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A SIMPLE METHOD FOR DIFFERENTIATING HAZARDOUS FROM NON-HAZARDOUS SOLID MEDICAL WASTE CONTAMINATED WITH PATHOGENS

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ABSTRACT
Solid medical waste generated during patient care and contaminated with pathogens is generally classified as hazardous. It must be managed in accordance with a strict legal framework, including special packaging and mandatory destruction by incineration. In this paper, we focus on the potential health impact of this medical waste on employees who handle it. Using a simple algorithm based on pathogen properties, we describe a flexible method for distinguishing hazardous from non-hazardous medical waste and conclude on the risk to employees. The procedure involves constructing a two-dimensional coordinate system, where the x-axis represents the WHO scoring system, ranging from I to IV for disease severity and where the y-axis represents a quantitative score for pathogenicity. This score is obtained by answering and quantifying a sequence of questions, only if the pathogen survives outside the host: transmission of the disease linked to the pathogen through body fluids, mode of entry into a potential victim, and infectious dose. The resulting coordinates of each pathogen enable an objective assessment of its risk to waste handlers. By applying rational threshold values, the approach allows for data-driven classification of waste as either equivalent to household waste or genuinely hazardous. Implementing this method could significantly reduce the volume of hazardous waste without compromising the health of waste handlers.

1. INTRODUCTION

Many established operational protocols in the healthcare sector were severely challenged during and after the COVID-19 pandemic. Even in countries with highly developed healthcare systems, which are usually of excellent quality, the systems were unprepared for the massive influx of COVID-19 patients and nearly collapsed (Blumenthal, Fowler, Abrams, & Collins, 2020; Filip, Puscaselu, Anchidin-Norocel, Dimian, & Savage, 2022; Sachs et al., 2022). Likewise, the pandemic exposed severe weaknesses in medical waste management systems, particularly regarding the volume of pathogen-contaminated waste in hospitals (Anand et al., 2022; Fraeyman et al., 2022; Kanwar et al., 2023). Alarming reports contributed to a panic-like mindset among many people, and waste management was not guided by rational approaches. It was concluded that waste management systems needed to be adapted (Ranjbari et al., 2022), even beyond the exceptional conditions of a pandemic. The WHO explicitly stated that there is "an urgent need to improve waste management systems" (https://www.who.int/news/item/01-02-2022-tonnes-of-covid-19-health-care-waste-expose-urgent-need-to-improve-waste-management-systems). Concerns over health issues related to medical waste management were extended to municipal waste, as waste produced through home healthcare could also pose a risk to waste handlers (Wankhede & Wanjari, 2021).

Medical waste is an enigmatic waste stream. Compared to the volume of household waste, it is negligible and accounts for only 1-3% of the total hazardous waste volume. However, medical waste carries an image of danger due to the presence of medical devices (sharps) and bodily fluids, such as blood or urine, which may be contaminated with infectious pathogens. It has an ethical component, suffice to refer to amputated limbs, preterm born dead babies, placentas or lumps of tissues, eventually cancerous, handled as waste. All this has led to a simple distinction between non-patient hospital waste, comparable to house-

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hold waste, and patient-related waste, which, as a whole, is considered hazardous. Both types of medical waste are incinerated by law; the main difference between them is the type of containers or plastic bags used for transport or collection, as well as the cost of destruction.

According to European regulations, solid medical waste is classified as either non-hazardous (EWC/Eural code 180104) or hazardous/contagious (EWC/Eural code 180103*), requiring specific UN3291-certified containers for collection and transportation.

There is general agreement that approximately 80% of hospital waste is indistinguishable from household waste, while about 20% is hazardous. One of the earliest mentions appears in the WHO Blue Book (1999), with additional references in sources such as Eker & Bilgili (Eker and Bilgili, 2011). This figure is reiterated in the second edition of the Blue Book (2013), on the WHO website in 2018 (https://www.who.int/news-room/fact-sheets/detail/health-care-waste), and is cited in reputable documents such as the United Nations General Assembly report of 2011 (https://www2.ohchr.org/english/bodies/hrcouncil/docs/18session/a-hrc-18-31_en.pdf), the Red Cross report of 2011 (https://www.icrc.org/en/doc/assets/files/publications/icrc-002-4032.pdf), and in almost all scientific literature (Janik-Karpinska et al., 2023).

