Research Article

Human Exposure to Arsenic and Toxic Metals Through Meat Consumption in Africa: A Review of Scientific Literature

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While meat consumption trends show decreases in some high-income countries, significant increases are observed elsewhere. Although this includes African nations, average meat consumption in Africa remains generally lower than in many other continents, though patterns vary regionally. Meat provides essential nutrients, but inadequate consumption can pose health problems, while consumption also carries risks including potential exposure to environmental contaminants. This review focuses on recent scientific literature (published 2000-2024) regarding human exposure to specific toxic metals/metalloids—namely the non-essential elements arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb), along with potentially toxic forms/elements like chromium (Cr, particularly Cr(VI)) and nickel (Ni)—through the consumption of meat (muscle, organs, processed products) in Africa. Searches in PubMed and Scopus databases indicate that published information on this topic is limited for many African regions, with a notable concentration of studies originating from Nigeria. Concentrations of these toxic metals/metalloids reported in meat tissues and estimated dietary intakes vary significantly across the reviewed studies, influenced by the element, tissue type (organs like liver and kidney often show higher concentrations than muscle), geographical location, and local pollution sources. While some studies raise concerns about specific metals (e.g., Pb, Cd, As) potentially exceeding exposure guidelines in certain contexts, the available literature suggests that, similar to findings in other continents, meat is generally not the primary dietary contributor to total human exposure for most of these toxic trace elements in African countries compared to other food groups like fish, seafood, or staple crops affected by local contamination.

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Introduction

Meat consumption has increased remarkably since the mid-20th century[1]. However, this global increase varies across continents[2]. In high-income countries like those in the European Union, the USA, and Canada, meat consumption, particularly of red meat, has shown signs of decreasing or stabilizing. This trend may be linked to growing public awareness regarding health implications (e.g., associations between high red and processed meat intake and cardiovascular disease, type 2 diabetes, and certain cancers)[3][4][5][6][7][8][9], environmental concerns related to livestock production[3], and ethical considerations. Conversely, many countries worldwide are experiencing significant increases in meat consumption, often correlated with rising incomes and urbanization[10][11]. China, accounting for approximately 27% of global consumption, is the largest total meat consumer, although its *per capita* consumption still generally lags behind that of Western countries[12][3].

Regular meat consumption offers nutritional advantages, being a complete source of high-quality proteins, B-vitamins, and essential trace elements (Fe, Co, P, Se, and Zn), along with fats[4][5]. However, regular consumption of large amounts of certain meats, particularly red and processed meats, can pose health risks. The high saturated fat content in some meats is linked to increased risks of heart disease, stroke, and diabetes[6][7][8][9]. In 2015, the International Agency for Research on Cancer (IARC) classified processed meat as "carcinogenic to humans" (Group 1) and red meat as "probably carcinogenic to humans" (Group 2A), primarily increasing the risk of colorectal cancer[13][14][15][16][17]. Furthermore, antibiotic resistance stemming from the extensive use of antibiotics in livestock production is a significant public health concern[18][19].

Like other food groups, meat consumption can result in exposure to environmental pollutants. Regarding metals/metalloids, toxic elements such as arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg), as well as chromium (specifically the more toxic hexavalent form, Cr(VI)) and nickel (Ni), are frequently detected at various levels in food alongside essential trace elements. These toxic elements can enter the animal through various pathways and accumulate in tissues. Sources of contamination for livestock include industrial emissions, mining activities, urban waste, agricultural practices (e.g., use of contaminated fertilizers or pesticides on grazing land), contaminated water sources, and the consumption of contaminated feed (including soil or grass ingestion)[20][21][22][23][24][25][26]. However, based on previous comprehensive reviews, meat (referring to tissues from terrestrial animals in this context, distinct from fish/seafood) is generally not considered the primary source of environmental inorganic and organic contaminants for the general human population globally[5][27][28]. Fish and seafood (including marine species, shellfish, crustaceans) typically contribute the most to human dietary exposure to toxic trace elements like mercury and sometimes arsenic and cadmium[29][30][31].

