TOXIC TRACE ELEMENT POISONING IN THE REMAINS OF BRITISH NAVAL PERSONNEL INTERRED IN THE ROYAL NAVAL HOSPITAL CEMETERY AT ENGLISH HARBOUR, ANTIGUA C. 1800

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ABSTRACT

Lead exposure is thought to have affected the health of the British military stationed in the West Indies during the Napoleonic War era but the investigation of this idea has been hampered by questions of post-mortem contamination. A formerly excavated naval cemetery associated with a Royal Naval Hospital (A.D. 1793-1822) presented a good opportunity to address this question utilizing technological advances to tackle concerns about diagenesis. A previous study demonstrated that the individuals interred in the cemetery consisted of lower ranking naval personnel including enslaved laborers of African descent. Analysis of bone samples from 17 individuals showed a pattern of variable lead levels ranging from 13 to 336 ppm with a mean level of 107.5 ppm. Based on present day measures, many of these men may have had clinical lead poisoning. Although the larger project was focused on lead exposure, bulk trace element analysis revealed that one individual had high levels of another toxic compound, mercury. The implications of having variable, sometimes substan-

tially high, levels of these toxic trace elements are discussed, as well as the use of synchrotron technology to establish their biogenic nature. This study illustrates the great potential for such technology to illuminate past lifeways that might not otherwise be revealed.

RESUMEN

La exposición al plomo afectó la salud de los militares británicos estacionados en el Caribe durante la era de la guerra napoleónica. Sin embargo, la investigación de esta idea ha sido obstaculizada por preguntas sobre la contaminación durante la autopsia. Un cementerio naval previamente excavado y que se relacionó con el Hospital Naval real (1793-1822 D.C.) presentó una buena oportunidad para responder esta pregunta utilizando avances tecnológicos para abordar preocupaciones con respecto a la diagénesis. Un estudio previo demostró que los individuos enterrados en el cementerio eran de personal de bajo rango naval, incluyendo esclavos de origen africano. El análisis de las muestras óseas de 17 individuos mostró patrones de niveles variables de plomo que iban de los 13 a los 336 ppm con un nivel promedio de 107.5 ppm. Basándose en las medidas actuales, muchos de estos hombres pueden haber sufrido de envenenamiento clínico de plomo. Aunque el proyecto en general se enfocó en la exposición al plomo, el análisis de restos de elementos reveló que un individuo tenía altos niveles de otro compuesto tóxico, mercurio. Las implicaciones de tener niveles variables, y algunas veces altos, de estos elementos tóxicos serán discutidas. Asimismo, se discutirá el uso de la tecnología sincrotrón para establecer su naturaleza biogénica. Este estudio ilustra el gran potencial de dicha tecnología para iluminar sendas pasadas que no se hubieran revelado de otra manera.

RÉSUMÉ

L'impact négatif de l'exposition au plomb sur la santé de l'armée Britannique en poste dans les Antilles pendant la Guerre Napoléonienne a été suggéré, mais l'enquête de cette idée a été entravée par des questions de contamination post-mortem. Les fouilles d'un cimetière marin associé à l¢Hôpital de la Marine Royale (AD 1793-1822) ont présenté une bonne occasion d'aborder cette question en utilisant les progrès technologiques pour lutter contre des préoccupations au sujet de la diagenèse. Une étude antérieure a démontré que les individus inhumés dans le cimetière composait du personnel de la marine de rang inférieur, y compris les ouvriers esclaves d'origine Africaine. L'analyse des échantillons d'os de 17 individus ont montré un motif de niveaux de plomb variables allant de 13 à 336 ppm avec un niveau moyen de 107.5 ppm. Sur la base des présentes mesures du jour, beaucoup de ces hommes ont peut-être eu un empoisonnement clinique au plomb. Bien que la majorité du projet a porté sur l'exposition au plomb, l'analyse des oligo-éléments en vrac ont révélé qu'une personne avait des niveaux élevés d'un autre composé toxique, le mercure. Les implications d'avoir de niveaux variables et parfois considérablement élevée de ces oligo-éléments toxiques, ainsi que l'utilisation de la technologie synchrotron pour établir leur nature biogénique sont discutés. Cette étude illustre le grand potentiel de cette technologie pour éclairer les modes de vie du passé qui ne pourraient autrement pas être révélés.