Waste containing used needles or sharps, certain toxic pharmaceutical compounds such as cytostatics and biologicals, as well as ambulatory radioactive tracers, is unequivocally classified as hazardous. However, the classification of waste generated through daily medical care of patients infected with pathogens is less clear. The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) includes a "list A" of pathogens considered hazardous that require special precautions for handling, storage, etc. For all other pathogens not on "list A", there are no specific regulations to determine whether waste from handling patients infected with these pathogens is hazardous; decisions on this are often based on gut feeling (Janik-Karpinska et al., 2023). In practice, waste from these "non-list A" pathogens is almost always regarded as hazardous by default. The question remains whether this assumption is justified and supported by scientific evidence.

In this manuscript, we examine the risks associated with individuals handling medical waste produced in hospitals during the diagnosis, treatment, and daily care of patients with infectious diseases. We outline a semi-quantitative approach based on known pathogen characteristics, using a straightforward algorithm to enable an objective decision on whether this waste should be classified as hazardous. As a result, guidelines for selecting and handling the waste can be adjusted accordingly.

2. METHODOLOGY

2.1 People at risk

This paper focuses on the people who handle medical waste in a hospital setting, excluding healthcare workers directly involved in patient care (see assumptions). It includes: (1) hospital employees who collect waste from the ward and transport it to the central storage area on campus; (2) personnel responsible for preparing the waste for transport, which involves stacking UN-certified bins and compacting plastic bags containing medical waste in waste compactors; (3) drivers who transport the waste from the hospital to incineration plants; (4) (eventually) employees at the incineration plants who handle the waste; and (5) (eventually) employees at the plant who analyze the waste before incineration. This manuscript does not consider individuals who collect household waste.

2.2 Assumptions

The methodology is feasible provided the following assumptions are met. (1) The individuals involved (see "People at risk") are in good health. Those with weakened immunity, for example, due to medical interventions, are not permitted to perform this task. (2) The individuals involved have access to suitable personal protective equipment, including gloves, aprons, masks, and other necessary items. The responsible managers within the hospital are aware of the importance of using these materials. (3) In case of accidents involving waste, such as during transport, or leakage from the containers due to incorrect filling or sealing of UN-certified containers, it is assumed that the organization has an appropriate protocol to manage the consequences of such incidents, in addition to standard waste handling procedures. (4) The procedure for collecting and sorting solid waste at the patient's bed has been established, is known to the relevant staff, and is subjected to strict oversight. (5) Typically, healthcare personnel (nurses, aides, paramedics) collect waste from patients' rooms and transport it to a designated temporary storage area. The waste is then collected by other employees not involved in direct patient care. The staff handling waste in the hospital do not enter the room of the patient, consequently, direct infection with airborne pathogens from patients is avoided. The likelihood of waste handlers being directly infected by patients is considered very low, if not zero.

2.3 Risk analysis

The risk for waste handlers to come into contact with, for example, blood was calculated using the following model. Hazardous waste is collected in UN3291-designated bins, which are sealed when properly closed and remain sealed irreversibly. The bin and its contents are incinerated without opening. In daily practice, we observe that not all bins are correctly closed; therefore, assuming body fluids such as blood are present in the bin, and considering that during handling, the bin might fall on its side, blood or other bodily fluids could leak out and potentially infect the waste handler. An unannounced count was conducted over 10 working days at a university hospital to determine the total number of UN3291 bins and the number that were not correctly closed. On average, 164 ± 45 bins were observed per day, with 1.7 ± 1 not properly closed—about 1% of the total bins. Recalculation of the total number of hospital beds and the average bed occupancy suggests that, assuming all bins could contain waste from infected patients (worst-case scenario), roughly one bin every two working days could pose an infection risk to handlers. Under these cautious assumptions, the risk of handler infection from improperly closed bins remains low but is not zero. Wearing protective gear, especially suitable gloves, helps minimize exposure, making the risk very low and nearly negligible.