Organizations like WHO/FAO, US EPA, and EFSA have established recommended intakes or tolerable exposure limits for trace elements. However, rigorous control and monitoring of toxic element levels in food, including meat, is lacking or inconsistent in many countries, including those where meat consumption is increasing. A recent review examined toxic trace element levels (As, Cd, Hg, Pb, Cr, Ni) in meat across Asian countries, finding significant variation in concentrations and confirming that meat was not the primary contributor to dietary exposure for most elements studied[32].

Meat consumption in Africa varies widely due to cultural, economic, and environmental factors. Overall, average per capita consumption is lower than in other regions like Europe or the Americas, but demand is growing, driven by population growth, urbanization, and economic development[10][11][33][34][35][36][37]. Access and preferences vary based on local resources (beef, goat, sheep, poultry are common; pork and bushmeat are significant in certain areas) and economic conditions[35]. Contamination of meat by pollutants, particularly toxic metals/metalloids (As, Cd, Hg, Pb etc.), is a growing concern due to the presence of various pollution sources across the continent[20][21][22]. Considering the increasing consumption and potential for contamination, this review examines scientific studies published in English between 2000-2024 on human exposure to toxic trace elements (specifically As, Cd, Hg, Pb, Cr, Ni) through meat consumption in African countries. The concentration of studies found from Nigeria reflects the availability of published research retrieved through the search strategy, rather than a pre-determined focus.

Search strategy

PubMed (https://www.ncbi.nlm.nih.gov/pubmed/) and Scopus (https://www.scopus.com) databases were used to search for information. These databases were chosen as they provide broad coverage of peer-reviewed international biomedical and life sciences literature. The search considered only articles published in English, covering the period from January 1, 2000, to December 31, 2024. Search terms included combinations of: ('meat' OR 'meat products') AND ('dietary exposure' OR 'human intake') AND ('metals' OR 'metalloids' OR 'trace elements' OR 'arsenic' OR 'cadmium' OR 'lead' OR 'mercury' OR 'chromium' OR 'nickel') AND ('human health risks' OR 'risk assessment') AND ('Africa' OR names of individual African countries). Studies were included if they reported original quantitative data on the concentration of at least one target toxic element (As, Cd, Hg, Pb, Cr, Ni) in edible meat tissues (muscle, organs) or meat products from African countries, and/or estimated the associated human dietary exposure or health risks. Reviews, studies focusing solely on essential elements without toxic element data, or those lacking quantitative concentration/exposure data were excluded. Information from the reviewed studies is summarized below by country, in chronological order.

