaei-Mahroo et al., 2015; Schaetti et al., 2012). *Boiga* and *Telescopus* species in Iran are functionally venomous, whereas symptomatic envenoming after bites by *Hemorrhois* and *Platyceps* species has not been adequately documented.

The black-headed cat snake (*Boiga trigonata melanocephala*) occurs exclusively in eastern Iran, whereas *Hemorrhois, Platyceps and Telescopus* species collectively inhabit most regions of the country, although their diversity is greatest in the western third of the country, and lowest in the deserts of the center (Moshtaghie et al., 2018; Safaei-Mahroo et al., 2015). The recent discovery of the black-headed tiger snake (*Telescopus nigriceps*) in the southwest of Iran, close to the Iraq border, has increased the number of *Telescopus* species in Iran to five (**Table 1S**) (Nilson & Rastegar-Pouyani, 2013; Rastegar-Pouyani et al., 2008; Safaei-Mahroo et al., 2015). The type specimen of *Platyceps rhodorachis* was from Persia (De Filippi, 1865). *P. rhodorachis* and *T. rhinopoma* have also been recorded on some southern islands of Iran (Latifi, 1991), i.e., *P. rhodorachis* on Kharg (or Khark), Kish, Qeshm, Hengam and Hormoz Islands; and *T. rhinopoma* on Kharg Island.

3.1.1.2. Lamprophiidae

The four species of Iranian Lamprophiidae are members of the subfamily Psammophiinae in the genera *Psammophis* and *Malpolon* (**Table 2S**). Snakes in the closely-related Lamprophiidae and Elapidae families are sometimes referred to jointly as the superfamily Elapoidea (Kelly et al., 2009), but Elapoidea have now been shown to be paraphyletic. *Psammophis lineolatus*, *Psammophis schokari*, *Malpolon insignitus fuscus* and *Malpolon moilensis* occur in Iran. In the Persian Gulf, *P. schokari* is recorded from Kharg and Qeshm Islands, and *M. moilensis* from Kharg Island (Latifi, 1991). Iran has been the easternmost global distribution of the genus *Malpolon* (Safaei-Mahroo et al., 2016).

3.1.2. Front-fanged venomous snakes

Iran's front-fanged venomous snakes belong to two families, Elapidae (terrestrial and marine elapids) and Viperidae [Crotalinae (pit vipers) and Viperinae (true/Old World vipers)], which altogether include 30 species (**Tables 1SB & 3S**) (Gholamifard et al., 2012; Rastegar-Pouyani et al., 2008; Rezaie-Atagholipour et al., 2016; Safaei-Mahroo et al., 2015). The truly endemic venomous species of Iran are *Macrovipera razii*, *Montivipera latifii*, *Montivipera kuhrangica*, and *Bungarus persicus* (Abtin et al., 2014; Bok et al., 2017; Fathinia et al., 2016; Gholamifard, 2011; Oraie, 2020; Oraie et al., 2018; Rajabizadeh et al., 2011a; Rajabizadeh et al., 2012).

3.1.2.1. Elapidae

In Iran, 14 elapid species in 4 genera have been recorded, characterized by their proteroglyphous fangs and circular pupils (**Table 1SB & 3S**) (Firouz, 2005; Latifi, 1985; Rastegar-Pouyani et al., 2008; Shoorabi et al., 2017). Among the terrestrial elapids, the most widely distributed species are the Central Asian/Oxus/Caspian Cobra (*N. oxiana*) (Shoorabi et al., 2017), and the Eastern black desert or Morgan's Cobra (*Walterinnesia morgani*) (Nilson & Rastegar-Pouyani, 2007). The Iranian/Persian krait (*Bungarus persicus*), a relatively recent addition to the list of Iranian Elapidae, is restricted to the southeastern part of the country (Abtin et al., 2014; Rajabizadeh, 2018). It is the westernmost geographically distributed member of the genus Bungarus (Abtin et al., 2014).

Bungarus: *B. persicus* was discovered approximately 100 kilometers west of the Pakistan border, north of Sarbaz in Iran's Sistan and Baluchistan province (Abtin et al., 2014). It is distinguished from its closest relative *B. sindanus* by a unique small loreal scale or loreal black spot and higher numbers of ventral and subcaudal scales. Recently, there were two other reports from Bashagard, Hormozgan province (Shahi et al., 2022). There has also been a report of likely specimen collected in Ras Jiwani in Pakistan's Baluchistan region, just across the Pakistan-Iran borders, which was perhaps misidentified as *B. caeruleus* (Shockley, 1949).

Naja: *N. oxiana* is distributed in northeastern and possibly eastern Iran, Afghanistan, northwestern India (Jammu and Kashmir, and Himachal Pradesh), northern and western Pakistan, southern Turkmenistan, southwestern Tajikistan and southern Uzbekistan (Kazemi et al., 2021a; Kazemi et al., 2021b; Yousefi et al., 2020).

Walterinnesia: *W. morgani* has been reported from northern, western and southern parts of Iran, and, elsewhere, in Iraq, southeastern Turkey (Urfa), Syria, Saudi Arabia, and Kuwait (Gholamifard & Rastegar-Pouyani, 2012; Nilson & Rastegar-Pouyani, 2007).

Hydrophis: Marine elapids are represented in the Persian Gulf and the Sea of Oman by 11 species in the monophyletic clade Hydrophiini (viviparous sea snakes) (Gillett et al., 2014; Heydari Sereshk & Riyahi Bakhtiari, 2014; Lillywhite et al., 2014; Mirtschin et al., 2018; Nabipour, 2012; Rezaie-Atagholipour et al., 2016; Rezaie-Atagholipour et al., 2012a; Rezaie-Atagholipour et al., 2012b; Sanders et al., 2013). The most recent addition to Iran's list of sea snakes is Günther's or Cantor's narrow-headed sea snake (*Hydrophis cantoris*) (Rezaie-Atagholipour et al., 2016). *H. cantoris*, *H. viperinus* and *H. cyanocinctus* live in deep waters and are occasionally caught in fishing nets. Although rarely seen, they are not in danger of extinction. The beaked sea-snake (*H. schistosus*) has a very potent venom, making it perhaps the deadliest snake of Iran (**Tables 1S, 3S**). Elsewhere, it has been proven to be the most medically important sea-snake species (Mirtschin et al., 2018). The yellow-bellied sea-snake (*H. platurus*) is a pelagic species (inhabiting the open ocean) which floats, feeds, and, remarkably, drinks fresh rain water after storms on the sea surface (Gillett et al., 2014; Lillywhite et al., 2014). Stokes's sea-snake (*H. stokesii*) has been recorded in the Makran coast of Baluchistan in Pakistan, contiguous with Iran's Makran coast of Baluchistan, making it highly probable that this species also occurs in Iran's coastal waters (Rastegar-Pouyani et al., 2008). Despite their prodigious numbers, all species of sea-snakes are threatened by rapidly-increasing water pollution, fishing activities and marine vessel traffic (Heydari Sereshk & Riyahi Bakhtiari, 2014; Rezaie-Atagholipour et al., 2012a; Rezaie-Atagholipour et al., 2012b; Yaghmour et al., 2022).

3.1.2.2. Viperidae

The 16 Viperidae species (belonging to eight genera and two subfamilies) recorded in Iran (**Table 1S & 3S**) are characterized by vertically elliptical pupils, marked flattened triangular (wedge-shaped) head, and retractable solenoglyphous fangs (**Fig. 4**). The most widely distributed species are the Sindh or Sochurek's Saw-scaled viper (*Echis carinatus sochureki*), Blunt-nosed or Levantine Viper (*Macrovipera lebetina*), and Persian Horned Viper (*Pseudocerastes persicus*) (Dehghani et al., 2014b; Fathinia & Rastegar-Pouyani, 2010; Moradi et al., 2014; Rastegar-Pouyani et al., 2008; Safaei-Mahroo et al., 2015). These species are responsible for the majority of human snakebite envenomings in Iran (Dehghani et al., 2014b; Dehghani et al., 2012; Monzavi et al., 2019a; Monzavi et al., 2019b).

Cerastes: The Arabian or Desert Horned Viper (*Cerastes gasperettii*) occurs in southwestern Iran, inhabiting arid areas around oases in Khuzestan (Carné et al., 2020; Spawls & Branch, 1995). It has also been seen on Tahmadu (Jabrin) Island in the Persian Gulf (Latifi, 1991). Based on morphological observations, Werner et al. proposed that *C. gasperettii* be divided into to two subspecies (i.e., *C. g. gasperettii* and *C. g. mendelssohni*). However, a recent molecular phylogenetic analysis has questioned this subspecific division (Carné et al., 2020).

Echis: Despite studies suggesting that two distinct taxa of *Echis* occur in Iran, *E. multisquamatus* Cherlin, 1981 and *E. carinatus sochureki* Stemmler, 1969 (Bagherian & Kami, 2008; Cherlin, 1981; Cherlin, 1990), they have been synonymized based on more recent evidence of molecular phylogeny and clinal variation in morphology (Arnold et al., 2009; Navidpour et al., 2019; Pook et al., 2009). Hence, only one *Echis* taxon, i.e., *E. carinatus sochureki*, is recognized in Iran. The species is widely distributed in the country, except in the northwest parts. It also occurs on Kharg, Shif, Lavan, Kish, Qeshm, Greater Tunb and Hormoz Islands in the Persian Gulf (Latifi, 1991).

Eristicophis: MacMahon's Desert Viper or Leaf-nosed Viper (*Eristicophis macmahonii*) is an uncommon monotypic species native to the dry loose sandy desert regions in the extreme east of Iran (e.g., Tasouki) that share borders with Afghanistan and Pakistan (**Tables 1S, 3S**). It was first described by Alcock, Finn, Maynard and McMahon in 1896 close to the Iran border in Pakistan (Amirchah, Zeh, Drana Koh and Robat I. between 760 and 1,360 m altitude (Alcock et al., 1896), and in Iran by Guibé (Guibé, 1957) as "*Pseudocerastes latirostris*" from "Taraki 120 km after Zabol on the way to Zahedan" near to the Afghanistan border, and by Latifi (Latifi, 1991), who examined one specimen from Kerman and a few others from the Iran-Pakistan border (Latifi, 1991). Sindaco shows a record from near Zahak (Sindaco et al., 2013) and Joger (Joger, 1984) shows two records from the Zahak "bulge" but does not specify a source. Based on Papenfuss et al.'s assessment, this species also occurs near Jiroft, Kerman province (Papenfuss et al., 2021). It is a small irritable viper, characterized by two butterfly-shaped laterally projecting naso-rostral scales, which help prevent sand entering its nostrils, especially when the animal burrows down into the sand concealing itself to ambush prey.

Gloydius: The Caucasian Pit Viper (*Gloydius caucasicus*) is Iran's only pit viper. Recently it was elevated from being a subspecies of *G. halys* to full species rank (Asadi et al., 2019; Shi et al., 2016). It inhabits a range of environments in the Hyrcanian broad-leaved forest of the Alborz range, in northeastern to northwestern Iran, and in southeast Azerbaijan, ranging in altitude from 30 to 3000 m above sea level (Ghelichy Salakh et al., 2020; Khani et al., 2017). It is the most westerly species of Crotalinae in the Palearctic (Asadi et al., 2019; Ghelichy Salakh et al., 2019; Shi et al., 2016). This species has been regularly collected by the Razi Institute for antivenom production since 1924 (Asadi et al., 2019).

Macrovipera: The Blunt-nosed or Levantine Viper (*Macrovipera lebetina*) is widely distributed from Turkey and Cyprus east to Kashmir. In Iran, two sub-species are recognized, *M. lebetina obtusa* in the northwest and *M. l. cernovi* (Cernov's Viper) in the northeast (Stümpel & Joger, 2009; Stümpel et al., 2016). Recently, a second species of potential medical importance, Razi's viper (*Macrovipera razii*), has been identified in the Zagros Mountains of central and southern Iran, distinguished from *M. lebetina* by mitochondrial Cytb gene sequence phylogeny and morphology (Oraie, 2020; Oraie et al., 2018). Compared to *M. lebetina, M. razii* has higher ventral scale counts, elongated anterior chin-shields, and lower numbers of canthal and inter-supraocular scales.

Montivipera: The three closely-related species of the *Montivipera raddei* complex in Iran comprise *M. raddei*, *M. latifii*, and *M. kuhrangica* (Behrooz et al., 2018; Fakharmanesh et al., 2014; McDiarmid et al., 1999; Rajabizadeh, 2013; Stümpel et al., 2016; Yousefi et al., 2015). Through molecular analyses (on the basis of nuclear and mitochondrial genes), the sub-specific status of *M. raddei kurdistanica* and *M. raddei albicornuta* was not supported, implying that they should be collapsed into *M. raddei* (Stümpel et al., 2016). Phylogenetic evaluations also suggested that *M. latifii* is a separate evolutionary lineage from the closely-related Armenian, Caucasus or Radde's Viper (*M. raddei*). This was confirmed by the distinctive ecological adaptation of *M. latifii* to alpine habitats in the Alborz Mountains, where it can remain active despite the cold climate (Stümpel et al., 2016; Yousefi et al., 2015). Although regarded by some as diverging populations of the same species (Rastegar-Pouyani et al., 2014), using mitochondrial gene assay, phylogenetic and phylogeographic analyses, it has been shown that *M. latifii* and *M. kuhrangica* represent two monophyletic clades (Behrooz et al., 2018). Latifi's Viper (*M. latifii*), an endemic species, possesses a venom more potent than the venoms of other Iranian Viperidae except *E. c. sochureki* and *M. raddei* (**Table 1**) (Archundia et al., 2011; Latifi, 1984; Weinstein & Minton, 1984). Several species of the raddei complex, especially *M. latifii*, are rare and listed as "threatened" in the IUCN's red list (Ahmadi et al., 2019; Yousefi et al., 2015) with *M. latifii* classed as "endangered". This latter species has been subject to irrational killings, and its distribution is restricted to the Lar Valley, central Alborz region (Asadi et al., 2016; Behrooz et al., 2015; Rajabizadeh et al., 2012). The Kuhrang mountain viper (*M. kuhrangica*) is another endemic *Montivipera* that is restricted to the Central Zagros region and is rarely observed (Rajabizadeh et al., 2011a). The occurrence of Wagner's or ocellate mountain viper (*M. wagneri*) in Iran is uncertain. Although Nilson and Andrén reported a type locality of the species in the "vicinity of Lake Urmia" in northwestern Iran (Nilson & Andrén, 1984), it has not been reliably observed in the country since then (Kumlutas et al., 2015; Rastegar-Pouyani et al., 2008), although recent explorations have demonstrated a wide range for *M. wagneri* in eastern Turkey towards its border with northwestern Iran (Mebert et al., 2020).