2.4 Legal obligations

Within Europe, the legal obligations related to waste management are summarized in https://eur-lex.europa.eu/EN/legal-content/summary/eu-waste-management-law.html. These obligations include rules for collecting the waste, separating different streams of waste (e.g., sharps, cytostatic drugs, etc), storage in the appropriate containers with specified UN numbers and incineration in a certified plant as the only valid destruction method. The implementation of EU rules may vary slightly among EU countries, but the general layout remains very similar (Mahnik, Hoffmann, Fraeyman, & Komilis, 2023).

2.5 Definition of pathogens, commensals as pathogens

Pathogens are (micro)organisms that can cause disease in humans and/or animals and include viruses, bacteria, fungi, various parasites, and prions (Mims et al., 2004). The bacteria in the enteric system, the microbiome, defined as commensals, do not cause diseases in everyday situations but might become (opportunistic) pathogenic in less favourable conditions, such as increased vulnerability due to e.g. reduced immunity after organ transplantation or during intensive cytostatic drug treatment (Athanasopoulou, Adamopoulos, & Scorilas, 2023; Sorboni, Moghaddam, Jafarzadeh-Esfehani, & Soleimanpour, 2022). As a consequence, commensals present in regular waste are harmless but may pose a danger to workers handling the waste if those workers are immunocompromised. As described in “assumptions”, these types of employees are not accepted to do the work.

2.6 Operational definition of pathogens, construction of the algorithm

Generally, pathogens are identified based on their pathogenicity and virulence. Pathogenicity is the capacity to cause disease; it is a dichotomous variable, meaning it has only two possible outcomes: yes or no. Virulence is a continuous variable that quantifies a pathogen’s degree of pathogenicity (Shapiro-Ilan, Fuxa, Lacey, Onstad, & Kaya, 2005). Among the properties contributing to virulence are cell attachment, survival within and outside the host, the infective dose, and resistance to immune attacks, among others. See also https://www.nature.com/scitable/topicpage/pathogenicity-microbial-virulence-763161/ and http://www.differencebetween.net/category/science/health/. (Leggett, Cornwallis, Buckling, & West, 2017; Martinez, 2014; Schmid-Hempel & Frank, 2007).

The operational definition used in this manuscript, referred to as pathogenicity, comprises two variables: the disease associated with the pathogen and an estimate of the risk that waste handlers will contract the disease.

For the disease parameter, the WHO classification on severity of diseases was chosen: class I: no to minimal body burden, class II: a distinct disease with measurable body burden and with evidence-based cure, class III, a severe disease with heavy body burden and with evidence-based cure and class IV, deadly disease with no or hardly any effective treatment.

The risk approximation is a tiered assessment. The first question is whether the pathogen is viable outside the host. If the answer is “yes”, three consecutive variables: transmission mode, body entry, and infectious dose, as described for the pathogen, were further quantified using an arbitrary score ; the scoring system’s numeric values are shown in Table 1.

Comments to Table 1:

A. The pathogen could spread via aerogenic transmission, but direct infection of waste handlers through contact with the patients is unlikely (see methodology). The possibility of infection is nevertheless retained through indirect contact between waste handlers and, e.g. nurses.
B. The possibility of formation of fomites, i.e. biofilms on the surfaces of inanimate recipients such as cell phones, doorknobs, keyboard, tables….) has been described. If these objects are disposed of as medical waste, this might pose an increased risk, since the waste Handlers might come into contact with them.
C. The pathogen could spread through contact of the skin with blood. The risk analysis (see methods) concludes that the risk is non-relevant. Depending on the institutional organization (e.g. presence or absence of disas-

TABLE 1: Scoring system for pathogen calculation. nr: not relevant.

pathogen characteristics		arbitrary score	comment	max. value
Mode of transmission	aerogenic	2	A	2
	fomites	1 or 2	B	2
	body liquids	nr		
Body entry	skin	2	C	2
	others	nr	D	
Infection dose	<100 particles	4	E	4
	100-10000 particles	2	F	
	> 10000 particles	1	G	

ter treatment protocols – see assumptions), a value of 2 is acceptable.