The idea that lead poisoning was a contributor to ill health in the colonial British military (Buckley 1978; Curtin 1989) and civilian populations (Wedeen 1984) of the West Indies has been suggested but not yet tested. A cemetery associated with the Royal Naval Hospital that existed on a hill to the north of the harbor presented a unique opportunity to address this question, at least for the Navy. The interred at this site include both regular naval personnel and enslaved workers belonging to the Navy (Varney and Nicholson 2001). Initially this study focused solely on lead exposure but took on a greater scope when trace element analysis, that included measurement of multiple trace elements at once, revealed that a bone sample from one individual had a surprisingly high level of mercury. This paper reports on the findings to date of an ongoing investigation into the degree of toxic trace element exposure from lead (Pb) and mercury (Hg) of the individuals interred in a cemetery associated with a Royal Naval Hospital (RNH) that once served English Harbour, Antigua.

Lead poisoning has been cited as a contributing factor to poor health in both the British military and civilian populace of colonial era Antigua (Buckley 1978; Curtin 1989; Wedeen 1984). An early seventeenth century naval surgeon listed 'Dry Belly-Ache' as the third most prevalent disease plaguing the Navy in the West Indies, and he likened its symptoms to that of *'Devonshire cholic'* which was recognized by the medical profession of the time as being caused by the *'poison of lead'* (Turnbull 1806:179). While it is well known that exposure to lead in the colonial world was commonplace (Lessler 1988; McCord 1953), the extent of that exposure remains unknown.

Lead (Pb) was a pervasively used metal because it is easily worked, non-corrosive and durable. The metal was used for piping, eavesdropping, and to line containers including water catchment systems. The metal was also found in many items including eating and cooking utensils, gaming pieces, ammunition, and as a component of cosmetics and medicinal compounds. Pb was also frequently used as both a flavor and color enhancer. These latter properties meant that it was not only used for boosting paint colors, but also as an additive to food and drink. Although the toxicity of Pb had long been recognized, its usefulness seemed to have overruled its dangers, or the latter where unacknowledged in many circumstances (Waldron 1973).

Pb is a chemical element that is classified as a heavy metal, and it is highly toxic to all animals, including humans. Exposure can occur through inhalation (primarily of dust or vapors), ingestion, or absorption via skin contact. It accumulates in both soft and bony tissues, and it affects every system in the body but mainly impacts the nervous system. Acute exposure, even at lower doses, results in symptoms that include headache, joint and muscle pain, extreme fatigue, apathy, weakness in the extremities, cognitive impairment, and the distinctive severe ab-

dominal cramping from constipation (Brodkin et al. 2007; Kosnett et al. 2007). It is that last symptom that has led to many of the labels for lead poisoning (eg. various cholics and dry belly-ache). In children, growth and cognitive development are negatively affected.

In order to assess the validity of the assertion that Pb was a contributing factor to poor health in the colonial military, human remains were analyzed that had been previously excavated from a cemetery associated with the former site of a RNH that would have served English Harbour and the surrounding populace. The site is situated atop of a hill on the north end of English Harbour and was excavated from 1997 to 2001 as part of a University of Calgary archaeological field school (Nicolson & Varney 1999). The skeletal remains of a total of 31 individuals were recovered from 26 graves, ranging from infants to adults over 50yrs. The burials were remarkably consistent in simple six sided wooden coffins with ferrous nails, and very little was recovered in terms of associated funerary items or personal effects. All but one grave represented single burials, some of which had been disturbed by subsequent inhumations. All graves were very similar to one another, and there were no obvious sources of heavy metals in or near the excavated area. There was also little in terms of pathological conditions evident on the remains from a gross level examination. Only the remains of an older adolescent (16-18 yrs) and adult individuals were part of the present study and of those only 14 individuals had cranio-facial skeletons that were sufficiently intact to provide an assessment of ancestry. It became readily apparent that men of both European and African ancestry were interred at the site. This is significant as it is the only mixed ancestry cemetery known to the authors for this time period and provides a unique opportunity to shed more light on the lived experiences of the 'rank and file' of the Navy.