Pseudocerastes: The horns of "false horned vipers" (*Pseudocerastes*) are composed of numerous small supraocular scales, rather than the single supraocular scales of the genus *Cerastes* (Bok et al., 2017; Fathinia et al., 2014). The Persian horned viper *(Pseudocerastes persicus*) is perhaps the most widely distributed viper species in the Middle East, from Northern Iraq to Pakistan with isolated populations in mountains of the South-East Arabian Peninsula (Sindaco et al., 2013). Field's horned viper (*P. fieldi*) is separated from *P. persicus* in its geographical range by the Zagros Mountains, and, although formerly classified as a sub-species, is now recognized as a separate species, based both on morphological features and differences in venom composition (Bdolah, 1986; Dehghani et al., 2014c; Gholamifard & Esmaeili, 2010). *P. persicus* has uniformly keeled scales and a longer tail than *P. fieldi*. The southern localities for *P. fieldi* in Iran need to be confirmed (Sindaco et al., 2013), while it is likely that the Fars record from a decade ago (Gholamifard & Esmaeili, 2010), was based on a misidentified *P. persicus*. In general, controversy has remained, and while some scientists do not recognize *P. fieldi* from Iran and suggest that all *P. fieldi* records from Iran were perhaps *P. persicus* (Fathinia et al., 2018; Safaei-Mahroo et al., 2015), others have reported the occurrence of *P. fieldi* in western and central Iran (Dehghani et al., 2014c; Mozaffari et al., 2016). The spider-tailed horned viper (*Pseudocerastes urarachnoides*), occurs in the west of Iran, and is also reported from the extreme East of Iraq (Al-Sheikhly et al., 2019; Al-Sheikhly et al., 2020; Fathinia et al., 2020). It has an extraordinary bristle-brush-like appendage on the tip of its tail (**Table 1S**). It was first collected during an American museum expedition in 1968, but neither the integrity of its solpugid/solifugid (camel spider)-like caudal appendage, a lure that attracts prey such as small birds and lizards, nor its specific status were appreciated until 2006 (Bostanchi et al., 2006; del Marmol et al., 2016; Fathinia et al., 2009; Fathinia et al., 2016).

Vipera: The Alburzi or Armenian steppe viper (*Vipera eriwanensis*) is distributed over northwest Iran, northeast Turkey and Transcaucasia (Rajabizadeh et al., 2011b), and is in danger of extinction (Tuniyev et al., 2009a). It was formerly considered a subspecies of the *V. ursinii* complex (Rajabizadeh et al., 2011b). Höggren et al. recognized *V. eriwanensis* as a distinct species (Höggren et al., 1993), a status supported by a more recent study (Zinenko et al., 2015). Ebner's viper (*V. ebneri*) has been reported from the central Alborz and the northernmost Zagros mountains. It was previously regarded as a sub-species of *V. eriwanensis* (Kukushkin et al., 2012; Rajabizadeh et al., 2011b; Rastegar-Pouyani et al., 2008), but species status was supported by Zinenko et al. (Zinenko et al., 2015). The zoogeographic status of the Transcaucasian sand viper (*Vipera ammodytes transcaucasiana*), has remained controversial (Mülder, 2017; Stümpel & Joger, 2009; Tok & Kumlutş, 1996). While it has been reported from extreme northwestern Iran, these reports seem unreliable, and its presence in the country has not been rigorously established (Mülder, 2017; Safaei-Mahroo et al., 2015; Tuniyev et al., 2009b). Elsewhere, it occurs in northern Turkey, Georgia, and northwest Azerbaijan (Mülder, 2017). Some herpetologists consider it a sub-species of *V. ammodytes,* whereas others accord it the status of a full species (Nilson et al., 1999).

3.2. A brief review of studies on the venoms of some Iranian snakes

Experimental studies of Iranian snake venoms date from Latifi's original studies on venom yield and lethal potency (Latifi, 1984), to more recent cytotoxic assays, and the application of proteomics or venomics (Ghezellou et al., 2021; Ghezellou et al., 2019). Lethal doses (LD_{50}) of the venoms of some common Iranian snakes of medical importance are presented in **Table 1.**

Table 1. Lethal doses (LD_{50}) of Iran's medically important snakes (Studies on mouse using crude venom)				
Species/Subspecies	**Route of injection**	**Reporting format**	**Result (mg/kg)**	**Reference**
Cerastes gasperettii	i.p.	Median	0.98	(Al-Sadoon et al., 2016)
	i.p.	Median	1.32	(Zaeri et al., 2021a)
Echis carinatus sochureki	i.p.	Median	1.68	(Ghezellou et al., 2021)
	i.v.	Mean ± SD	0.25 ± 0.06	(Latifi, 1984)
	i.v.	Median (Range)	0.26 (0.2-0.32)	(Latifi & Tabatabai, 1989)
	i.v.	Median (95% CI)	0.55 (0.44-0.69)	(Salmanizadeh et al., 2013)
	i.v.	Median	0.57	(Nasri Nasrabadi et al., 2022)
Gloydius caucasicus (halys)	i.p.	Median	1.45	(Fathi et al., 2022)
	i.v.	Mean ± SD	0.69 ± 0.04	(Latifi, 1984)
	i.p	Median	0.84-0.92	(Rasoulinasab et al., 2020)
Hydrophis cantoris	s.c.	Median	0.5	(Reid, 1956)
Hydrophis curtus	i.v.	Median	0.7	(Alam & Qasim, 1993)
	i.p.	Median	0.12	(Carey & Wright, 1960)
	i.v.	Median (95% CI)	0.2 (0.18-0.24)	(Tan et al., 2018)
Hydrophis cyanocinctus	i.v.	Median	0.6	(Alam & Qasim, 1993)
	i.p.	Median	0.8	(Ali et al., 1999a)
	i.v.	Median (95% CI)	0.29 (0.26-0.32)	(Baxter & Gallichio, 1976)
	s.c.	Median (95% CI)	0.49 (0.44-0.56)	
	i.v.	Median	0.13	(Calvete et al., 2012)
	i.p.	Median	0.17	
Hydrophis gracilis	s.c.	Median (95% CI)	0.51 (0.44-0.59)	(Baxter & Gallichio, 1976)
Hydrophis ornatus	i.m.	Median	0.16	(Tamiya & Puffer, 1974)
	i.v.	Median	2.2	(Tu, 1974)
Hydrophis platurus	i.p.	Median (95% CI)	0.12 (0.08-0.18)	(Lomonte et al., 2014)
	i.v.	Median (95% CI)	0.2 (0.04-0.32)	
Hydrophis schistosus	i.v.	Median (95% CI)	0.1 (0.08-0.11)	(Baxter & Gallichio, 1976)
	s.c.	Median (95% CI)	0.12 (0.1-0.14)	
	s.c.	Median (95% CI)	0.16 (0.15-019)	(Broad et al., 1979)
	i.v.	Median (95% CI)	0.07 (0.05-0.09)	(Tan et al., 2015)
	i.v.	Median	0.14-0.21	(Tu, 1974)
Hydrophis spiralis	i.v.	Median	0.4	(Alam & Qasim, 1993)
	i.p.	Median	0.58	(Carey & Wright, 1960)
Hydrophis stokesii	i.v.	Median (95% CI)	0.17 (0.15-0.2)	(Baxter & Gallichio, 1976)
	s.c.	Median (95% CI)	0.28 (0.24-0.31)	
Hydrophis viperinus	i.v.	Median	4.5	(Tu, 1974)
Macrovipera lebetina cernovi	i.v.	Median (95% CI)	0.88 (0.65-1.2)	(Archundia et al., 2011)
	i.v.	Median (95% CI)	0.99 (0.92-1.0)	(Garcia-Arredondo et al., 2019)
Macrovipera lebetina obtusa	i.v.	Median (95% CI)	1.51 (1.32-1.72)	(Archundia et al., 2011)
	i.v.	Median	0.9	(Elfiky et al., 2022)
	i.p.	Range	2.5-2.8	(Eskafi et al., 2021)
	i.p.	Median	3.87	(Fathi et al., 2022)

Table 1. Lethal doses (LD_{50}) of Iran's medically important snakes (Studies on mouse using crude venom)

Species/Subspecies	Route of injection	Reporting format	Result (mg/kg)	Reference
	i.v.	Median (95% CI)	0.82 (0.79-0.85)	(Garcia-Arredondo et al., 2019)
	i.v.	Mean ± SD	0.92 ± 0.07	(Kurtovic et al., 2014)
	i.v.	Mean ± SD	0.32 ± 0.07	(Latifi, 1984)
	i.p.	Median (95% CI)	1.75 (0.95-2.75)	(Pla et al., 2020)
	s.c.	Median	3.0	(Schöttler, 1938)
Malpolon insignitus (*monspessulanus*)	i.v.	Median	6.5	(Rosenberg et al., 1985)
Montivipera latifii	i.v.	Median	0.4	(Archundia et al., 2011)
	i.p.	Median	0.84	(Fathi et al., 2022)
	i.v.	Median (95% CI)	0.28 (0.24-0.31)	(Garcia-Arredondo et al., 2019)
	i.v.	Mean ± SD	0.28 ± 0.04	(Latifi, 1984)
	i.v.	Median (95% CI)	0.35 (0.31-0.42)	(Weinstein & Minton, 1984)
	i.p.	Median (95% CI)	2.07 (1.73-2.47)	
	s.c.	Median (95% CI)	4.61 (3.82-5.55)	
Montivipera raddei	i.v.	Median (95% CI)	0.19 (0.19-0.2)	(Archundia et al., 2011)
	i.p.	Range	1.63-2.05	(Fathi et al., 2022)
	i.v.	Median (95% CI)	0.2 (0.16-0.23)	(Garcia-Arredondo et al., 2019)
	i.v.	Mean ± SD	0.46 ± 0.03	(Kurtovic et al., 2014)
	i.v.	Mean ± SD	0.36 ± 0.05	(Latifi, 1984)
Naja oxiana	i.v.	Median	0.56	(Kazemi-Lomedasht et al., 2019)
	i.v.	Mean ± SD	0.42 ± 0.05	(Latifi, 1984)
	i.v.	Median	0.49	(Latifi & Tabatabai, 1989)
	s.c.	Median	0.45	(Minton, 1967)
Pseudocerastes fieldi	i.v.	Median	0.25	(Batzri-Izraeli & Bdolah, 1982)
	i.v.	Median	1.06	(Elfiky et al., 2022)
	i.p.	Median	1.0	(Gitter et al., 1962)
Pseudocerastes persicus	i.v.	Mean ± SD	0.81 ± 0.14	(Latifi, 1984)
	i.v.	Median	1.1	(Madani et al., 2018)
Vipera ammodytes transcaucasiana	i.v.	Median (95% CI)	0.4 (0.35-0.31)	(Garcia-Arredondo et al., 2019)
Vipera eriwanensis	i.v.	Mean ± SD	1.09 ± 0.03	(Latifi, 1984)
Walterinnesia morgani	i.p.	Median (95% CI)	0.66 (0.13-3.37)	(Calvete et al., 2021)
Pooled venom (*N. oxiana, C. gasperettii, E. c sochureki, M. l. obtusa, G. caucasicus,* and *M. raddei*)*	i.p.	Median	0.57	(Kadkhodazadeh et al., 2020)

* The six common snakes of medical importance in Iran

Abbreviations: i.p. = intraperitoneal, i.v. = intravenous, s.c. = subcutaneous, LD50 = 50% lethal dose

The LD_{50} values summarized in **Table 1**, indicate that some Hydrophiini have the most potent venoms among Iranian venomous snakes. *H. schistosus* has the most lethal venom, followed closely by *H. platurus*, *H. curtus* and *H. cyanocinctus*. Among Iranian terrestrial species, *M. raddei* has the most lethal venom, closely followed by *M. latifii* and *E. c. sochureki*.

3.2.1. Colubridae and Lamprophiidae: Despite advances in 'omics' profiling of venoms, the venoms of non-front-fanged snakes remain largely unexplored (Modahl et al., 2016). However, a combination of transcriptomic, proteomic and genomic studies has revealed that some non-front-fanged snake venoms contain many protein families similar to those found in Viperidae and Elapidae, such as three-finger toxins (3FTxs), snake venom metalloproteinases (SVMPs), phospholipases A_2 (PLA_2), serine proteases, hyaluronidases, L-amino acid oxidases (LAOs), C-type lectins (CTLs) and Cysteine-Rich Secretory Proteins (CRiSPs) (Junqueira-de-Azevedo et al., 2016; Modahl et al., 2016). These venoms are highly toxic to diapsid (birds and reptiles) prey, but are usually less potent and typically produce weaker, negligible, or no neurotoxic effects in mammals (Dashevsky et al., 2018). Clinically, bites by most non-front-fanged species pose lower risks to humans compared with vipers and elapids, as discussed earlier.