D. The spread of the pathogen through other body fluids (salivary or oral), having a possible effect on waste handlers, is considered non-relevant
E. The lowest infective dose is the most contagious and gets the highest score
F. The intermediate value represents intermediate infectivity
G. The lowest score represents the highest infective dose and weakest infectivity

The final score is obtained by multiplying all variables mentioned in Table 1. In case the pathogen survives outside the patient, a score can be calculated:

The score is calculated as A * B * C x E (or * F or * G).
Max. Score is A(=2) * B(=2) * C(=2) * E(=4) = 32

Based on the procedure and the numerical values shown in Table 1, a pathogenicity score is obtained for each pathogen. This value constitutes the y-axis in a Coordinate system. The x-as in this system is the WHO class for the particular pathogen. The result is presented in Figure 1.

Theoretically, four zones can be distinguished in Figure 1: zones A and B on the left side of the graph represent relatively mild diseases for which evidence-based treatments are available (eventually including vaccination), while zones C and D stand for serious, potentially deadly diseases. Conversely, zones A and C indicate low pathogenicity, while zones B and D indicate highly infectious pathogens. The (x-y) coordinates of each pathogen allow the positioning of the pathogen in zones A, B, C, or D. The grey zone for pathogenicity indicates the possibility of choosing the boundary between low and high pathogenicity (see discussion).

Pathogens included in the ADR regulation's A-list, as well as those capable of causing diseases in WHO class IV, are consistently regarded as hazardous. Their calculated pathogenicity values according to the algorithm are sufficiently high to place them within zone D of the coordinate system. In situations where empirical data are unavailable or pathogens are unidentified, a worst-case assessment is applied, assigning them to zone D.

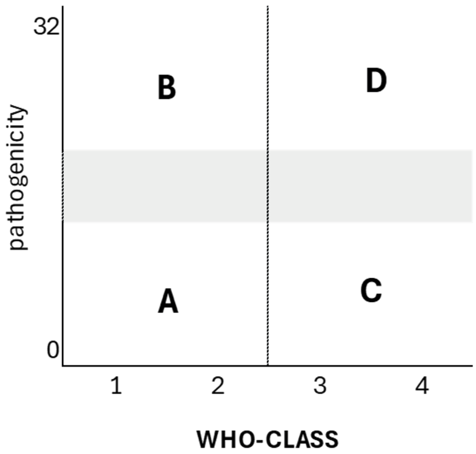

FIGURE 1: Matrix for pathogenicity allocation. WHO-class 1, 2, 3 and 4 correspond to disease severity as defined by the WHO; this is explained in the text.

3. RESULTS

The entire procedure is illustrated for two pathogens that have recently caused concern: the coronavirus (Table 2) and the monkeypox virus (Table 3).

3.1 Coronavirus

Fraeyman et al. (2022) demonstrated that survival duration varies by author. Fraeyman et al. (2022) found no viral particles on hospital solid materials relevant to solid medical waste. Other literature reports the presence of fomites on various hospital materials. Here, we assume the "worst-case principle" and consider the virus viable outside the host. Hence, pathogenicity can be calculated.

Comment to Table 2:

The table illustrates how literature data are utilized to finalize the risk analysis and construct the algorithm. The

TABLE 2: Variables related to the COVID-19 virus. Data are obtained from WHO (https://www.who.int/news-room/fact-sheets/detail/coronavirus-disease-(covid-19)) and the Mayo Clinic (https://www.mayoclinic.org/diseases-conditions/coronavirus/symptoms-causes/syc-20479963).

Variable	Rationale	Score	
Transmission	The well-documented aerogenic transmission of the virus is relevant for healthcare workers who come into close contact with patients, but not for waste handlers. The possibility of fomite transmission remains, although it is considered a low risk. Here, we assume the "worst-case principle" and consider the virus viable outside the host. Infection through blood contact or other body fluids is considered as less important.	2	
Entry into the victim	The only relevant entry route is through the skin, whether or not damaged. The worst-case scenario, i.e. contact with blood from patients, is retained. Other possible entry routes are considered irrelevant, as discussed in Table 1.	2	
Infection dose	In one paper, the infective dose, expressed as particles, is reported to be between 300 and 2000, which, according to the authors, is comparable to the infective dose of influenza (Prentiss, Chu, & Berggren, 2022). Both figures are retained, resulting in a double score. Score for low infectivity Score for high infectivity	2	4
Total score		**8**	**16**

TABLE 3: Variables related to the monkeypox virus. Data were obtained from the WHO (https://www.who.int/news-room/questions-and-answers/item/monkeypox) and from CDC (https://www.cdc.gov/poxvirus/mpox/if-sick/transmission.html). nr: not relevant.