Previous research on this assemblage focused on the identification of geographic origin and socially defined class based on ancestry via dietary reconstruction (Varney 2011). A more recent direction of research has been investigating the lead burden of colonial Navy personnel (Swanston et al. 2012; Varney et al. 2012). To begin our exploration of the question of detecting Pb exposure during life, a preliminary study involved a novel application of synchrotron radiation. The brilliant light produced by a synchrotron increases the resolution of analyzes such as the x-ray florescence (XRF) used in this study. Two samples, one from an individual from the RNH cemetery (Burial 13) and one from an individual dating to the precontact era to serve as a control, were initially scanned with synchrotron XRF (SR-XRF) in order to map the distribution of the Pb. The preliminary results confirmed our expectations that there was indeed Pb in the historic era sample, while there was little to no detectable Pb in the precontact sample. Furthermore, the presence of the toxic element within discrete biological structures (osteons – structures consisting of concentric rings of bone - that are formed during regular

bone tissue maintenance or turnover) in higher levels than the surrounding bone tissue strongly suggested the biogenic nature of the Pb. In other words, the Pb must have been deposited during life rather than after burial due to post mortem contamination or a diagenetic origin. It is known that trace elements can be incorporated into bone from the burial environment. However, with this preliminary finding, the main challenge, to any study of trace elements in archaeological bone was overcome. The fact that the SR-XRF elemental map matched very well with conventional light microscopy images of the same samples is illustrated in Figure 1.

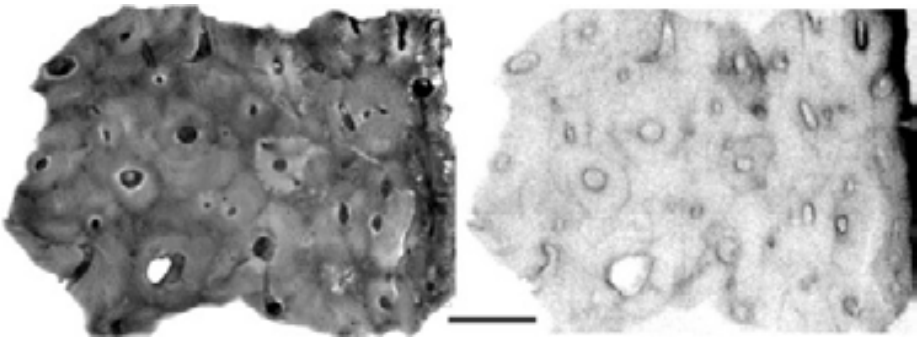

Figure 1.

With this proof of principle work completed and published (Swanston et al. 2012; Varney et al. 2012), additional bone samples have been scanned with SR-XRF revealing similar patterns in many of the individuals that were excavated from the RNH cemetery, which confirmed our preliminary findings. Figure 2 shows the SR-XRF scans for a male of African ancestry who died in his mid to late 40s with a relatively moderate Pb burden, and it is evident that the Pb is not uniformly distributed or on the outer surface of the bone as would be expected if it were present due to post-mortem contamination. Figure 2b is a scan of the Ca distribution which is uniform since it is the most common mineral found in bone. The data obtained to date is qualitative in nature, but still provides a means of mapping the distribution of the Pb, and other elements within the bone.

While further work to obtain quantifiable data from the synchrotron scans progresses, we analyzed a second sample from each individual by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This conventional means of trace element analysis detects metals at very minute concentrations, in this case parts per million (ppm). While there are some issues complicating the precise quantification of elements within bone due to its heterogeneous ionic rich composition, the data obtained with ICP-MS provided a relative measure of Pb within each sample, and a quick means of identifying those individuals