Iranian non-front-fanged snake genera, whose venoms are rich in 3FTxs, include *Boiga* and *Psammophis* (Modahl & Mackessy, 2019; Sunagar et al., 2013). *Platyceps rhodorachis* venom is also rich in 3FTxs, as analyzed with liquid chromatography and mass spectrometry (Fry et al., 2003). Likewise, *Telescopus* species venoms contain 3FTx (such as denmotoxin and irditoxin) but in lower yields (Dashevsky et al., 2018; Junqueira-de-Azevedo et al., 2016; Lumsden et al., 2004; Modahl & Mackessy, 2019). *Hemorrhois* species venoms may contain anticoagulant toxins (Ana Maria, 2021) and venoms of some *Boiga* species such as *B. irregularis* contain serine proteases, with known fibrinogenolytic activity (Mackessy, 2002). Venoms of *Malpolon* species are potentially dangerous because of their pro-hemorrhagic fraction (intravenous LD_{50} = 1 mg/kg), but coagulopathy has never been reported in human victims (Rosenberg et al., 1992).

3.2.2. Elapidae and Viperidae: Venoms of Iranian elapids are usually rich in 3FTxs, whereas those of Iranian vipers are usually rich in SVMPs (Ghezellou et al., 2021; Modahl et al., 2016; Mohebbi et al., 2016; Monzavi et al., 2019a). The composition, and pharmacological and pathophysiological properties of venoms of some species are described as follows:

Bungarus sp.: There is no published report of *B. persicus* venom or clinical effects of envenoming. However, the venoms of closely-related species such as *B. sindanus* and *B. caeruleus*, which are notorious for their neurotoxic effects, are rich in 3FTxs (including α-bungarotoxin) and PLA_2s (including β-bungarotoxins) and also contain SVMPs, LAOs, acetylcholinesterase, CRiSPs and Kunitz-type serine protease inhibitors (Oh et al., 2019; Patra et al., 2019; Sunagar et al., 2021).

Cerastes gasperettii: The major components of *C. gasperettii* venom are SVMPs, serine proteases, PLA_2, CTLs, disintegrins, CRiSPs, and LAOs (Al-Sadoon et al., 2016; Zaeri et al., 2021a).

In mice, the venom can cause severe hepatic inflammation and necrosis, glomerular degeneration and coagulative necrosis of the kidney, lung congestion, testicular tissue degeneration, myonecrosis, hemodynamic disturbances (reduction in mean arterial pressure and bradycardia), and hemorrhage (Al-Sadoon et al., 2013a; Al-Sadoon et al., 2013b; Al-Sadoon et al., 2014; Al-Sadoon et al., 2016; Bassam, 1995; Zaeri et al., 2021a).

Echis carinatus sochureki: Its venom is rich in SVMPs, and also contains serine proteases, PLA_2s, LAOs, CTLs, disintegrins, CRiSPs, hyaluronidase, and growth factors (Casewell et al., 2009). The venom possesses pro-coagulant properties such as prothrombin activation (Babaie et al., 2013a; Mehdizadeh Kashani et al., 2012; Nasri Nasrabadi et al., 2022; Salmanizadeh et al., 2013), and anticoagulant activities (Amrollahi Byoki & Zare Mirakabadi, 2013; Babaie et al., 2013b; Ghezellou et al., 2021; Latifi & Tabatabai, 1989; Mehdizadeh Kashani et al., 2012; Nasri Nasrabadi et al., 2022), such as fibrinogenolytic (Kamyab et al., 2017) and anti-platelet effects (Babaie et al., 2013b; Mehdizadeh Kashani et al., 2012). Animal and *in vitro* experiments revealed that the venom can also induce hemodynamic instability, acute tubular necrosis, interstitial pulmonary inflammation, neurotoxicity and myotoxicity (Barfaraz & Harvey, 1994; Harvey et al., 1994; Zaeri et al., 2021b). In addition, it has *in vitro* cytotoxic effects (Balali Bahadorani & Zare Mirakabadi, 2016; Zare Mirakabadi & Horrieh, 2020).

Eristicophis macmahonii: Venom of a specimen from Nushki, Baluchistan in Pakistan, consisted of SVMPs, kallikrein serine proteases, LAOs and PLA_2, disintegrins, lectins, CRiSPs and vascular endothelial growth factor (VEGF) (Ali et al., 2015). The venom inhibits platelet aggregation and causes edema in mice (Ali et al., 1999b). Its venom is also procoagulant (Op den Brouw et al., 2021a), fibrinogenolytic (Op den Brouw et al., 2021b), and has anti-cancer activities (Op den Brouw et al., 2021a; Op den Brouw et al., 2021b).

Gloydius caucasicus: Its venom has pro-hemorrhagic, necrotizing, and edematogenic activities, and contains a non-protease anticoagulant factor (Ghorbanpur et al., 2010), and pro-coagulant effects (Rasoulinasab et al., 2020), attributable to a serine protease (Ghorbanpur et al., 2009). *In vitro*, the venom has shown anti-cancer effects on colon cancer cells (Salmanzadeh Zehkesh & Mohammadpour Donighi, 2021)

Hydrophis spp.: The venoms of Iranian *Hydrophis* are rich in 3FTxs (> 50%), and neuromyotoxic PLA_2s, explaining their lethal potency. Other components include SVMPs, LAOs and CRiSPs in very low quantities. (Calvete et al., 2012; Mohebbi et al., 2016). Venoms are powerfully anti-bacterial *in vitro* (Abtahi et al., 2014).

Macrovipera lebetina: Venom of both *M. l. obtusa and M. l. cernovi* contain enzymes, such as PLA_2 and hyaluronidase, explaining local tissue damage , and pro-coagulant factor V and X activators (Amoozegari et al., 2016; Amoozegari et al., 2013; Ghezellou et al., 2022; Igci & Demiralp, 2012; Sanz et al., 2008; Shanaki Bavarsad et al., 2009), linked to coagulopathy.

Experimental evidence showed a PLA_2 vasodilator component responsible for hemodynamic instability and circulatory failure (Fatehi-Hassanabad & Fatehi, 2004). Proteomic studies revealed a serine protease that can lead to coagulopathy and platelet aggregation (i.e., a unique short disintegrin known as obtustatin, dimeric disintegrin, CTLs and LAO), and Zn^{2+}-SVMPs that can damage the vascular endothelium (Amoozgari et al., 2020; Bazaa et al., 2005; Ghezellou et al., 2022; Hamza et al., 2010; Pla et al., 2020; Sanz et al., 2008). The venom also contains large amounts of bradykinin-potentiating peptides (BPPs), C-type natriuretic peptides (C-NAP) and possibly nitric oxide or nitric oxide-like compounds contributing to hypotensive effects (Bazaa et al., 2005; Fatehi-Hassanabad & Fatehi, 2004; Pla et al., 2020; Sanz et al., 2008), and VEGF-like molecules (svVEGF) that cause increased capillary permeability (Bazaa et al., 2005). The venom has shown *in vitro* fibrinolytic activity (Amoozgari et al., 2020; Hamza et al., 2010), cytotoxicity (Esmaeili Jahromi et al., 2016; Kakanj et al., 2015; Oghalaie et al., 2017), and considerable affinity to mimic epitopes of human alpha 1 neuronal nicotinic acetylcholine receptors (Chowdhury et al., 2022), and in animal models has caused cardiovascular collapse and neuromuscular blockade (Fatehi-Hassanabad & Fatehi, 2004).

Montivipera latifii: Its venom contains a pro-coagulant serine protease isoform (Taherian et al., 2016), and can cause pro-hemorrhagic and necrotizing effects (Weinstein & Minton, 1984). It can damage the lipid bilayer of erythrocyte membrane causing hemolysis (Ghulikyan et al., 2016; Kirakosyan et al., 2016). It also has anti-cancer and anti-bacterial effects *in vitro* (Moridikia et al., 2018).

Montivipera raddei: Proteomics of Armenian *M. raddei* venom revealed toxins similar to those of *M. l. obtusa* venom, such as dimeric disintegrin, CRiSPs, PLA_2, serine protease, CTL, LAO, svVEGF, Zn^{2+}-dependent SVMPs, BPPs and C-NAP (Sanz et al., 2008). An isoform of the serine protease has shown to possess procoagulant activity (Taherian et al., 2016). The venom also contains an anti-coagulant Kunitz-type serine protease inhibitor (Sanz et al., 2008). Anti-proliferative and cytotoxic effects of the venom have been observed *in vitro* (Amirian et al., 2022; Malekara et al., 2020).

Montivipera wagneri: Its venom is potently anticoagulant by inhibiting factor Xa (Chowdhury et al., 2021) and has anti-cancer properties *in vitro* (Nalbantsoy et al., 2016).

Naja oxiana: Its venom contains post-synaptic 3FTxs, such as a long neurotoxin (Nasiripour et al., 2008; Samianifard et al., 2021; Talebzadeh-Farooji et al., 2004), cardiotoxins (Angaji et al., 2016; Gasanov et al., 2015), and cytotoxins that can cause local tissue inflammation, necrosis, hemolysis and inhibition of platelet aggregation (Derakhshani et al., 2020; Esmaili et al., 2021; Gasanov et al., 2014; Gasanov et al., 2015). Coagulopathic properties of *N. oxiana* venom (Mitel'man, 1966), have never been detected clinically. The venom also exhibits anti-plasmodial (Hajialiani et al., 2020), anti-leishmanial (Fallahi et al., 2020; Sharifi et al., 2021), anti-bacterial

(Talebi Mehrdar, 2020; Talebi Mehrdar et al., 2017), anti-rabies (Farzad et al., 2020), and anti-cancer activities (Barati & Davoudi, 2017; Derakhshani et al., 2020; Ebrahim et al., 2015; Ebrahim et al., 2016; Javani Jouni et al., 2022; Sinaei et al., 2022).

Pseudocerastes fieldi: Its venom is unusual in lacking the metalloproteinase hemorrhagin, procoagulant and LAO activities that are typical of most Viperidae, but it possesses CRiSPs, serine proteases, Kunitz peptide, lectin, VEGF, and a heterodimeric PLA_2 complex with pre-synaptic neurotoxic activity in experimental models (Ali et al., 2015; Bdolah, 1986; Francis et al., 1995; Gitter et al., 1962; Op den Brouw et al., 2021a; Op den Brouw et al., 2021b; Tsai et al., 1983). Some venom fractions can inhibit platelet aggregation, and have fibrinogenolytic and hemolytic activities (Batzri-Izraeli & Bdolah, 1982; Mehdizadeh Kashani et al., 2012; Op den Brouw et al., 2021b).

Pseudocerastes persicus**:** Its venom contains SVMPs, kallikrein and CRiSPs, acidic and basic PLA_2 enzymes, lectin toxins, VEGF, nerve growth factor (Ali et al., 2015; Op den Brouw et al., 2021b), a natriuretic peptide (Amininasab et al., 2004; Elmi et al., 2006) and Kunitz-type proteins (Banijamali et al., 2019; Op den Brouw et al., 2021b). Unlike *P. fieldi* venom, the venom of *P. persicus* has prohemorrhagic and LAO activities (Bdolah, 1986). The venom also has fibrinogenolytic, cytotoxic, antibacterial and anti-cancer effects (Ghezellou et al., 2021; Nodooshan et al., 2021; Op den Brouw et al., 2021b; Shahbazi et al., 2019; Zargan et al., 2022).

Pseudocerastes urarachnoides: Its venom contains SVMPs, serine proteases, LAOs, PLA_2 and lectin isoforms, and causes strong procoagulant, fibrinogenolytic and cytotoxic effects (Op den Brouw et al., 2021a; Op den Brouw et al., 2021b). The procoagulant activity of the venom is attributed to prothrombin and factor X activation (Op den Brouw et al., 2021a).

Vipera ammodytes transcaucasiana**:** Its venom contains PLA_2s (including a potentially-neurotoxic Vipoxin homologue), SVMPs, serine proteases, LAOs, CRiSPs, CTLs, VEGF, a disintegrin and a phosphodiesterase (Hempel et al., 2018). The venom has shown anticoagulant (Chowdhury et al., 2021), cytotoxic and anti-cancer activities (Celen et al., 2018).

Walterinnesia morgani**:** No studies of Iranian *W. morgani* venom have been published, but, the composition of venom from a Turkish specimen has been characterized using mass spectrometry (Calvete et al., 2021). It consists of 3FTxs, PLA_2s, CRiSPs, and Kunitz-type serine proteinase inhibitor, with a low content of class PIII SVMPs, LAO, endonuclease, phosphodiesterase, VEGF and acetylcholinesterase (Calvete et al., 2021). A procoagulant factor X activator (probably a serine protease) has been identified in the venom of the closely-related *W. aegyptia* (Khan & Al-Saleh, 2015).