Concentrations of toxic trace elements in African countries

Nigeria

Nigeria has the most data available regarding toxic metal/metalloid levels in meat. While most studies focused on Cd and Pb, data for other elements were also found. Ihedioha and Okoye[38] measured Cd and Pb concentrations in muscle and edible offal (kidney, intestine, and tripe) of cows in Enugu State. Mean Cd levels ranged from 0.24 to 0.44 μg/g, detected in 43% of muscle samples and varying percentages of offal samples (100% of kidney, 95% of liver, 70% of intestine, and 50% of tripe). Mean Pb levels ranged from 0.09 to 0.26 μg/g, detected in 70% of muscle and 100% of offal samples. Cd concentrations were relatively high, while Pb concentrations were moderate. In a subsequent study, Ihedioha and Okoye[39] assessed Cd and Pb exposure through consumption of cow tissues by the Enugu State population. Mean Cd levels were 0.35±0.27, 0.44±0.27, 0.24±0.26, 0.29±0.33, and 0.41±0.33 μg/g (dry weight, dw) for muscle, kidney, liver, intestine, and tripe, respectively. Cd intakes for adult men were 0.23, 0.45, 0.15, 0.55, and 0.50 μg/kg body weight (bw)/week, respectively. Mean Pb concentrations were 0.09±0.16, 0.13±0.07, 0.26±0.25, 0.17±0.12, and 0.17±0.16 μg/g dw for muscle, kidney, liver, intestine, and tripe, respectively, with intakes of 0.89, 0.42, 0.50, 0.94, and 1.21 μg/kg bw/week for adult men. Target hazard quotients (THQ) ranged from 0.42 to 0.90 for Cd and 0.05 to 0.10 for Pb, all < 1, indicating no significant health risks for consumers in that region. Further analysis by Ihedioha et al.[40] on the samples of cow meat assessed Zn, Cr, and Ni, calculating mean Estimated Daily Intakes (EDIs) of 299 (Zn), 88.9 (Cr), and 0.76 (Ni) μg/kg bw/day; only Cr intake exceeded the recommended daily intake (RDI), suggesting a potential concern. Meanwhile, Olusola et al.[41] analyzed frozen chicken (thighs and wings) from Lagos and Ibadan, reporting mean Cd (0.0065-0.0078 μg/dL) and Pb (0.0207-0.0227 μg/dL) levels, stating they were within Nigerian limits. In another investigation, Adetunji et al.[42] measured Cd and Pb concentrations in cattle samples (muscles, liver, and kidney) from Ogun State. Mean Cd concentrations in muscle, liver, and kidney were 0.156, 0.172, and 0.197 μg/g, respectively. Mean Pb levels were 0.721, 0.809, and 0.908 μg/g, respectively. Cd concentrations were within Nigerian standards, while Pb levels exceeded standards in all tissues. Furthermore, Adejumo et al.[43] assessed metals in cured meat products from South-West Nigeria; they did not detect Pb, Cr, or Ni, but found Cd levels in corned beef and meaty sausage ranging from 0.35 to 1.20 μg/g (mean 0.76 μg/g), exceeding the Nigerian limit. Related to specific pollution sources, Orisakwe et al.[44] studied livestock near a Pb-polluted goldmine in Zamfara State, noting concern about potential Cd and Pb levels in meats based on high levels found in animal blood (Pb up to 7.75 μg/g, Cd up to 0.32 μg/g). Similarly focusing on environmental context, Ogbomida et al.[45] assessed risks from consuming free-range animals near municipal solid waste sites in Benin City, finding As concentrations up to 0.081 μg/g ww (chicken), Cd up to 0.890 μg/g ww (chicken kidney), Pb up to 0.588 μg/g ww (chicken kidney), and Hg up to 0.034 μg/g ww (chicken liver); they highlighted higher concentrations in organs versus muscle and suggested potential risks from Cd and As with prolonged consumption of contaminated chicken liver. On the other hand, Njoga et al.[46] evaluated As, Cd, and Pb in goat carcasses in Enugu State, reporting mean ranges (μg/g) of 0.45-0.57 (As), 0.02-0.06 (Cd), and 0.45-0.82 (Pb) across muscle, liver, and kidney; although EDIs exceeded recommendations, the combined Hazard Index (HI) was < 1. Finally, extensive risk assessments by Okoye et al.[47][48] in the Niger Delta found potential risks for Pb exposure (vs BMDL0.1) in children/seniors from goat/cow meat, and significant contributions of meat consumption to dietary As intake (potentially exceeding BMDL0.1 for children) and Cd intake (especially in adolescents).

Egypt

Kamaly and Sharkawy[49] measured multiple elements in chicken from Assiut city markets, finding Cd concentrations up to 0.104 μg/g (liver) and Pb levels ranging from 0.146 μg/g (liver) to a high of 5.552 μg/g (chest muscle); calculated EDIs suggested low risk for Cd but potential concern for Pb, especially from chest meat. Additionally, Mohamed et al.[50] determined As, Cd, Hg and Pb levels in chilled and frozen beef from Sharkia Governorate, reporting average As concentrations of 4.66 μg/g (chilled) and 5.32 μg/g (frozen); while EDIs for Cd, Hg and Pb were below RfDs, the estimated As intake exceeded the As RfD by 46.7-60%, indicating a potential health concern from arsenic exposure via this beef.

Ghana

Adei and Forson-Adaboh[51], analyzing liver tissues from various animals in Accra and Kumasi, found over 50% of samples exceeded Ghanaian limits for Cd (0.5 µg/g) and Pb (0.5 µg/g). In turn, Bortey-San et al.[52] assessed metals in free-range animals near gold mines in Tarkwa, detecting As up to 0.14 µg/g ww (chicken kidney), Cd highest in chicken kidney (mean 0.73 µg/g ww), and Hg highest in chicken kidney (0.12 µg/g ww) and liver (0.11 µg/g ww); they noted organ accumulation and expressed concern over high Hg levels in free-range chicken exceeding Ghanaian limits.