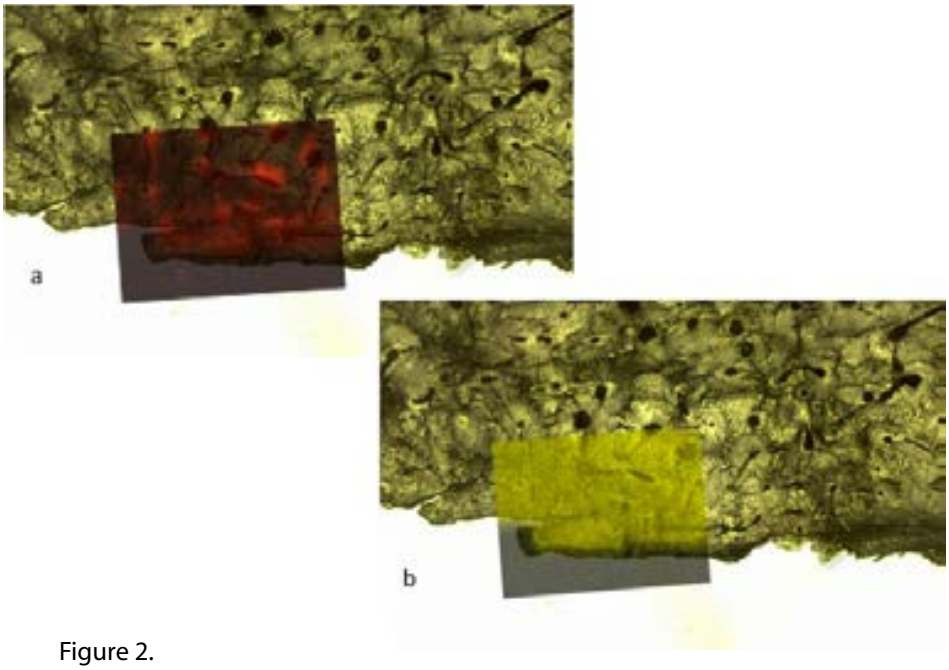

Figure 2.

with high levels of Pb in order to allow prioritization of samples for the more time intensive and expensive SR-XRF. The ICP-MS data represents a bulk or average measure of burden of Pb accumulated over the lifetime of the sample. To date, cortical bone samples from 17 of the older adolescent and adult individuals have been tested for Pb with ICP-MS yielding a mean value of 107.5ppm with a range from 13 to 336ppm. Obviously there is a fair amount of variability in Pb levels between individuals. To put these results into perspective, the 'normal' range in present day populations not exposed to occupational Pb contamination is in the range of 5-30ppm. While there is no established clinical threshold, Pb levels over 80ppm are generally associated with symptomatic lead poisoning. Using this figure as a benchmark, it could then be expected that at least 14 of the 17 individuals tested experienced at least mild Pb poisoning, with nine having high enough levels to suggest much more severe poisoning. A mild Pb burden would not necessarily be symptomatic and might remain subclinical throughout an individual's lifetime. The typical symptoms of mild Pb poisoning, headaches, fatigue, and slightly lower cognitive functioning, might seem relatively unremarkable. However, quality of life may still have been affected with even seemingly mild symptoms over the long-term.

There have only been two other studies of Pb poisoning in colonial era West Indian populations, and both have been on the remains of enslaved laborers from Newton Plantation on Barbados (Corruccini et al. 1987; Handler et al. 1986, Schrodeder et al. 2013). However, since many of the individuals interred at the RNH cemetery were not on Antigua, or even in the West Indies for more than a relatively brief time in their naval service, studies of eighteenth and nineteenth century European expeditions such as the Franklin

Expedition to the Canadian Arctic (Keenlyside et al. 1996, 1997; Kowal et al. 1989; Martin et al. 2013) and the sealing disaster at the Knapp Thordsen House in Sweden (Aasebo 2009; Kjaer et al. 2010) are also of interest for comparison. All of these aforementioned studies found comparable levels and variability of Pb using conventional means of trace element analysis. Although it may be reasonable to expect the majority of colonial era European and European-derived populations to have elevated Pb levels due to the pervasive use of Pb during that period of history, there have been good hypotheses suggested for the high levels found in these particular archaeological assemblages. All of these groups were relatively constrained in terms of ease of movement, occupation, and/or accessibility to resources. The high and variable levels found among the enslaved laborers of the Newton Plantation were attributed to exposure to Pb vapors during sugar processing and rum distillation, as well as consumption of Pb contaminated products of the sugar industry such as rum (Handler et al. 1986). The potential source of the high lead levels of European explorers has been suggested to have been the consumption of tinned food contaminated by lead solder.