3.3. Snakebites in Iran

3.3.1. Epidemiology

According to available statistics released from the Iranian Ministry of Health (2002-2011) (Dehghani et al., 2014a; Dehghani et al., 2014b), there are 5,000-7,000 snakebite envenomings/year or 6.3-8.8/100,000 population/year, which falls within the very wide WHO guesstimates of 210-11,079/year or 0.3-47.2/100,000/year in Iran (Kasturiratne et al., 2008). Snakebite in Iran results in 3-12 snakebite deaths/year or 0.003-0.01 snakebite deaths/100,000 population/year, compared to WHO estimates of 6-13.2 snakebite deaths/year, or 0.01-0.02/100,000/year (Dehghani et al., 2014a; Dehghani et al., 2014b; Kasturiratne et al., 2008; Monzavi et al., 2014). These estimates for Iran are lower than worldwide estimated average incidences of 25.7-40 snakebite envenomings/100,000 population/year; and 1.2-2 snakebite deaths/100,000 population/year (Gutierrez et al., 2017), which is surprising considering the country's extensive desert and rural areas, and possessing a rich and diverse venomous snake fauna. A low mortality might be explained by the high priority accorded to snakebite as a toxicological emergency and the access to toxicology trained physicians in the Iranian healthcare system, together with the provision of antivenom, as part of an essential pharmaceutical stockpile (IFDA, 2021), even in remote and less developed areas of the country. Urbanization may have reduced the number of snakebite encounters (rural areas are inhabited by < 25% of total population). However, under-reporting might be concealing the real magnitude of the snakebite problem in Iran. In India, for example, a well-designed community-based survey revealed 25-fold higher snakebite mortalities than a government figure based on returns from health facilities (Suraweera et al., 2020). In Iran, the problem of under-reporting may be partly addressed by the introduction of a standardized national minimum dataset registry for poisoning (Banaye Yazdipour et al., 2020).

Hospital-based epidemiological studies have shown that only approximately 0.5-1% of acute poisoning cases admitted to emergency departments of tertiary hospitals in Iran are due to snakebites (Afshari et al., 2004; Alavi & Alavi, 2008; Rasouli et al., 2011; Shadnia et al., 2007). Using species-distribution models and considering the habitat preferences of the 4 most common medically-important venomous snakes, the northeast of Iran was predicted to have the highest snakebite risk (Yousefi et al., 2020). However, most snakebites are reported from the middle and southern provinces of Iran (Alavi & Alavi, 2008; Alinejad et al., 2017; Dehghani et al., 2014a; Dehghani et al., 2014b; Hafezi et al., 2018; Jalali et al., 2012; Kassiri et al., 2019; Sagheb et al., 2011b; Soleimani et al., 2021), partly because of their warmer climate (Ebrahimi et al., 2018), which affords more favorable snake thermoregulation and that prolongs the snakes' active seasons. In Iran, most snakebites occur during the warm months of the year, when outdoor agricultural and leisure activities increase (Dehghani et al., 2022; Khosravani et al., 2018; Monzavi et al., 2019b; Oghabian et al., 2022). More than 70% of snakebites occur in rural areas of Iran (Dehghani et al., 2014b; Dehghani et al., 2014c; Dehghani et al., 2016c; Ebrahimi et al., 2018; Eslamian et al., 2016; Monzavi et al., 2019b; Moradiasl et al., 2018; Nejadrahim et al., 2019), and, as in other parts of the world, young adult men are most commonly affected (Dadpour et al., 2012; Dehghani et al., 2014a; Dehghani et al., 2014b; Ebrahimi et al., 2018; Eslamian et al., 2016; Farzaneh et al., 2017; Khadem-Rezaiyan et al., 2018; Monzavi et al., 2019b; Nejadrahim et al., 2019; Oghabian et al., 2022; Soleimani et al., 2021). The economic burden caused by snakebite has been estimated to be less than 0.001% of the Iran's gross domestic product (Mashhadi et al., 2017; Patikorn et al., 2022).

3.3.2. Clinical features of snakebite

Many clinico-epidemiological studies of snakebite have been reported from Iran, nonetheless, in very few of them the species of snake responsible was reported. As a result, clinical envenoming syndromes attributed to Iranian snakes, have not been verified in most cases. One reason might be polyvalent antivenoms produced by Razi Vaccine and Serum Research Institute, and Padra Serum Alborz company, both covering the common local species of greatest medical importance and being available in tertiary referral hospitals throughout the country (Abouyannis et al., 2021; Dehghani et al., 2014a; Dehghani et al., 2014b; Monzavi et al., 2014), have made species diagnosis less important. Another reason is that the species of snake responsible is not among the essential data that should be recorded in the medical forms of snakebite patients in Iran. To identify the species of snake responsible, immunodiagnostic methods can be used, but only in Australia snake venom diagnostic/detection kits (SVDK/VDK) are commercially available for clinical use despite some problems in interpreting their results (Dhananjaya et al., 2015; Johnston et al., 2017). Elsewhere, confirmation of species identity relies on competent identification of the snake brought with the patient, or of photographs captured at the scene of the bite. Alternatively, its identity might be inferred from by observing the evolving clinical signs of envenoming, using a syndromic algorithm (Bawaskar & Bawaskar, 2019; Monzavi et al., 2014). However, for optimal medical management of an envenomed snakebite patient, it is important to know which species was responsible, so that likely complications can be anticipated, prevented or managed. There are, however, a few clinical reports from Iran based on expertly identified snakes (Dadpour et al., 2012; Hassanian-Moghaddam et al., 2022; Kazemi et al., 2021c; Kazemi et al., 2023b; Monzavi et al., 2019a; Monzavi et al., 2019b; Monzavi et al., 2015). This information has been augmented by published accounts of snake envenoming in other countries caused by the same species occurring in Iran (see below).

3.3.2.1. Dry bites

Bites by venomous snakes, with evidence that fangs have pierced the skin, do not always result in envenoming. An average of at least 20% of venomous snake strikes (globally and in Iran) fail to cause local or systemic envenoming (i.e., no systemic effects with no or very limited local effects), so called "dry bites" (Afshari & Monzavi, 2016b; Gold et al., 2002; Lavonas et al., 2011; Mehta & Sashindran, 2002; Monzavi et al., 2019b; Monzavi et al., 2015; Naik, 2017; Riley et al., 2011). The highest rate of dry bites by venomous snakes, up to 80%, has been reported following some Oceanian Elapidae and sea-snake strikes (Naik, 2017). Bites by mildly-venomous non-front-fanged snakes, due to position of fangs and lack of a high-pressure venom delivery apparatus, more often result in dry bites, as reported in studies from central and northeast Iran (Dehghani et al., 2014c; Monzavi et al., 2019b). Only 1-20% of bites by colubrids result in envenoming (Minton, 1990). Dry bites may be wrongly inferred, if victims failed to see the animal involved, or mistook a non-venomous snake or snake-like animal, such as a legless lizard for a venomous snake (Bazi et al., 2019), or suffered a painful penetrating injury from thorns, splinters, or other sharp objects. Since there is usually a delay between the bite and appearance of signs and symptoms of envenoming, "dry bites" should not be diagnosed too hastily. Following viper and cobra bites, local pain and swelling usually appear within 1-2 hours, but systemic effects of viper envenoming may be delayed for some hours. Bites by kraits and sea-snakes may not cause local envenoming, and systemic envenoming may not become evident until 12 hours or more after the bite (Gold et al., 2002; Monzavi et al., 2014; Riley et al., 2011). The initial absence of symptoms in an apparently-well patient can be deceptive, persuading clinicians to discharge the patient prematurely. A wise precaution is a statutory observation period of 24 hours for all suspected snakebite patients.

3.3.2.2. Clinical effects of envenoming (Clinical syndromes)

In the acute phase following a venomous snakebite, there are sets of clinical manifestations, "envenoming syndromes", that may suggest a genus or species diagnosis (Ariaratnam et al., 2009; Blaylock, 2014; Warrell, 2016). **Table 2** summarizes the common local and systemic effects of snakebite envenoming in Iran. Most bites by venomous snakes and a few by mildly-venomous non-front-fanged snakes cause local effects, while some elapids, particularly kraits and sea-snakes, may cause minimal or no local effects during the early hours after the bite (Mehta & Sashindran, 2002; Monzavi et al., 2014; Riley et al., 2011). Local and systemic effects and their severity differ depending on the species responsible, the amount of venom injected, and its depth of injection, and the composition of the venom (Lavonas et al., 2011; Monzavi et al., 2014; Riley et al., 2011). Punctures made by paired fangs or teeth may be visible at the bite site, suggesting snakebite, but bites by rodents, fish, large spiders, lizards or inanimate sharp objects such as thorns and splinters, as well as incisions made intentionally at the bite site may cause confusion (Bazi et al., 2019; Lavonas et al., 2011; Mehta & Sashindran, 2002; Monzavi et al., 2014; Riley et al., 2011; Zamani et al., 2016).

Systemic effects of Viperidae envenoming often include shock and hemostatic disturbances, while envenoming by Elapidae usually causes neurotoxic effects manifesting typically with descending flaccid paralysis (Afshari & Monzavi, 2016b; Dadpour et al., 2012; Isbister et al., 2013; Lavonas et al., 2011; Monzavi et al., 2014; Riley et al., 2011; Warrell, 2010; White, 2005), and in the case of *Hydrophiini* envenoming, generalized rhabdomyolysis (Mehta & Sashindran, 2002;

Nabipour, 2012; Nabipour et al., 2015). However, these descriptions cannot be generalized to all snakebite cases in all regions. For example, envenoming by Oceanian (or Australasian) elapids, some North American rattlesnakes, or European *V. a. ammodytes,* may induce both hemostatic disturbances and neurotoxic effects (Di Nicola et al., 2021; Farstad et al., 1997; Isbister et al., 2013; Karabuva et al., 2016; Logonder et al., 2008; Massey et al., 2012; White, 2005). Moreover, presumption of clinical effects following bites by a species based on its venom components may not be sensible. As for example, venom of *P. fieldi* contains potentially neurotoxic components (Ali et al., 2015), but there are no clinical reports of neurotoxic human envenoming by this species.

Table 2. Common clinical features of snakebite envenoming in Iran

Venom effects	Description	Plausible offending snake – (sub)Family
Local		
Fang marks	Presence of one or two puncture marks suggests a bite by a venomous snake	Venomous snakes[*]
Tooth marks[¶]	Numerous small shallow puncture wounds arranged in an arc	Non-venomous and mildly venomous snakes
Pain[†]	Burning, bursting or throbbing pain localized to the bite site and sometimes radiating up the limb	Venomous snakes especially Viperidae, mildly venomous snakes
Local lymphadenopathy/ lymphadenitis[†]	Painful, tender swelling of local lymph nodes draining the bite site	Venomous snakes
Local swelling[†]	Swelling around the bite site that may extend rapidly and involve the entire limb and/or areas of adjoining trunk	Venomous snakes especially Viperidae
Local cutaneous damage[†]	Erythema, local ecchymosis, blister/bulla formation and sometimes local necrosis may appear over hours to few days following the bite	Venomous snakes especially Viperidae
Local myonecrosis	Necrosis of local muscles adjacent to the bite site	Venomous snakes
Compartment syndrome	It is a potential, but in practice very rare, manifestation in envenomed tissue that is contained in a tight fascial compartment including the pulp space of digits, anterior forearm or anterior tibia	Viperidae
Systemic		
Parasympathetic excitation	Uncontrollable vomiting, fasciculations, congested conjunctivae, gooseflesh, sweating, sialorrhea, lacrimation, respiratory tract secretions, cramping abdominal pain, diarrhea	Venomous snakes (especially Elapidae)
Neurotoxic effects[#]	Descending flaccid paralysis (starting with bilateral ptosis and external ophthalmoplegia with diplopia and blurred vision), bulbar palsy, respiratory paralysis (paralysis of intercostal muscles and diaphragm), fasciculations, limb paralysis	Elapidae
Myotoxic effects[§]	Myalgia, myopathy, marked increase in serum creatine kinase, muscle stiffness, necrosis of muscle fibers, systemic rhabdomyolysis (occasionally), cardiac dysrhythmia, abnormal echocardiogram, trismus, myoglobinuria, generalized trunk pain	Elapidae (particularly sea-snakes)
Vasculotoxic and hemotoxic effects[#]	Spontaneous bleeding, thrombocytopenia, coagulopathy (consumption coagulopathy), microangiopathic hemolysis/thrombotic microangiopathy (schistocytes), local or spontaneous systemic hemorrhage, diffuse cutaneous ecchymosis,	Viperidae

		gingival bleeding, epistaxis, hematemesis, melaena/blood in feces, hemoptysis, intracranial hemorrhage, hematuria, uterine bleeding	
	Shock	Severe hypotension, hypovolemia, myocardial depression and elevated levels of troponins	Venomous snakes
	* Bites by mildly venomous snakes (e.g., Iranian colubrids) may also produce fang marks. ¶ Some elapid bites may produce this pattern. † Bites by elapids, especially kraits and sea-snakes, may be painless and without swelling or other local effects. Bites by mildly venomous snakes may produce erythema, blister formation, lymphadenopathy and limited local swelling without (or with limited) progression. §Although rare, in bites by some vipers may also be seen. # Bites by mildly venomous snakes very rarely may also produce neurotoxic effects and limited bleeding from the bite site.		

3.3.2.3. Species-specific descriptions of snakebite envenoming

Species-specific descriptions of envenoming following bites by the medically important snakes of Iran provided in this section are based on reports of cases, in which the snake responsible for the bite was competently identified using the methods described above, either in Iran, in neighboring countries or other countries inhabited by the species same as those occurring in Iran:

Colubridae and Lamprophiidae: Although the venoms of some colubrid and lamprophiid species contain toxic components similar to those of vipers and elapids, bites by these non-front-fanged species usually do not result in envenoming in humans. Reports of lethargy and respiratory difficulty following these bites are unlikely to be neurotoxic in origin. In general, the bites of opisthoglyphous species rarely cause systemic effects; and local effects such as swelling, pain, blister formation, erythema/ecchymosis and bleeding from fang punctures are the most common clinical features (Araujo et al., 2018; Dehghani et al., 2014c; Dehghani et al., 2012; Weinstein et al., 2014). Systemic effects include cranial nerve palsy, coagulopathy and thrombocytopenia (Brandehoff et al., 2019; Kuch & Mebs, 2002; Pommier & de Haro, 2007; Weinstein et al., 2023a).