Uganda

Kasozi et al.[53] measured Cd and Pb in beef, finding no detectable Cd but a high mean Pb concentration (18.90 µg/g); the estimated Pb intake was deemed unsafe for children (high THQ/HI). More recently, Kasozi et al.[54] carried out another beef study, reporting mean levels (µg/g) of 0.41 (Cd), 19.37 (Cr), 14.96 (Ni), and 5.42 (Pb); the calculated EDIs for Cr, Ni, and Pb were higher than WHO TDIs, suggesting potential risks. A subsequent survey by Kasozi et al.[55] found similar mean levels in beef: 0.4 (Cd), 19 (Cr), 15 (Ni), and 5.5 (Pb) µg/g, with the authors suggesting the high Cr and Ni might be ubiquitous in the sampled beef, possibly from environmental sources.

Other African countries

- **Ethiopia:** A systematic review by Mengistu[56] covering studies from 2016-2020 reported mean concentrations in Ethiopian meat/milk (µg/g or similar units) ranging 0.79-2.96 (As), 1.032-2.72 (Cr), 0.233-0.72 (Cd), and 1.32-3.15 (Pb), noting that levels often exceeded limits, posing potential health risks.
- **Algeria:** Benamirouche et al.[57] measured Hg and Pb in broiler parts, finding the highest Pb in liver (0.480 µg/g) and highest Hg in breast (0.007 µg/g); calculated EDIs for Hg and Pb exceeded tolerable intakes, and risk assessment suggested potential carcinogenic risks from Pb.
- **Senegal:** Missohou et al.[58] linked Hg contamination in poultry meat (> 0.011 µg/g in 20% of samples) to a nearby landfill impacting well water used for poultry.
- **South Africa:** Ambushe et al.[59] investigated bovine tissues from mining areas, confirming differential tissue accumulation with the highest Cd (1.35 µg/g) and Pb (0.62 µg/g) found in bone, but also high levels in kidney and liver compared to muscle.

- **Mauritania:** Ahmed et al.[60] analyzed dromedary meat, reporting mean toxic element levels (µg/g) of 0.055 (As), 0.064 (Cd), 0.027 (Hg), and 0.040 (Pb), recommending further monitoring, especially of edible organs.

Discussion

Meat consumption varies considerably between countries depending on various factors. Africa is no exception, as meat consumption varies significantly based on income levels, cultural practices, urbanization, and the availability of meat. Africa generally has a lower average per capita meat consumption compared to other regions like Europe or North America, but demand has increased in recent decades due to population growth, economic development, and urbanization[36][37]. The animal species most consumed in African countries include beef, goat, sheep, poultry, pork, and sometimes bushmeat.

Various pollution sources can contaminate meat with environmental pollutants, including toxic trace elements[27][61][62]. Sources relevant to Africa include mining operations, industrial discharges, agricultural runoff (pesticides, fertilizers), improper waste disposal (municipal and e-waste dumpsites), contaminated irrigation water, and the use of contaminated animal feed or grazing on contaminated land[23][24][25][26]. Toxic trace elements such as As, Cd, Hg, and Pb can be taken up by livestock from these sources and subsequently accumulate in their tissues, particularly in organs like the liver and kidneys, potentially affecting the safety of the meat consumed by humans[21][44][63][64]. This review synthesized studies on toxic trace element levels (As, Cd, Hg, Pb, Cr, Ni) in meats published in English in international journals indexed in PubMed and/or Scopus between 2000-2024. The analytical techniques used in the original studies and detailed results comparisons were not the primary focus, assuming rigorous peer review by the publishing journals.

Most studies identified focused on Cd and Pb, although As, Hg, Cr, and Ni were also investigated in several instances. Results showed significant variation depending on the country/region, the type of meat and tissue analyzed (e.g., muscle vs. organ), and the specific metal/metalloid. A consistent finding across multiple studies has been the tendency for higher concentrations of elements like Cd, Pb, and Hg in edible viscera (liver, kidney) compared to muscle tissue[38][44][50][51][59]. Some authors expressed concern regarding the consumption of certain meats (especially organs) in specific areas due to elevated toxic element concentrations potentially exceeding national or international safety limits or contributing

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significantly to exposures exceeding health-based guidance values (e.g., TDI, RfD, BMDL)[41][42][46][47][49][50][51][52][53][57].