The assemblage in this study predates the advent of the usage of canned foods by the Royal Navy, but one point of commonality for all of these groups is the consumption of lead contaminated alcoholic beverages, notably rum. Rum was both formally and informally distilled using lead worms (condensation coils) on stills, and it was consumed in quantity by naval personnel who were entitled and accustomed to at least their daily allotment of rum, a well established tradition in the Royal Navy that was only discontinued 43 years ago. Sailors and other naval personnel also had other sources of rum available to them. An affordable and readily available source was 'new rum' or 'low wine' (Handler et al. 1986), the first distillation product in the rum making process. It was well known for it noxious effects upon consumers.

Another potential source of exposure for some individuals may well have been medicinal treatments, and given this cemetery is associated with a hospital it is likely that they may very well have been exposed via medical treatment. In fact analysis of residue found in a broken beaker recovered from excavation of one of the hospital's middens revealed Pb as a component (Nicholson 1993). And not to be overlooked is the fact that Antigua is a dry island without natural sources of fresh water. Just as today, throughout time rainwater has been captured and stored in cisterns. These catchment systems were often made, at least in part, of Pb. It is expected that Pb contaminated water, and certainly rum, were the most probable sources of the high Pb levels found in the bones of those interred at the RNH cemetery near English Harbour, Antigua. These sources, in addition to the many others that were common in the colonial environment, may have been the tipping point to symptomatic poisoning for many of these individuals. If nothing else, even non-symptomatic Pb poisoning would have made one more susceptible to other health dangers such as infectious diseases. And even the symptoms of mild poisoning would have the potential to affects one's quality of life on a daily basis.

Future directions for this research include examining demographic patterns of Pb levels and distribution in bone, and expanding our sample to other contemporary Royal Naval and contemporary civilian assemblages in order to better understand life in the colonial West Indies.

As mentioned at the beginning of this paper, there were some interesting yet unexpected findings upon obtaining the ICP-MS data that is being further pursued. The sample from one individual had very low Pb levels but very high levels of mercury (Hg) compared to the other 16 individuals. In fact, the sample, a cortical bone (tibia) fragment from the individual interred in Burial 6, contained 94ppm Hg whereas the other samples had Hg levels ranging from 0-2ppm. A second sample was sent for analysis with similar results. This finding opened up a whole new set of questions for us. Why did this individual, who was a male of European descent between 25-29 years of age upon his death, have such high levels of Hg? And, of course, as with Pb did the Hg in his bone originate from exposure during life or did it originate from post-mortem contamination?

Hg can exist in three forms: elemental, organic, and inorganic. Elemental Hg is a heavy metal that is often referred to as quicksilver because it is a liquid at room temperature. Organic Hg occurs when it is combined with carbon to form compounds such as methyl mercury, which can be found in the food chain due to bioaccumulation from the environment. This form is most commonly known from news reports warning about contaminated fish. Inorganic Hg can be found when the element combines with a salt and forms compounds including mercury chloride and mercury sulfide. Large deposits of Hg are found in the earth as cinnabar, which is a compound of mercury and sulfur, and has been mined by people for thousands of years (Goldwater 1972). It is this latter form of Hg that was of interest in this case, as it is inorganic Hg that has often been sourced from cinnabar, and has been a common feature in medicine for a large part of human history. It was surmised that this last point might have been key to answering the question of why this individual had a high Hg level.

Burial 6 became an interesting case study. It was not distinctive from the other burials at the site. Associated artifacts included eight bone buttons found adjacent to the lower portions of the spine, and no visible exogenous sources of Hg were apparent. The skeleton itself did not reveal any osseous signs of infectious disease.

As with our investigation of Pb, the first step in addressing our questions regarding the presence of the Hg was to identify the spatial distribution of the element within the bone with high resolution in order to determine if its distribution matched that of biological features such as osteons. Again as with the Pb study, we applied a synchrotron technique, specifically SR-XRF.

The resulting scans produced a 1.5mmx1.5mm elemental map of Hg that matched with the bone histology revealing osteons that contained Hg (see Figure 3), and confirmed evidence of the biogenic uptake of the element. Thus, this individual had been exposed to Hg and it was incorporated into his bones while he was alive.