Bites by *Boiga trigonata melanocephala* have not been reported, but in Sri Lanka, bites by the closely-related *B. t. trigonata* caused no systemic nor significant local envenoming (Ariaratnam et al., 2009). A case bitten by a large male *Hemorrhois ravergieri* developed rapidly progressive swelling, that spread from bitten fingers to involve the whole hand, 10-15 minutes after the bite. There was also dizziness, and pain in axillary lymph nodes. Symptoms persisted for 3 days (Darevsky, 1969). Mamonov reviewed Darevsky's case and another case reported by Ishunin (Ishunin, 1950), in which there was profuse bleeding of the bite wound, pain, swelling and bluish and reddish discoloration of the hand, which began to resolve 30 hours later, but it took 10 days to recover completely; and also reported a similar case of his own (Mamonov, 1977). Pain, transient bleeding and edema quickly spreading from the bite site to affect entire limb (10-15 min after bite) were also reported by Kazemi et al. in three cases of bites by *H. ravergieri* and *H. nummifer* in central and western Iran (Kazemi et al., 2023a). Kocourek reported pain and local swelling in the arm (Kocourek, 1990), and Schweiger reported burning sensation, severe local swelling in the hand, and severe bleeding from puncture marks after bites by *H. ravergieri* (Schweiger, 1991), the symptoms of both cases resolved a day later. A bite by *H. nummifer* produced similar symptoms (Weinstein et al., 2023b). Branch reported only mild symptoms from a bite by *P. rhodorachis* from Saudi Arabia (Branch, 1982), less severe than those of a bite by this species in Israel, which caused immediate erythema, lymphangitis, swelling and numbness of the bitten hand, and generalized irritation (Perry, 1988). In southern Saudi Arabia, Malik described five confirmed bites by *P. rhodorachis*, all of which produced local pain and tenderness, with local swelling and redness in three, elevated serum creatine kinase in two, and blistering with lymphadenitis, and leukocytosis in one (Malik, 1995). An anecdotal report of "moderate systemic paralysis of the skeletal muscles and breathing difficulty following *P. rhodorachis* bite, which resolved spontaneously after 7 hours" (Fry et al., 2003), is discounted as being medically unsubstantiated. Multiple bites by a presumed *P. najadum* in Greece, initially caused local swelling, diffuse myalgia, and axial muscle stiffness, which progressed to areflexic quadriplegia 3 months after the bite. The patient died from a progressive segmental neuropathy about 6 months after the incident (Chroni et al., 2005). The authors suggested that auto-immune damage to neural antigens provoked by *P. najadum* venom toxins might have been responsible, but causation was not confirmed (Weinstein et al., 2023a). In Nakhchivan Autonomous Republic, Azerbaijan, a 35-year-old farmer was bitten on his index finger by a *Telescopus fallax iberus*, and shortly afterwards, developed hypotension, a hemorrhagic blister on the bitten finger, and pain and swelling extending to the dorsum of the hand. These symptoms resolved after 3 days (Sultanov, 1966). No bites by *T. rhinopoma, T. nigriceps,* or *T. tessellatus* have been reported so far.

A bite by Moila's Snake (*Malpolon moilensis*) caused only local swelling and numbness of the bitten digit (Perry, 1988), while bites by the Eastern Montpellier Snake (*M. insignitus*) are said to have caused only local symptoms such as swelling, paresthesia, stiffness of the affected limb and lymphangitis, which resolved within 48 hours (Jimenez-Cazalla, 2012). Similarly, a bite by *M. insignitus* was reported from central Iran causing only mild local symptoms (Dehghani et al., 2014c). In France, a bite by the closely-related Montpellier Snake (*Malpolon monspessulanus*) caused self-limiting local effects, but some hours later, the patient developed blurred vision, nystagmus, partial oculomotor paralysis with ptosis and complete paralysis of accommodation. These neurological symptoms took 6 days to resolve completely (Pommier & de Haro, 2007). Among 60 reported cases of *M. monspessulanus* bites in Spain, most (50 cases, 83%) were asymptomatic, while nine had local envenoming, and only one developed neurologic symptoms (ptosis, dysphagia, mild dyspnea, difficulty in speaking and loss of reflexes and paresthesia in the bitten limb) in addition to severe swelling. Laboratory tests were normal (Gonzales, 1978). A bite by the Schokari Sand Racer, *Psammophis schokari*, was reported from central Iran (Dehghani et al., 2014c), with only local erythema. In Oman, a bite by *P. schokari* caused mild local swelling, erythema, and pruritus of the bitten finger followed by protracted morbidity (Ineich et al., 2020).

A review of other *Psammophis* bites suggested nothing more than mechanical injury by teeth and fangs (Ineich et al., 2020). No bites by *P. lineolatus* have been reported so far.

Bungarus persicus: No bite by the Persian krait (*Bungarus persicus*) has yet been reported. However, in the northern region of Sarbaz, in Iran's Sistan and Baluchistan province, where this species was discovered, it is well known locally under the name "Siah Mar" (black snake) and it is greatly feared (Abtin et al., 2014). There can be no doubt about the potential danger of envenoming. Features typical of bites by other *Bungarus* species, such as the closely-related Sindh krait (*B. sindanus*) and common krait (*B. caeruleus*), include the risk of painless nocturnal bites inflicted on people sleeping on the ground, minimal or absent symptoms of local envenoming, and evolution of abdominal pain, myalgia, autonomic disturbances and descending paralysis, sometimes after a delay of several hours (Kularatne, 2002; Pillai et al., 2012; Theakston et al., 1990).

Cerastes gasperettii: While there is no report from Iran, a bite by a *Cerastes* in Qatar caused progressive local swelling, consumptive coagulopathy, and cardiotoxic effects (right bundle branch block, bradycardia, chest pain, electrocardiographic ST segment abnormalities, with cardiac troponin elevation) (Razok et al., 2020). However, the authors' attribution to *C. cerastes* (Razok et al., 2020), is impossible on geographical grounds and the snake must have been *C. gasperettii*. In two patients bitten by imported specimens of the closely-related *C. cerastes* in Europe, there were extensive swelling and life-threatening systemic envenoming, characterized by systemic hemorrhage, coagulopathy, increased fibrinolysis, thrombocytopenia, micro-angiopathic hemolytic anemia and acute kidney injury (AKI) (Schneemann et al., 2004).

Echis carinatus sochureki: In a series of confirmed cases of bites by this species in northeast Iran, extensive local edema (55.6%), ecchymoses (48.1%), elevated serum creatine kinase (44.4%), coagulopathy (40.7%), thrombocytopenia (33.3%), lymphadenopathy (29.6%), nausea/vomiting (25.9%), blister formation (11.1%), and local necrosis (25.9%) were documented (Monzavi et al., 2019b). There have also been reports of local and systemic bleeding (epistaxis and gingival bleeding) (Monzavi et al., 2019a; Monzavi et al., 2019b) (**Fig. 5**). AKI has been reported in a case in southern Iran (Sagheb et al., 2011a). *E. c. sochureki* venom contains procoagulants, platelet-activating toxins, and hemorrhagins that are responsible for consumption coagulopathy, thrombocytopenia, vascular endothelial damage and microangiopathic hemolysis leading to local and occasionally serious systemic bleeding (Afshari & Monzavi, 2016b; Babaie et al., 2013a; Balali-Mood & Shariat, 1999; Monzavi et al., 2019b; Salmanizadeh et al., 2013; Warrell, 1995; Warrell, 2016). Outside Iran, among 117 proven cases of *E. c. sochureki* envenoming in Jammu, Northern India, all developed coagulopathy, 68% had evident bleeding and the rest had defective coagulation (Bhat, 1974). Hemorrhages were in the form of local bleeding from the bite wound, hematuria, hemoptysis, gingival bleeding, hematemesis, epistaxis, rectal and subarachnoid hemorrhage. Other symptoms included fever, vomiting, upper abdominal pain, leukocytosis, blisters, regional lymphadenitis and shock (Bhat, 1974). In another report from the Thar Desert region of Rajasthan, India, all the victims developed coagulopathy, the majority had local swelling (92%), and vomiting (92%), two-thirds had local or systemic bleeding (i.e., from bite site, hematuria, hemoptysis, gingival bleeding, hematemesis, melena and intracranial hemorrhage), 25% developed local blistering, and 16.7% necrosis (Kochar et al., 2007). Mortality rates in *E. c. sochureki* victims treated with antivenom have been very low (Bhat, 1974; Kochar et al., 2007; Monzavi et al., 2019b), but in untreated cases, fatalities are common and may be delayed for several days after the bite (Bhat, 1974; Minton, 1966).

Eristicophis macmahonii: There has been no report of bites in Iran. Five cases were described from Baluchistan in Pakistan (Shaw, 1925). Two died several hours after the bite, having developed local swelling, abdominal pain and distension. One of them was weak and feverish, and complained of thirst, but was unable to swallow. She would not raise her eyelids, suggesting the possibility of neurotoxicity. The other victim developed marked local swelling, signs of bleeding, and died after becoming comatose. In two other cases, there was extensive local swelling which persisted for 3 days. Local ulceration developed in one of them (Shaw, 1925). In another report from western Asia, the life of a patient was seriously endangered after an *Eristicophis* bite in spite of treatment with antivenom (Mertens, 1965). In Belgium, a man previously envenomed by four other species, was bitten on one finger by his pet *E. macmahonii,* rapidly become nauseated, developed a rash, collapsed, and become transiently unconscious (Van den Enden & Bottieau, 2005). The affected limb became tender and swollen, with axillary lymphadenopathy and an ecchymosis. He felt weak and breathless with a dry mouth and bilateral eyelid swelling (angioedema). His symptoms resolved with corticosteroids and antihistamines suggesting anaphylaxis caused by hypersensitization by his previous envenomings. Laboratory investigations, including tests of blood coagulation, were normal and the only features directly attributable to envenoming were the local effects (Van den Enden & Bottieau, 2005). Two bites by pet *E. macmahonii* in Switzerland caused local swelling, and in one, minimal coagulopathy (Fuchs et al., 2022).

Gloydius caucasicus**:** Envenoming can cause local swelling and necrosis (Latifi, 1991, 1985). Since the venom contains a procoagulant serine protease and anticoagulant factor (Ghorbanpur et al., 2010; Ghorbanpur et al., 2009), bleeding and coagulopathy are to be expected. In Ýolöten in south-eastern Turkmenistan, a 5-year-old boy bitten by *G. caucasicus* bled from the bite wound on the foot. Swelling spread up to the shin, while severe anemia (2.9×10^6 red blood cells/mm^3) and lymphocytosis emerged. He recovered and was discharged after 8 days of hospitalization despite highly irregular treatment with wound incision, application of a tourniquet and local novocain infiltration (Tushiev, 1963). In Germany, a snake-keeper who was bitten by a closely-related species, *Gloydius halys*, developed incoagulable blood, afibrinogenaemia, elevated plasma fibrin(ogen) degradation products, thrombocytopenia and mildly reduced plasminogen concentrations within two hours after the bite. At the bite site, he developed serosanguineous blisters and necrosis requiring debridement. Hemorrhagic signs included oral mucosal bleeding and frank hematuria. He was given two doses of antivenom 9 and 16 hours after the bite. Blood clotting returned to normal within 48 hours (Meissner et al., 1989).

Hydrophis spp.: No sea-snake bites have been reported from Iran or other Middle-Eastern countries, but symptoms produced by the same species that occur in Iranian waters have been described from other regions (Warrell, 2016; Warrell, 1994). Bites are usually painless with minimal or no local swelling. Early systemic symptoms include headache, a thick feeling of the tongue, thirst, sweating, and vomiting followed by neurotoxicity and generalized rhabdomyolysis in cases of envenoming by many species (Mehta & Sashindran, 2002; Nabipour, 2012; Warrell, 2016; Warrell, 1994). Myotoxic symptoms include generalized muscle aching, stiffness, and tenderness that becomes noticeable 30 minutes to over 3 hours after the bite. Trismus is common, and passive stretching of the muscles is painful. Later, there is progressive flaccid paralysis starting with ptosis, as in other neurotoxic envenomings. The patient remains conscious until respiratory muscle paralysis results in respiratory failure. Myoglobinemia and myoglobinuria become evident 3-8 hours after the bite. Myoglobin and potassium released from damaged skeletal muscles may cause AKI, whereas hyperkalemia developing within 6 to 12 hours of the bite may precipitate diastolic cardiac arrest (Nabipour, 2012; Reid, 1961; Sitprija, 2006; Warrell, 2016; Warrell, 1994).