However, when placed in the context of total dietary exposure, several studies suggested or concluded that meat was not the primary contributor to overall intake of certain toxic metals compared to other food groups like fish/seafood or staple crops, aligning with findings from other global regions[5][29][30][32]. This emphasizes the importance of considering the whole diet in risk assessments.

The significant presence of studies from Nigeria highlights a potential publication bias or simply reflects more active research and publication on this topic in that country compared to others in Africa found via the selected databases. Data from large parts of the continent remain scarce. Furthermore, variations in sampling strategies, analytical methods (though not reviewed in detail here), and reporting units (e.g., ww vs dw) across studies can complicate direct comparisons and synthesis.

Strategies to reduce potential exposure through meat could include stricter control of environmental pollution from industrial, mining, and waste sources; monitoring of animal feed and water quality; targeted surveillance of meat (especially organ meats) from high-risk areas; and potentially consumer advice on dietary diversity and limiting frequent consumption of organs known to accumulate contaminants.

A general trend observed globally, which should also apply to Africa, is the notable reduction in environmental lead (Pb) contamination over recent decades. This is primarily attributed to the successful international phase-out of leaded gasoline and restrictions on lead-based paints, which has lowered background Pb levels in soil, water, and the food chain[64]. While localized Pb hotspots remain a concern, overall dietary Pb exposure from sources like meat is expected to be lower now than several decades ago.

Conclusions

Synthesizing the findings from studies published between 2000 and 2024, drawing definitive continent-wide conclusions regarding the health risks associated with toxic metal exposure through meat consumption in Africa remains challenging. This difficulty stems primarily from the scarcity of published data for many African nations within the searched scientific databases (PubMed, Scopus), coupled with significant heterogeneity observed in the reported contaminant levels, risk assessment outcomes, study scope, and methodologies employed across the available literature, which hinders direct comparisons.

Nevertheless, several consistent themes emerge from the available evidence. For instance, toxic trace element content is typically found to be lower in muscle tissues compared to edible organs such as liver and kidney, where accumulation is more pronounced. Moreover, while meat can be a relevant source in specific dietary patterns or contaminated environments, it generally appears to be a less significant contributor to total human dietary exposure for most toxic metals compared to other major food groups like fish, seafood (including shellfish and crustaceans), or staple crops grown in polluted areas. It is clear, however, that actual concentrations and potential risks vary greatly, depending significantly on the specific geographical location, proximity to pollution sources like mines or waste sites, the animal species, the tissue consumed, and the particular element in question.

Indeed, studies conducted in specific regions, notably Nigeria, Egypt, Ghana, and Uganda, have underscored potential health concerns. These investigations highlighted instances where elevated levels of Pb, Cd, As, Cr, Ni, or Hg in certain types of meat or meat products exceeded regulatory limits or contributed to estimated intakes surpassing health-based guidance values. Such risks appear particularly relevant for vulnerable groups, such as children, or for populations engaging in frequent consumption of organ meats sourced from potentially contaminated areas. On a more positive note, the well-documented global decrease in environmental lead (Pb) contamination, largely due to regulatory actions like phasing out leaded gasoline, is expected to contribute to lower Pb levels in African food sources, including meat; however, continued monitoring is essential to confirm the extent of this trend on the continent.

Consequently, bridging the current geographical knowledge gaps through further research encompassing a wider range of African countries is crucial. Employing standardized methodologies and considering total dietary exposure patterns in future studies would greatly enhance comparability and the ability to perform comprehensive risk assessments. In the interim, continued surveillance and monitoring of toxic elements in meat—especially organ meats and products sourced from known high-risk areas—remain paramount for public health protection, particularly as meat consumption patterns continue to evolve across Africa.