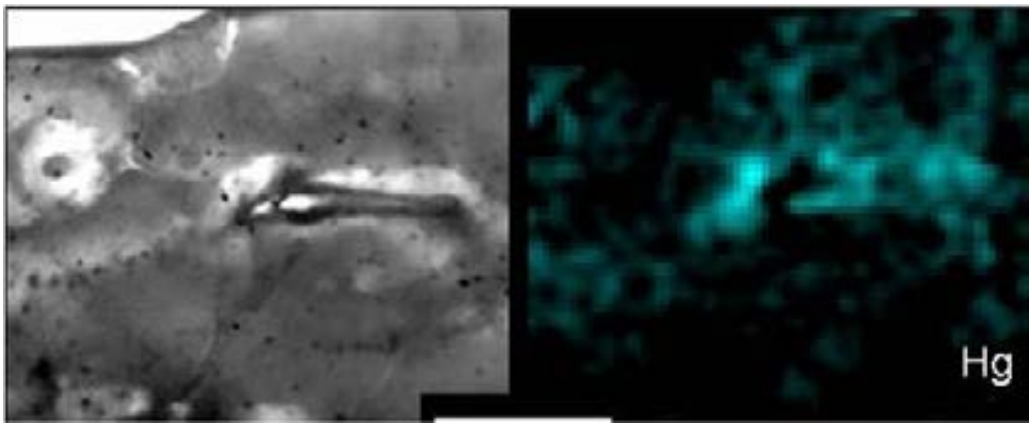

Figure 3.

The next step in determining the origin of the element was to explore the nature of the Hg itself. The sample was tested for the type of Hg by using another synchrotron technique, x-ray absorption near edge structure (XANES). Spectra for Hg containing compounds were also collected for comparison. It was determined that the Hg present in the bone sample was an inorganic mercuric sulfide.

This result made sense given the context of Burial 6 in a cemetery associated with a hospital. Mercury and mercurial compounds have long been part of medicinal treatments, and were valued for its anti-microbial and purgative qualities. The element played a large role in medicine prior to the advent of antibiotics in the 20th century. In terms of its medicinal applications, Hg is most often association with syphilis – a bacterial disease that was treated with Hg for centuries. It is from that application that the saying "A night in the arms of Venus leads to a lifetime on Mercury" arose. Although the treatment seemed to have been beneficial superficially, its overall efficacy remains unknown. However, applications of the element were certainly not limited to the treatment of syphilis. Many physicians of past centuries considered mercury and mercurial compounds to be an essential component of their practice. Throughout the seventeenth and nineteenth centuries, it was administered topically, orally, and as an inhalant in the management and treatment of a variety of aliments ranging from non-specific illnesses to yellow fever. It was a common feature of medicinal care during the 1793 yellow fever outbreak in Philadelphia after an influx of people from the West Indies to the city (Harvard University Open Collections Program). The use of orally dispensed quicksilver (mercury containing) pills is also documented to have been used for management of syphilis and yellow fever in early nineteenth century Antigua (Musgave 1827). Its purgative action was taken advantage of to purge patients' systems during the outbreak. At higher doses, those treated will secret excess saliva (salivation), and suffer hair and tooth loss. These signs are indicative of acute Hg poisoning (Habershon 1860).

The toxicity of Hg has been long known, but many physicians considered that if it was sensibly administered, it could be essential to the restoration of their patients' good health (Habershon 1860). The level of toxicity will vary depending upon the chemical form of the element. It is most toxic as a vapor with poisoning symptoms including tremors, salivation, insomnia, and memory loss. Inorganic Hg, which is the form of the element identified in this study, resides in the kidneys and will result in severe damage to those organs. A perusal of ship physicians' logbooks indicated that it was not uncommon for more than one form of mercury to be administered at the same time. In 1852 aboard the *HMS North Star*, a Dr. McCormick was both prescribing Hg containing pills and salves to one of his patients. His daily monitoring of the patient's mouth and gums belay his awareness that the early signs of mercury poisoning involved the oral cavity and its structures (McCormick 1852). It is very likely that the individual buried in Burial 6 had been treated for ill health with a mercury containing medicinal compound during lifetime, and those treatments may very well have contributed to his demise in Antigua. While this case study was limited to one individual, there is no doubt that many other patients of the colonial era were in the same situation in terms of their medicinal treatment.

In conclusion, the application of synchrotron techniques allowed for the identification of biogenic uptake of two toxic heavy metals. Both the larger investigation of Pb, and the case study involving Hg, showcase the exciting new opportunities that synchrotron radiation imaging present for the fields of paleopathology and bioarchaeology.

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