Macrovipera lebetina: Local pain and swelling, thirst, nausea, vomiting and sometimes diarrhea, are early symptoms of envenoming. Swelling may extend to involve the whole bitten limb, and trunk, with bruising, lymphangitic markings, regional lymphadenitis, and serosanguinous blistering that preceded necrosis (Balali-Mood & Shariat, 1999; Dadpour et al., 2012; Kazemi et al., 2021c; Monzavi et al., 2019b) (**Fig. 6**). Latifi illustrated extensive swelling, ecchymoses, and digital necrosis with residual deformity in two victims of bites by this species (Latifi, 1991, 1985). Consumption coagulopathy and thrombotic microangiopathy may develop in cases of more severe envenoming, making the victims susceptible to spontaneous local and systemic bleeding from mucous membranes, subconjunctival and retinal hemorrhages, and melena or blood in the feces (Dadpour et al., 2012; Monzavi et al., 2019a; Monzavi et al., 2019b). Anemia is associated with hemolysis and thrombocytopenia (Monzavi et al., 2019b), consistent with microangiopathic hemolysis, and there is neutrophilic leukocytosis. Delayed severe thrombocytopenia, poorly responsive to antivenom, may also occur (Abukamar et al., 2022). Body temperature may be elevated even in the absence of infection and large increases in serum creatine kinase levels (>1000 IU/L) suggest rhabdomyolysis (Monzavi et al., 2019b). AKI and oliguria may develop but this does not appear to be common. In cases of *M. lebetina* envenoming reported from Azerbaijan, Cyprus, Israel, India, Iraq and Jordan; trembling, rigors, dizziness, reduced consciousness, subarachnoid hemorrhage, massive ecchymoses, hemodynamic instability progressing to shock with tachycardia and cold sweats were also noted (Abu Baker et al., 2022; Amr et al., 2020; Sultanov, 1983). The largest published experience of *M. l. obtusa* bites (1,122 cases between 2009 and 2020) is from Azerbaijan (Efendiev, 2021). This species is known locally as "gyurza". In this report, the diagnosis was based on the clinical picture of envenoming and detection of venom in patients' blood by spectrofluorimetry. Severe cases had local swelling and bruising, involving the entire bitten limb and beyond, especially when a tourniquet had been applied. Case-fatality was 1.9%, attributable to septicemia, consumption coagulopathy, shock, hepatic and renal toxicity, and hemolytic anemia. Various antivenoms were used, including Sanofi-Pasteur (probably "Favirept", now discontinued) that proved the safest and most effective, polyvalent "Antigyurza, antiefa, anticobra" produced in Uzbekistan that caused many adverse reactions, and "Antigadyuka" from a Russian manufacturer that was wholly ineffective (Efendiev, 2021). The only report of *M. l. cernovi* envenoming is from Ýolöten in south-eastern Turkmenistan (Tushiev, 1963). A 33-year-old male snake catcher was admitted 3 days after the bite with severe weakness, persistent vomiting, severe radiating pain, swelling and bruising in the bitten limb, thirst, chest tightness, shortness of breath, weak pulse, fever (39°C) and leukocytosis (13,100 white blood cells/µl). He was treated with two doses of "antigyurza" antivenom, began to improve after the fifth day, and was discharged on the 15th day (Tushiev, 1963).

Montivipera latifii: Bites are rare, as this snake is mainly restricted to a highly-protected national park in Iran. In the only report of a confirmed case of *M. latifii* envenoming, a teen-age girl who was bitten on her face, rapidly developed swelling of the head, neck and oropharynx (Hassanian-Moghaddam et al., 2022). Antivenom therapy was delayed, due to a misleading history of hymenoptera sting from the parents, and thus she developed acute upper airway obstruction, respiratory distress, hypoxia, loss of consciousness and cerebral edema. There was an extensive local ecchymosis, but no evidence of coagulopathy. She died several days later from complications of hypoxic brain damage and nosocomial septicemia secondary to hospital-acquired pneumonia (Hassanian-Moghaddam et al., 2022).

Montivipera raddei: Serious local effects and hemostatic disturbances are expected following envenoming by this species (Darevsky, 1966; Ettling et al., 2012; Nejadrahim et al., 2019). Latifi illustrates extensive blistering after a bite by this species (Latifi, 1991, 1985). In Armenia, during 1951-3, there were human fatalities, including two 14-year-old children bitten on their legs, and an adult man bitten on the shoulder who died within 12 hours of the bite (Darevsky, 1966). Also in Armenia, a 51-year-old man who was bitten on a finger and thumb developed intense burning and throbbing pain that radiated up the arm to his shoulder, dizziness, profuse sweating and blistering (Ettling et al., 2012). After admission, the patient was treated conservatively with a variety of unconventional medications, but no antivenom was given. At 24 hours, there was swelling and ecchymoses of the right side of his body, which increased, together with myalgia, arthralgia and severe local pain. The patient survived despite lack of antivenom therapy. His pain persisted for several weeks, and at 6th week, necrotic tissue was debrided from the thumb (Ettling et al., 2012).

Naja oxiana: Despite this species' wide distribution in Asia, there are very few reliable published reports about envenoming. According to Latifi (Latifi, 1991, 1985), weakness, drowsiness, and paralysis of the throat, usually develop within one hour and progress rapidly to respiratory distress and possible cardiac arrest. He considered that these symptoms might be delayed for up to 10 hours by applying a tourniquet (this first-aid method currently is not recommended). Local pain and swelling are said to be uncommon and mild, although local blistering and superficial necrosis are described after bites by other Asian cobras (Afshari & Monzavi, 2016a; Warrell, 2016). Neurotoxic envenoming usually starts with bilateral ptosis and external ophthalmoplegia and descends involving muscles innervated by the cranial then thoracic nerves eventually causing life-threatening bulbar and respiratory muscle paralysis. In northeast Iran, a 4-year-old child died after developing respiratory muscle paralysis and cyanosis, 30 minutes after being bitten by a *N. oxiana* (Balali-Mood & Shariat, 1999). Also in Iran (same region), a 39-year-old man bitten on the finger by *N. oxiana* presented with bilateral ptosis, mydriasis, sluggish pupillary light reflex and sialorrhea 30 minutes after the bite. After an hour, he developed difficulty in breathing from respiratory muscle paralysis, requiring intubation and mechanical ventilation. The patient was treated with an initial dose of 100 mL of Razi antivenom (hexavalent), followed by three 50 mL doses at 6-hour intervals. He was extubated 48 hours later (Rajabi et al., 2022). In Russia, a 28-year-old snake-keeper, bitten on his index finger by a captive *N. oxiana* from Turkmenistan, 147 cm in total length, developed increasing weakness in his legs 15 minutes later, a feeling of constriction in the throat, difficulty breathing, and hypotension with frequent extrasystoles (Kudriavtsev, 1983). After 20-25 minutes, there was complete paralysis of the lower extremities, respiratory arrest and coma. However, intravenous and local subcutaneous injection of "anticobra" antivenom resulted in rapid restoration of respiration and consciousness. He also suffered persisting periods of hypotension, multiple extrasystoles, vomiting and chills and showed marked mydriasis. There was swelling of the entire bitten arm with local tissue necrosis at the bite site. He recovered gradually over 5 days (Kudriavtsev, 1983). Barkagan described two patients bitten by *N. oxiana* in Tajikistan, who suffered progressive paralysis involving respiratory muscles and also dysphagia, loss of tendon reflexes, disturbances of superficial and deep sensitivity, dysarthria, aphonia and other disturbances of speech (Barkagan, 1964). In Turkmenistan, *N. oxiana* bite victims experienced local slight burning sensation, redness and swelling, followed after 30 minutes by "irresistible drowsiness", impairment of consciousness and lower limb weakness (Talyzin, 1963). Hypersalivation, paralysis of the tongue and larynx, generalized paralysis and respiratory failure may develop, leading to death in 2-7 h after the bite in untreated cases (Talyzin, 1963).

Pseudocerastes fieldi: Although the venom of this species is neurotoxic in small mammals, the very few human bite victims documented in Middle Eastern countries developed only local symptoms and all survived (Amr et al., 2020; Kochva, 1990).

Pseudocerastes persicus: The most common clinical manifestations of envenoming are localized pain and swelling, associated with local tissue necrosis. Passing through the superficial lymphatic vessels, the venom causes lymphangitis, swelling, ulceration, and superficial thromboses that slowly spread (Afshari & Monzavi, 2016b; Balali-Mood & Shariat, 1999). Consistent with the known venom composition of *P. persicus* (Mehdizadeh Kashani et al., 2012), consumption coagulopathy and thrombocytopenia have been reported following envenoming (Afshari & Monzavi, 2016b; Balali-Mood & Shariat, 1999; Heiner et al., 2013). A herpetologist bitten by an identified *P. persicus* in Kerman Province, Iran, developed local pain and swelling, bleeding from the bite site, mild non-specific symptoms, increased serum creatine kinase and minimal laboratory evidence of coagulopathy (Kazemi et al., 2023). Four days after a reported bite by this species in Pakistan, a young Makrani boy appeared very weak and jaundiced but seemed to be recovering (Minton, 1966).

Vipera ammodytes transcaucasiana: There have been no reports of bites by *V. a. transcaucasiana*. However, vomiting, diarrhea, thrombocytopenia, AKI, hypokalemia, proteinuria, elevated liver enzymes, hemolytic anemia, petechiae, hematoma, hematuria, thrombocytopenia, severe coagulopathy, and rarely neurotoxic symptoms (expressed as transient paresis of the bitten limb) have been reported from bites by the closely-related *V. a. ammodytes* (Liapis et al., 2019; Marinov et al., 2010; Nikolić et al., 2021).

Walterinnesia morgani: In Iraq, close to the western border of Iran, a man bitten on his leg by a “large black snake”, assumed to be *W. morgani*, was reported to have developed respiratory distress and generalized limb weakness along with mild edema, erythema, and numbness around the bite site. During recovery, he experienced diplopia without objective evidence of external ophthalmoplegia but made a complete recovery (Lauer et al., 2011). Also in Iraq, Corkill described three fatalities within 6-10 h of suspected bites by this species (Corkill, 1939, 1932). Clinical features included local swelling, vomiting, collapse and paralysis (Corkill, 1939, 1932). Envenoming by the closely-related Egyptian or Western Black Desert Cobra (*W. aegyptia*) has been reported to cause local pain and swelling, fever, nausea, vomiting, diaphoresis, generalized weakness, involuntary movements, respiratory distress, loss of consciousness, and peripheral neutrophilic leukocytosis (Abu Baker et al., 2022; Lifshitz et al., 2003; Yayon et al., 1988).

3.3.3. Secondary complications of snakebite envenoming

The etiology of the often poly-microbial wound infections and cellulitis in snake-bitten patients reflects the varied, unusual, and distinctive bacterial flora of snakes’ oral cavities (Dehghani et al., 2020; Dehghani et al., 2016b; Sadeghi et al., 2021). However, many snake venoms possess anti-bacterial activity. In a Brazilian study, bacterial contamination was very uncommon in venom of recently-captured snakes (Garcia-Lima & Laure, 1987). Another source of secondary bacterial or, rarely, fungal infection following snakebite is the use of non-sterile incisions at the bite site (Afshari & Monzavi, 2016b; Dehghani, 2010; Dehghani et al., 2016b; Dehghani et al., 2015).

Many of the systemic manifestations of envenoming arise from direct venom toxicity, but they may sometimes result indirectly through other mechanisms. For example, AKI may be caused by direct nephrotoxicity of snake venom, or it may result from profound or prolonged hypotension due to massive hemorrhage, hypovolemia, anaphylaxis or vasoactive venom toxins, or from "pigment nephropathy" in cases of rhabdomyolysis or hemolysis (Sitprija, 2006). Renal damage is usually transient and responsive to short-term hemodialysis without the complication of chronic renal failure (Elkabbaj et al., 2012; Rahmani et al., 2022; Valenta et al., 2010). In Iran, complications, such as pancreatitis, subarachnoid hemorrhage, compartment syndrome, ischemic contracture, and digital necrosis requiring amputation, have also been reported following snakebite envenoming (Dehghani et al., 2014b; Eslamian et al., 2016; Farzan et al., 2003; Nejadrahim et al., 2019; Sagheb et al., 2011a, 2011b; Zamani et al., 2016). In a rare case of envenoming by *E. c. sochureki* in southern Iran, the victim developed AKI and necrotizing pancreatitis (Sagheb et al., 2011a). AKI and pancreatitis, and posterior reversible encephalopathy syndrome, have also been reported following *C. cerastes* envenoming (Ibrahim et al., 2017; Valenta et al., 2010).

In addition to organic symptoms, snakebite victims may experience psychiatric symptoms and mental health problems such as visual hallucinations, and acute and chronic post-traumatic stress disorders (Khosrojerdi & Amini, 2013; Mehrpour et al., 2018).

3.4. Medical management of snakebite envenoming in Iran

Snakebite envenoming is a medical emergency. If intervention is delayed, irreversible sequelae and even death may ensue (Hassanian-Moghaddam et al., 2022; Monzavi et al., 2014). In fact, traditional therapeutic measures in rural areas, misleading self-reported history by the victims or relatives, and inadequate inspection of the bite wound and initial misdiagnosis by the clinicians, are the major contributory factors that delay appropriate medical interventions. In rural areas of Iran, traditional treatments include aggressive wound incision/pricks, suction, tight tourniquets above the bite site, and local application of various herbal medicines (e.g., mullein, dandelion, onion, turmeric, etc.) (Afshari & Monzavi, 2016b; Astaraki et al., 2020; Balali-Mood & Shariat, 1999; Besharat et al., 2008).