Region/City	Analyzed meat/meat products	Results for the analyzed toxic elements	Remarks	References
Enugu State	muscle and edible offal (kidney, intestine and tripe) of cows	Mean Cd levels (range): 0.24-0.44 μg/g. Mean Pb levels (range) 0.09-0.26 μg/g	The highest intakes of Cd and Pb were 0.55 μg/kg bw/week (intestine), and 1.21 μg/kg bw/week (tripe), respectively.	Ihedioha and Okoye[38] [39]
Lagos and Abadan	frozen chicken (thighs and wings)	Mean concentrations: 0.0065 and 0.0078 μg/dL for Cd, and 0.0207 and 0.0227 μg/dL for Pb	The Cd and Pb concentrations were within the maximum residue levels allowed in the country.	Olusola et al.[41]
Ogun State	cattle (muscles, liver and kidney)	The mean levels of Cd in muscle, liver and kidney were: 0.156, 0.172 and 0.197 μg/g, respectively. For Pb, the mean levels were: 0.721, 0.809 and 0.908 μg/g, for muscle, liver and kidney, respectively.	The levels of Pb were higher than the standards in all bovine tissues.	Adetunji et al.[42]
Nigeria (area/region not specified)	muscle and edible offal of cows	The minimum and maximum mean levels (μg/g fw) were: 1.24 (muscle) and 4.28 (liver) for Cr, and 0.20 (liver) and 0.36 (kidney) for Ni.	The mean EDIs were 88.9 and 0.76 μg/kg bw/day, for Cr and Ni, respectively. Only the intake of Cr was higher than the recommended daily intake.	Ihedioha et al.[40]
South-West of the country	cured meat products (ham, bacon, sausages, corned beef, and luncheon)	Pb, Cr and Ni were not detected in any sample, while Cd levels ranged between 0.35 and 1.20 μg/g, in samples of corned beef and meaty sausage,	Cd concentrations exceeded the maximum allowable limit in the country	Adejumo et al.[43]

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Region/City	Analyzed meat/meat products	Results for the analyzed toxic elements	Remarks	References
		respectively, being 0.76 μg/g its mean level.		
Dareta and Abare, Zamfara State (around a lead-polluted goldmine)	goat, sheep, cattle, and chicken	The highest mean levels of Pb and Cd, were found in samples of goat and chicken (blood), with values of 7.75 and 0.32 μg/g, respectively.	According to the authors, the levels of Cd and Pb in meats of the examined area would be of concern.	Orisakwe et al.[44]
Benin City (near municipal solid waste sites)	muscle, liver, kidney and gizzard of free-range animals (chicken, cattle and goats)	The highest concentrations were 0.081 μg/g ww for As in chicken muscle, and 0.890 and 0.588 μg/g ww for Cd and Pb, respectively. the highest Hg levels corresponded to chicken liver (0.034 μg/g ww) and kidney (0.030 μg/g ww),	Potential health risks were suggested for those individuals with continuous exposure to As and Cd by consumption of contaminated meats.	Ogbomida et al.[45]
Enugu State	muscle, liver and kidney from goat carcasses	The ranges of the mean concentrations (μg/g) were the following: As, 0.45 (muscle)-0.57 (liver); Cd, 0,02 (muscle and liver)-0.06 (kidney), and Pb, 045 (liver)-0.82 (muscle)	The hazard index (HI) was < 1 for As, Cd and Pb	Njoga et al. [46]
Six areas of the Niger Delta	goat, chicken and cow	As and various metals (Cd, Cu, Hg, Pb, V and Zn) were measured in meat samples of the indicated animals'	No potential health hazards were found for Hg and V. The risk for Pb exposure was above (or close) to $BMDL_{0.1}$ for developmental	Okoye et al. [47][48]

Region/City	Analyzed meat/meat products	Results for the analyzed toxic elements	Remarks	References
		species. Numerous data were obtained and classified by age groups of the population	neurotoxicity and nephrotoxicity (intake of meats of goat and cow, respectively) in children and seniors, in the six areas included in the survey. Meat consumption also contributed to the dietary intake of As (especially for children, exceeding the $BMDL_{0.1}$) and Cd (especially in the group of adolescents)	

Table 1. A summary of studies conducted in the current century in Nigeria on the levels of toxic trace elements in edible meat and meat products.

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Conflicts of Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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