Variable	Rationale	Score	
Transmission	Infection usually occurs through the bite of an infected animal or after close contact with the animal's blood or body fluids of patients. Human-to-human transmission happens via aerosolization or contact with the patient's skin lesions. Transmission via fomites is possible but considered less likely. During the 2022 outbreak, the virus was mainly spread through sexual contact. These transmission routes are not relevant to the management of solid medical waste. Transmission via blood contact is possible but less relevant. Transmission through other body fluids are not relevant.	nr	
Entry into the victim	The only relevant entry route is through the skin, whether or not damaged. The worst-case scenario, i.e. contact with blood from patients, is retained. Other possible entry routes are considered irrelevant, as discussed in Table 1.	2	
Infection dose	The infective dose for humans is unknown. The infective dose in animals using the Congo Basin monkeypox virus is from 100 to 10.000 particles. Two figures for infectivity are retained leading to the double score. Score for low infectivity Score for high infectivity	2	4
Total score		**4**	**8**

information for some variables is disparate. In this case, the worst-case scenario (fomites) is chosen, or both possibilities are retained (infective dose), leading to two possible total scores: 2*2*2 or 2*2*4.

3.2 Monkeypox virus

Similar to the result with the coronavirus: two infectivity-dose scores are retained, leading to two possible total scores: 2*2 or 2*4.

The same reasoning was applied to a large number of bacteria, viruses, moulds, and fungi. The numeric values for viruses and bacteria are provided in the Additional Results section. A representative example of viruses is shown in Figure 2. The Figure is intended for illustrative purposes only; not all viruses are shown due to layout constraints.

Nearly all viruses listed in ADR list A are located in zone D of the Figure, indicating that the corresponding diseases are severe and highly pathogenic.

4. DISCUSSION

To the best of our knowledge, we present the first rational approach to an objective and usable judgment of the risk for disease transmission of a pathogen when present in medical waste. Thomas and Elkinton (Thomas & Elkinton, 2004) attempted to quantify virulence using LD50 or

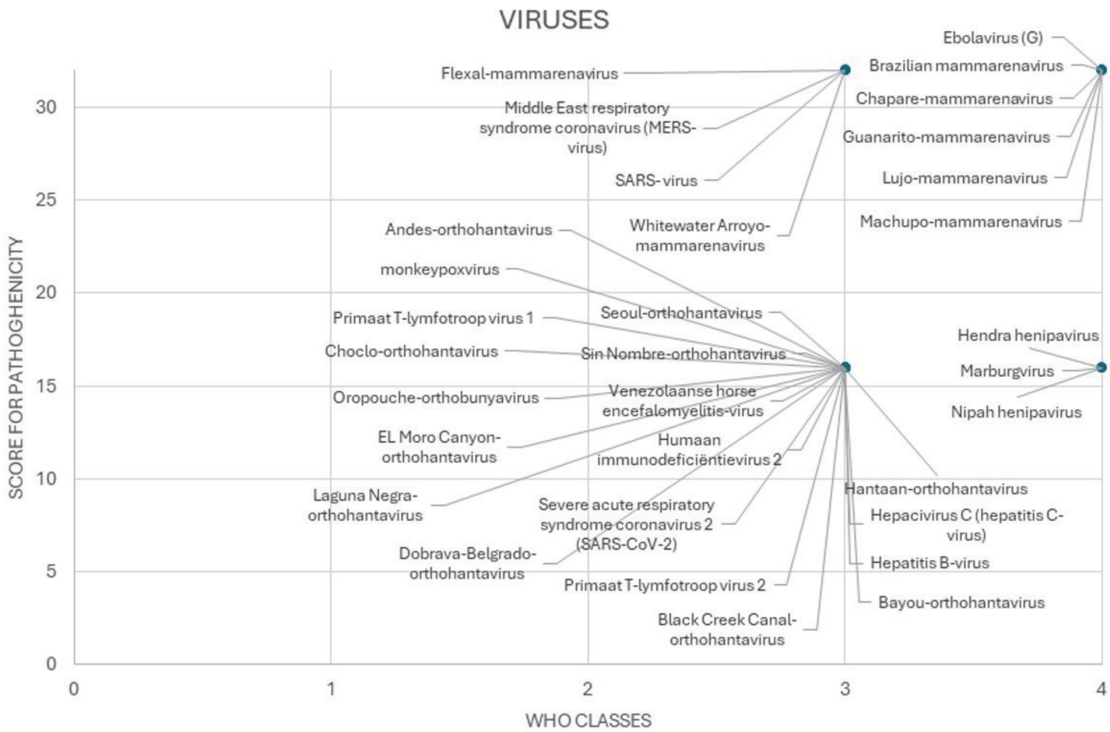

FIGURE 2: Matrix for viruses. WHO classes refer to diseases as explained in the text. Score for pathogenicity is calculated according to the algorithm shown in Table 1.

LC50-values in invertebrates as a criterion, and although these values are valuable in characterizing the pathogen, it is not helpful in the context of waste management. To translate our reasoning into practice, we adopted an operational definition of a pathogen that combines its biological properties with the disease it causes upon infection. This resulted in a representative figure for each pathogen and its position in a two-dimensional coordinate system. From this, some decisions for waste management are possible.

The figures in Table 1 reflect the authors' interpretations and are illustrative rather than definitive. For example, the weight of the infection dose in the algorithm is considered more significant than the mode of entry into the body, since if waste handlers correctly use their protective equipment (i.e., gloves) and the waste is stored appropriately, infection through the skin is virtually impossible. Similarly, the theoretical division of the four zones in Figure 1 is arbitrary. We classified diseases in Classes I and II as minor, easily treatable, and often vaccine-preventable. Conversely, diseases in Class III and definitely Class IV are regarded as severe and difficult to treat. Furthermore, the risk assessment that defines zones B/C and A/D, representing low and high infection potential, respectively, is arbitrary. Any decision about the risk to waste handlers depends on the chosen thresholds; in our model, pathogens with x-y coordinates corresponding to zones A, B, and C are deemed non-hazardous. The advantage of our system is that any responsible waste management professional in a hospital may adjust these thresholds according to their own judgment. For instance, the boundary between diseases of type II and III could be shifted to that between types I and II and the possibility of choosing a discriminating level of pathogenicity is illustrated by the grey zone in Figure 1. Clearly, any choice will affect the volume of medical waste and the procedures for handling it. All pathogens on list A in ADR are located in zone D of the x-y coordinate system, which is compatible with the legal requirements.

The algorithm uses data from the scientific literature, i.e., peer-reviewed papers or generally accepted and scrutinized databases. However, this information is not available for all pathogens. When information is insufficient or an unknown pathogen is involved, the precautionary principle applies, and a worst-case scenario is assumed.

The key point in this discussion is that the way a pathogen is transmitted during daily bedside patient care differs from its transmission during the handling of solid waste by waste handlers. Several examples clearly demonstrate this distinction. Malaria is caused by a mosquito bite, but the malaria patient cannot spread the parasite to bystanders, except through blood transfusion, organ donation, or from mother to baby during birth. These transmission routes are not relevant for waste handling. The virus responsible for severe diseases like dengue and Zika can be transmitted through blood contact in patients, but this is less significant during waste handling, as discussed in the "risk analysis" section. A pathogen with limited ability to survive outside the body, such as Rickettsia, may infect the healthcare worker treating the patient, but is unlikely to pose a risk to waste handlers, although the WHO classifies the diseases caused by such infections as class III. Complex transmission routes are also possible; for example, the Coronavirus can survive outside the body as a fomite on materials that waste handlers might come into contact with (Fraeyman et al., 2022). Therefore, it is essential to consider not only the properties of the pathogen but also to conduct a thorough risk analysis to identify potential adverse effects.

5. CONCLUSIONS

Taken together, adopting the highest standard of safety for pathogens in solid medical waste would mean treating all waste as if it were hazardous, and this is unnecessary. The authors' opinion is that the discussion should strike a balance between safety, ecological, and economic benefits. The method outlined in this document at least provides a framework for considering how to reduce the approximately 80% of medical waste that is incorrectly regarded as hazardous. In cases of uncertainty, safe solutions have to be chosen.

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