The most effective and the only specific treatment to prevent, halt and reverse venom effects is specific antivenom (Gutierrez, 2018; Warrell, 2016). *E. c. sochureki*, *M. lebetina*, *M. raddei*, *G. caucasicus*, *P. persicus* and *N. oxiana* have long been considered the species of greatest medical importance in Iran (Afshari & Monzavi, 2016b; Balali-Mood & Shariat, 1999; Latifi, 1985). That is why Iranian antivenoms were designed specifically to target the venoms of these species. Razi™ Polyvalent Antivenin (Razi Vaccine & Serum Research Institute, Tehran, Iran) has been commercially available for over five decades (Latifi, 1984). The antivenom is an equine-derived $F(ab')_2$ immunoglobulin, that is produced in two formulations: (1) pentavalent, capable of neutralizing the venom of 5 common medically important snakes in Iran including *E. carinatus*, *M. lebetina*, *M. raddei (albicornuta)*, *G. caucasicus (halys)* and *P. persicus*, and (2) hexavalent, with the addition of neutralizing *N. oxiana* venom (Latifi, 1984; Monzavi et al., 2019a; Monzavi et al., 2014; Theakston & Warrell, 1991). The hexavalent formulation is distributed only in northeastern regions of Iran, where *N. oxiana* is reported. The effectiveness of this antivenom has been predicted, based on both *in vitro* and *in vivo* studies, but no formal clinical trial has been carried out (Akbari et al., 2010; Heiner et al., 2013; Latifi, 1984; Monzavi et al., 2019a). For this antivenom, the average time needed to achieve a “therapeutic response” or “initial control" (judged by the reversal of systemic effects, or arrest of progression of local effects when there are no systemic effects) was approximately 2 (range 1-9) hours in viper envenomed victims in northeastern Iran after treatment with a median of 10 ampoules (100 mL, two doses of 50 ml/hour) (Monzavi et al., 2019b). In southern parts of the country, higher doses (10-20 ampoules) are usually administered (Rahmani et al., 2014), because different criteria for clinical response are considered (their criteria generally differ from the consensus definition of initial control according to widely-accepted guidelines and textbooks) (Lavonas et al., 2011; Monzavi et al., 2014; Riley et al., 2011; Warrell, 2016). The frequency and severity of early adverse reactions following treatment with this antivenom are reported to be low (4.5-6%) with few or no late reactions, but detection of all adverse events requires close monitoring of patients for at least 4 hours after antivenom treatment and follow-up for the next 4 weeks (Mohammad Alizadeh et al., 2016; Monzavi et al., 2019a; Monzavi et al., 2015). Recently, a new Iranian company (Padra Serum Alborz, Karaj, Iran) has started manufacturing snake antivenoms, i.e., SnaFab5® (pentavalent) and SnaFab6® (hexavalent), to expand antivenom production capacity and availability for Iran and neighboring countries (Abouyannis et al., 2021; Kazemi et al., 2023b). Both brands (Razi™ and SnaFab®) have been listed in the WHO database of antivenoms (World Health Organization, 2021), and share similar composition and formulation. However, to separate IgG, ammonium sulfate is used for Razi™, whereas caprylic acid is employed for SnaFab® production. Razi institute plans to produce a monovalent antivenom for *N. oxiana* (Akbari et al., 2010). In Iran, other suggested innovations have included raising antivenoms in chicken egg yolks (Zolfagharian & Dounighi, 2015), and development of recombinant antibodies against Iranian venomous snakes using phage-display technology (Eskafi et al., 2021; Kadkhodazadeh et al., 2020; Nazari et al., 2020), and species-specific human recombinant Fab antivenom (Kazemi-Lomedasht et al., 2019; Motedayen et al., 2018). Novel drug delivery methods to enhance antivenom efficacy have also been explored (Alirahimi et al., 2018; Shahidi Bonjar, 2014).

Venom-induced hemostatic disorders and shock are usually reversible with prompt and appropriate antivenom therapy. However, death due to envenoming may occur in the first few hours after elapid bites, due to neurotoxic bulbar and/or respiratory paralysis (Angaji et al., 2016; Gasanov et al., 2015; Lewis & Gutmann, 2004). Post-synaptic neurotoxicity following cobra envenoming is fairly responsive to antivenom therapy; whereas, presynaptic neurotoxicity of sea-snakes and kraits is poorly reversible, once established, since the PLA_2 neurotoxins permanently damage targeted nerve terminals at neuromuscular junctions (NMJ)s. Hence, in all cases of neurotoxic envenoming, airway management and assisted ventilation should be considered to keep the patient alive until the antivenom takes effect or venom effects wear off. Anticholinesterases given with atropine may also be helpful first-aid for postsynaptic neurotoxic effects. Since the appearance of effects of pre-synaptic neurotoxins may be delayed, snakebite victims, even those with only limited local signs, should be observed carefully, especially during the first 24 hours after admission to the hospital (Afshari & Monzavi, 2016b; Monzavi et al., 2014; Riley et al., 2011; Warrell, 2016).

Optimal medical management of a snakebite envenomed patient requires a comprehensive approach rather than antivenom therapy alone. Region-specific guidelines or protocols are advocated for this purpose, as medical system infrastructure, antivenom availability, and locally-important snake species vary in each country or geographical region (Chippaux & Goyffon, 1998; Lavonas et al., 2011; Monzavi et al., 2014). In Iran, a group of medical toxicologists has developed a nationally unified protocol for hospital management of snakebite (Monzavi et al., 2014). This protocol comprises: (1) a severity grading scale for initial assessment of the clinical condition, (2) a schematic algorithm that indicates a logical sequence of diagnostic and therapeutic measures with suggested antivenom dosing, and (3) recommended supportive and adjunctive treatments when necessary (Monzavi et al., 2014).

In clinical practice, this protocol has reduced antivenom usage, compared to a locally-practiced anecdotal recommendation for antivenom dosing (Monzavi et al., 2015). The protocol also reduced the healthcare costs and length of hospital stay (Monzavi et al., 2015). Nonetheless, the minimum recommended starting dose of antivenom in the new protocol (5 ampoules = 50 mL) (Monzavi et al., 2014; Monzavi et al., 2015), is still 2.5 times higher than the dosage (2 ampoules = 20 mL) recommended in the package insert of the Razi™ Antivenin (RVSRI, 2021). This is because the optimal starting dose of antivenom has not been established by formal clinical trials in Iran (as in many other parts of the world), and that the US guidelines, as a standard practice, has been adopted instead (Lavonas et al., 2011; Monzavi et al., 2014; Riley et al., 2011).

As mentioned, some clinicians in southern parts of the country consider their own antivenom dosing and use their own definition of clinical response, which results in administration of higher starting (10 ampoules) and maintenance doses of antivenom. Therefore, to establish rational antivenom dosing, a multi-center blinded randomized dose-finding clinical trial may be required, in which the envenoming species is identified, to compare the manufacturer's recommended dose of 20-ml with 50-ml and 100-ml doses.

In addition to antivenom therapy, supportive measures are essential for critically ill snakebite patients (Monzavi et al., 2014): (1) assisted ventilation for respiratory muscle paralysis; (2) intravenous fluid replacement with or without vasopressor drugs for hypotension and shock; (3) airway support for bites in the head and neck region with a risk of airway obstruction; (4) blood products to accelerate restoration of hemostasis in response to specific antivenom in patients with severe, spontaneous bleeding (e.g., gastro-intestinal bleeding) causing hemodynamic instability; (5) protection of kidneys from pigment nephropathy caused by myoglobinuria in cases of severe myotoxicity/rhabdomyolysis, or hemolysis; (6) use of anticholinesterases, such as neostigmine or edrophonium chloride, along with atropine to reverse NMJ blockade by post-synaptic neurotoxins in cases of cobra bite envenoming; (7) treatment of secondary bacterial bite wound infections. Despite all the evidence and guidelines discouraging early wound incision and fasciotomy for patients with extensive swelling of the bitten limb (Darracq et al., 2015; Greene et al., 2021; Monzavi et al., 2014; Warrell, 2016), these outdated practices persist in some parts of Iran, increasing the risk of complications such as bleeding, secondary nosocomial infections, prolonged hospital admission and residual deformities (Kazemi et al., 2021c). Whether or not anti-inflammatory treatments may help alleviate the local effects of envenoming is an unanswered question. Results of a recent study in Isfahan that compared single with multiple doses of anti-inflammatory treatments (histamine H1 and H2 blockers and hydrocortisone) suggested some benefit of multiple doses (Dorooshi et al., 2021). However, the results were inconclusive because the study was retrospective, non-randomized, unblinded, did not distinguish envenoming by different species, the two groups were not similar before treatment, and many patients had negligible symptoms.

Sea-snake bite envenoming in Iran is rare. Local sailors and fishermen are aware to avoid sea-snakes and release them untouched from the fishing nets. It should be noted that victims of sea-snake bite envenoming are at risk, because local and systemic effects may be absent during the first few hours after the bite, no specific antivenom is available in the country, and anticholinesterases are unlikely to be effective in sea-snake bite venom-induced neurotoxicity (Nabipour et al., 2015; Warrell, 2016). In the absence of a specific antivenom for sea-snake bite envenoming, medical management is based on supportive measures for controlling the neurotoxic and myotoxic effects that may include airway support, assisted ventilation, and prevention of myoglobinuria-induced AKI (Monzavi et al., 2014; Nabipour et al., 2015). An algorithm for the early-stage management of marine envenomings in Iran has been proposed, but it addresses only primary care measures (Nabipour et al., 2015).

4. DISCUSSION & CONCLUSIONS

4.1. Review of Iran's venomous snake fauna

In this review of medically important snakes of Iran, 17 species of mildly-venomous non-front-fanged Colubridae and Lamprophiidae, and 30 species of venomous snakes, including 15 Viperinae, 1 Crotalinae, and 14 Elapidae are discussed. Occurrence of these species, and their population densities vary across Iran with climate and other environmental characteristics (Dehghani, 2010; Dehghani et al., 2014b; Farzanpay, 1990; Firouz, 2005; Latifi, 1991, 1985; Rastegar-Pouyani et al., 2008; Safaei-Mahroo et al., 2015). Among these, three new species, endemic to Iran, were first described within the last 15 years. We have critically reviewed recent taxonomic revisions to produce an updated checklist with some new additions (e.g., *M. razii,* and *H. cantoris*), some former sub-species have been raised to species status (e.g., *Platyceps ladacensis, P. fieldi, G. caucasicus, V. ebneri*), and some sub-species have been subsumed (e.g., *E. c. multisquamatus, M. r. kurdistanica* and *M. r. albicornuta*). Morphological features are described and illustrated and the country-wide geographical distributions of medically-important species are updated and mapped (**Supplementary File**). However, further taxonomic and zoogeographic revisions are anticipated. Freitas et al. have emphasized that taxonomic status (species/sub-species) is important for understanding biodiversity, and for mobilizing efforts and allocating resources to develop conservation strategies (Freitas et al., 2020). In their review of Eurasian vipers, they questioned the species status of the following taxa, based on genetic divergence, and suggested more appropriate status within other species/species complexes: (1) *M. kuhrangica* and *M. latifii* show only 2% genetic divergence from *M. raddei*; (2) *M. wagneri* is part of the *M. bornmuelleri* group; (3) *V. eriwanensis* and *V. ebneri* show close genetic affinity suggesting sub-specific status within the *V. renardi* group (Freitas et al., 2020).

The occurrence of some species in Iran should be clarified. Despite some studies reporting or proposing presence of *M. wagneri* and *V. a. transcaucasiana* in Iran, their presence has not been supported with solid evidence, and hence needs further scrutiny. There are also questions over the occurrence of *P. fieldi* in Iran. Besides, *H. stokesii* has been recorded in the Makran coast of Pakistan, and it likely (but not definitely) occurs alongside this coast of Iran (Rastegar-Pouyani et al., 2008). Unless the statuses of these species are fully elucidated, the presence of these species in Iran should be considered as doubtful (questionable).

4.2. Importance of species identification of venomous snakes

Knowledge of the geographic range distribution of the different medically-important species will help hospital staff to interpret early symptoms of envenoming by the local species in their area, and to prepare patients and medical staff for the likely evolution and complications of envenoming (Amr et al., 2020; Warrell, 2016). In this way, treatment of envenoming by each species can be optimized. In Iran, as elsewhere in the world, there is a great need to design prospective studies to establish the clinical features (phenotype or syndrome) resulting from envenoming by each species, to form a sounder basis for diagnostic and therapeutic algorithms. Clinical toxicologists and emergency medicine clinicians should be strongly encouraged to establish and enter into the patients' medical records the identity of the biting species, especially when the responsible snake is brought to the hospital (Bawaskar & Bawaskar, 2019; Monzavi et al., 2019a). Alternatively, smart-phone images, taken at the location where the bite occurred, are increasingly available and can easily be sent electronically to a regional or national reference center/herpetologist for identification. When getting an expert opinion is not feasible, perhaps, a recent effort to devise state-of-the-art machine learning algorithms in Iran, which helps generating cellphone applications for snake image identification with reasonable accuracy and reliability can be seen as a solution (Rajabizadeh & Rezghi, 2021). Far less convincing is recognition by the bite victim of colored pictures or museum specimens of local species, or the use of local snake names. Future clinical research on snakebite in Iran will be greatly assisted if species identification can be confirmed using immunodiagnostic methods, especially in those snakebite cases where the responsible snake is not available for examination.

4.3. Venomous snake conservation and community education

Where natural and human environments interface, lack of public education has contributed to ignorance about the biological and ecological value of snakes, predisposing them to the danger of unnecessary human predation. On the other hand, the risk of snakebite envenoming depends on the extent to which human settlements and agricultural activities encroach upon areas with habitats supporting higher population densities of venomous snake species. Enhancing the level of public awareness and knowledge would appreciably reduce the number of adverse snakebite events and increase public support for the conservation of snakes in nature (Mashhadi et al., 2017; Warrell, 2016). Snakes play an integral role in maintaining ecological equilibrium and controlling rodent- and bat-related zoonoses of human and veterinary public health importance, such as plague, leptospirosis, hantavirus, coronavirus and arenavirus diseases. Studies have revealed some snake venom toxins of potential value in designing new treatments for human diseases such as hypertension, thrombophilia, diabetes mellitus, malignancy, infections and intractable pain, and providing useful diagnostic laboratory reagents (Ali et al., 1999b; Chan et al., 2016; Op den Brouw et al., 2021b). This is an additional argument for conserving venomous snakes. Data on geographical distribution of snakes are crucial for determining regions important for the conservation of species in danger of extinction and preserving their habitat. Given the diverse biogeographic status of Iran, a collaborative approach for the sustainable management of Iranian herpetofauna has been recommended to be made between Iranian governmental institutions and NGOs, and international agencies (Jowkar et al., 2016; Rastegar-Pouyani et al., 2015).

4.4. Clinical features of envenoming and management protocols

In this paper, we have provided species-specific descriptions of the clinical features of envenoming by the medically important snakes of Iran according to available literature. In addition, we discussed the improvements made in the medical management of snakebite victims in Iran, by rationalizing antivenom dosage and through appropriate use of supportive measures according to a recently-developed comprehensive protocol. The use of this protocol is more cost-effective and abandons long-practiced unsubstantiated treatments, while it provides step-by-step instructions for clinicians (Monzavi et al., 2015). Although the antivenoms in Iran are polyvalent, covering the most common venomous species, it is highly likely that the antivenom dosage requirements differ between species as well as with different levels of severity of envenoming. Therefore, formal dose-finding clinical trials are necessary, so that antivenom can be used more effectively, and in view of its economic cost and dose-related risk of adverse reactions, excessive dosage can be avoided.

4.5. Provision of antivenoms and medical staff training

Medical facilities, especially those in areas where snakebites are relatively common, should be provided with vital medications, such as adequate stocks of antivenom, especially during the warm seasons (Mondal et al., 2012; Monzavi et al., 2019b). In each geographical region, one of the main challenges affecting the treatment of snakebite victims has been the training of medical staff to recognize signs and symptoms of envenoming and to understand the distinction of the bites by non-venomous species from the bites by venomous species. Medical staff should receive training in snakebite management, including criteria for transferring severely-envenomed patients to higher levels of medical care when necessary (Warrell, 2016). Community education must also be prioritized along with medical staff training, that in case of a venomous snakebite, the victim should be transported quickly and passively to medical care, without delay for traditional treatments.

DECLARATIONS

Ethical clearance: No experimentation with human subjects was involved in this review.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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FIGURE LEGENDS

Fig. 1. Map of the geographic location of Iran and neighboring countries, and Iran's provinces

Fig. 2. Iran's pioneers in herpetology and snakebite, and textbooks of ophiology and natural conservation. **A,** Professor Mahmoud Latifi; **B,** Professor Reza Farzanpay; **C,** Engineer Eskandar Firouz; **D.** A group photo in the garden of the Razi Institute, Iran, Left to right: Professor Claus Andrén, Professor Mahmoud Latifi, Professor Göran Nilson, Professor Reza Farzanpay; **E,** The Snake Sultan, a nomadic Bakhtiari tribe snake catcher for the Razi Institute in the Zagros Mountains of eastern Iran, with *Pseudocerastes persicus*; **F,** A group photo at the Fifth symposium of International Society of Toxinology in Irazú Hotel, Costa Rica, 1976, Left to right: Professor Findlay E. Russell, Professor William B. Elliott, Professor Akira Ohsaka, Professor David Chapman, Professor Mahmoud Latifi, Professor Roger Bolaños, Professor H. Alistair Reid, Professor Yoshio Sawai, Professor Gastão Rosenfeld. **G,** *Snakes of Iran* (Persian version) by M. Latifi, **H,** *Snakes of Iran* (English translated version), **I,** *Ophiology* (in Persian) by R. Farzanpay; **J,** *The complete fauna of Iran* (in English) by E. Firouz.

Fig. 3. Flow diagram of literature search

Fig. 4. Cardinal characteristics of Viperidae. **A,** Vertically elliptical pupil; **B,** Solenoglyph dentition showing tubular (canaliculated) fangs of *Pseudocerastes persicus* - a viper with a wide geographic distribution in Iran.

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Fig. 5. Symptoms observed following a facial bite that resulted from severe *Echis carinatus* envenoming in northeast Iran (with permission). **A & B,** The patient was unable to open her eyes due to extensive edema. Ecchymosis and blister formation were also present. Arrows show the bite site (fang marks). The edge of edema was marked on the victim's face with a blue line. The patient developed thrombocytopenia and consumption coagulopathy; **C,** The patient on the 4th day post-bite, after administration of 24 vials of snake antivenom (Razi Antivenin), and other supportive treatments. The edema and ecchymoses were considerably reduced compared to the day of admission and she could open her left eye (of note, by the 7th day post-bite, the edema on the right side subsided and she could open her right eye, as well).

* Figures are taken with permission from the patient and legal guardians. The figures are from S. M. Monzavi's personal archive and require permission for reproduction.

Fig. 6. A & B, Edema, blister formation, and local necrosis following Viperidae snakebite in northeast Iran attributed to *Macrovipera lebetina obtusa* bite. The right upper limb of the patient is massively swollen; **C,** Rapidly developing swelling and necrosis in a toe attributed to *Macrovipera lebetina obtusa* bite

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TABLES

Table 1. Lethal doses (LD_{50}) of Iran's medically important snakes

Table 2. Common snakebite envenoming features in Iran

SUPPLEMENTARY FILE:

Table 1S. Photographs, conservation status and distribution of Iran's medically important snakes

Table 2S. Taxonomy and morphologic features of the mildly-venomous (non-front-fanged) snakes of Iran

Table 3S. Taxonomy and morphological features of the venomous snakes of Iran

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Caspian Sea
Tabriz
East Azerbaijan
Ardabil
West Azerbaijan
Gilan
Golestan
North Khorasan
Zanjan
Mashhad
Mazandaran
Kurdistan
Qazvin
Alborz
City of Tehran
Tehran
Semnan
Razavi Khorasan
Sanandaj
Hamadan
Qom
Kermanshah
Markazi
Isfahan
Lorestan
Ilam
City of Isfahan
South Khorasan
Chaharmhal & Bakhtiari
Yazd
Khuzestan
Kohgiluyeh & Boyer-Ahmad
Ahvaz
Shiraz
Kerman
Zahedan
Bushehr
Fars
Sistan & Baluchistan
Hormozgan
Persian Gulf
Gulf of Oman
ARMENIA
AZERBAIJAN
TURKMENISTAN
TURKEY
Caspian Sea
AFGHANISTAN
IRAQ
IRAN
KUWAIT
PAKISTAN
Persian Gulf
BAHRAIN
QATAR
Strait of Hormuz
UNITED ARAB EMIRATES
SAUDI ARABIA
OMAN


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مـارهای ایـران
G
THE SNAKES OF IRAN
Mahmoud Latifi
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1991
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مارشناخت
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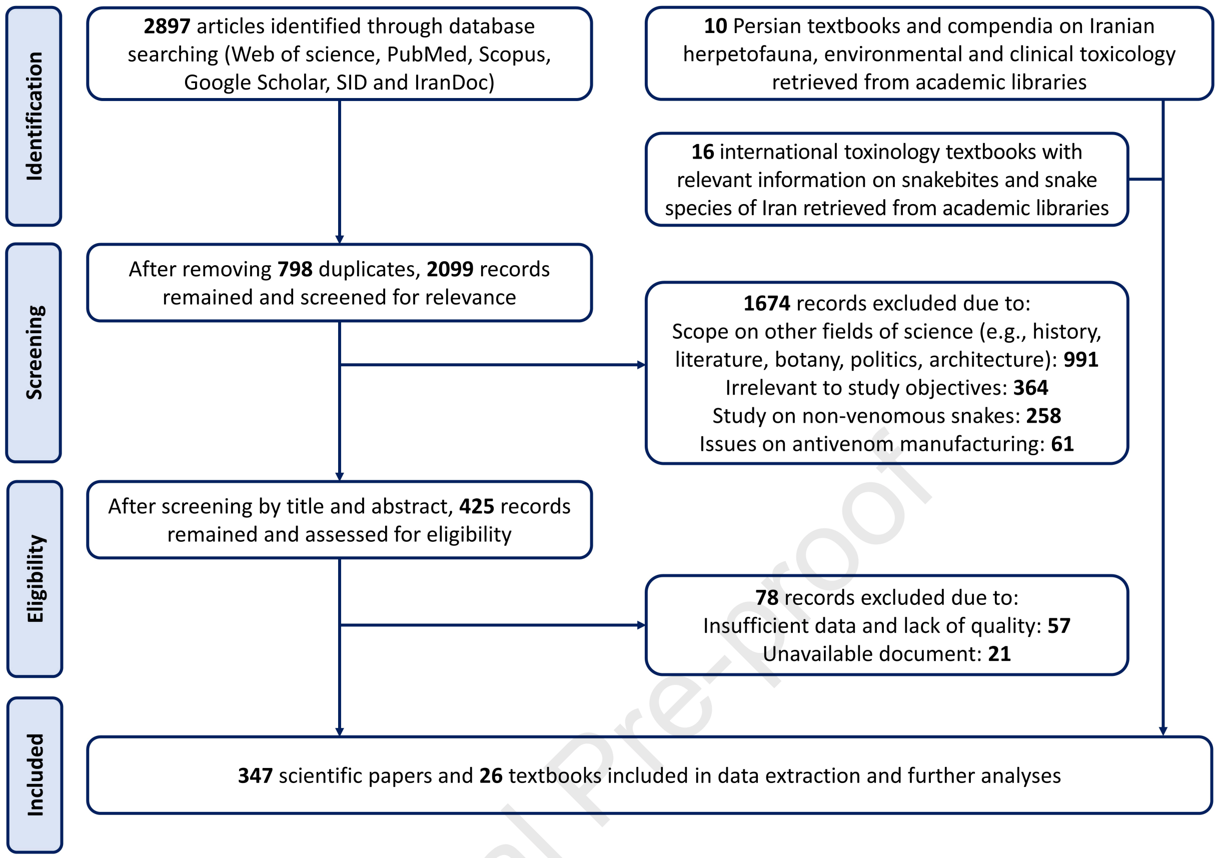
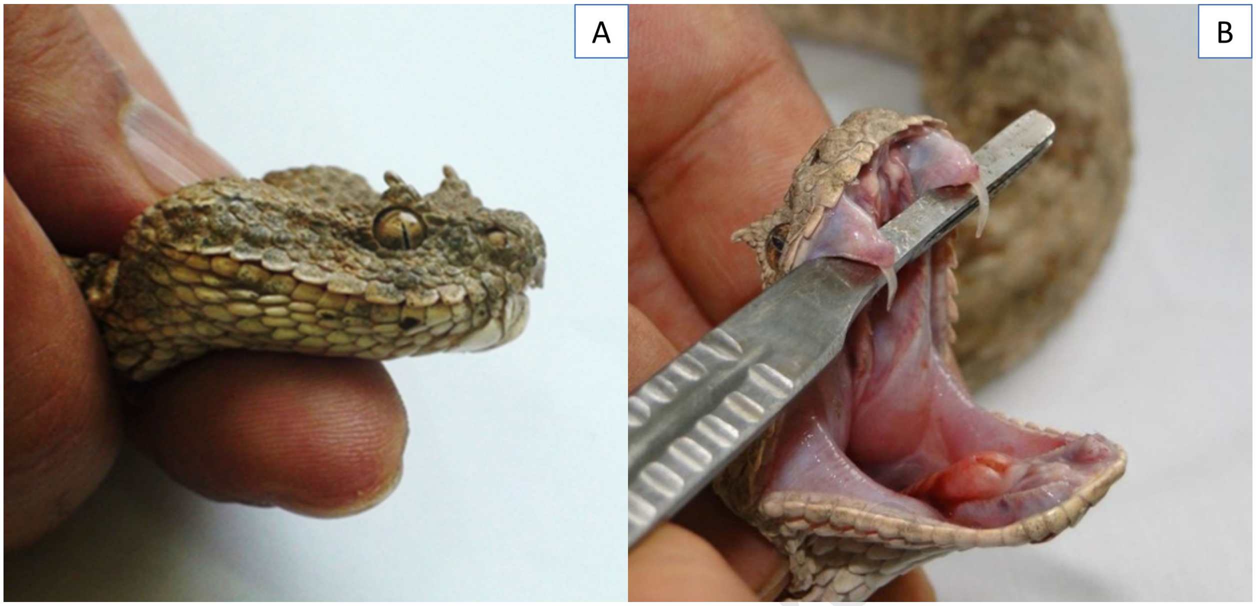

Identification
Screening
Eligibility
Included
2897 articles identified through database searching (Web of science, PubMed, Scopus, Google Scholar, SID and IranDoc)
10 Persian textbooks and compendia on Iranian herpetofauna, environmental and clinical toxicology retrieved from academic libraries
16 international toxinology textbooks with relevant information on snakebites and snake species of Iran retrieved from academic libraries
After removing **798** duplicates, **2099** records remained and screened for relevance
1674 records excluded due to:
Scope on other fields of science (e.g., history, literature, botany, politics, architecture): **991**
Irrelevant to study objectives: **364**
Study on non-venomous snakes: **258**
Issues on antivenom manufacturing: **61**
After screening by title and abstract, **425** records remained and assessed for eligibility
78 records excluded due to:
Insufficient data and lack of quality: **57**
Unavailable document: **21**
347 scientific papers and **26** textbooks included in data extraction and further analyses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HIGHLIGHTS

1. A comprehensive review on medically important snakes in Iran regarding geographical distribution, taxonomy, venom composition

2. A focus on environmental value of Iran's medically important snakes

3. A critical appraisal of clinical effects of medically important snakes in Iran

4. A detailed evaluation of clinical management of snakebite envenoming in Iran

Ethical Statement

No experimentation on human or animal subjects was involved in this study.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: