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ORIGINAL ARTICLE

# Geographic access to radiotherapy in Mexico

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## Abstract

**Background:** *No previous study has mapped the population's geographical access to radiotherapy (RT) services in Mexico.* **Objectives:** *To understand where communities are relative to RT centers, as it is key to identify where new services would have the largest impact.* **Method:** *Data from the 2020 census and the IAEA's DIRAC were combined to map access to RT. The road distance from the municipality to the nearest RT clinic was used to identify how geographic access varies across the country. Municipalities were categorized by distance, and a map was created to visualize them.* **Results:** *In Mexico, 32% of the population can access RT services locally while 23.38% must travel ≥ 100 km; for brachytherapy, 28.57% can access it locally, and 30.19% must travel ≥ 100 km. The southwest region – Oaxaca, Chiapas, and Guerrero – is the most underserved in the country.* **Conclusion:** *Geography is a major barrier to RT in Mexico: an estimated 30 million people face challenges accessing RT due to distance. The estimates presented in this paper are likely optimistic, but are a tool for prioritizing new services.*

**Keywords:** *Radiotherapy. Geography. Health services accessibility. Mexico.*

## *Acceso geográfico a la radioterapia en México*

## Resumen

**Antecedentes:** *Ningún estudio previo ha mapeado la distribución del acceso geográfico de la población a la radioterapia en México.* **Objetivo:** *Comprender dónde se encuentran las comunidades en relación con los centros de radioterapia, para identificar dónde tendrían el mayor impacto los nuevos servicios.* **Método:** *Se combinaron datos del censo del 2020 y de DIRAC del OIEA para mapear el acceso a la radioterapia. La distancia por carretera del municipio hasta la clínica de radioterapia más cercana se usó para identificar cómo la accesibilidad varía en el país. Los municipios se categorizaron según la distancia y se elaboró un mapa para su visualización.* **Resultados:** *En México, el 32.04% de la población del país puede acceder a radioterapia localmente, mientras que un 23.38% debe viajar ≥ 100 km; para acceder a braquiterapia, el 28.57% puede acceder localmente y el 30.19% debe viajar ≥ 100 km.* **Conclusión:** *La geografía es una barrera considerable al acceso a la radioterapia en México: aproximadamente 30 millones de personas enfrentan dificultades para acceder a la radioterapia por la distancia. Las estimaciones presentadas en este artículo probablemente sean optimistas, pero son una herramienta para la priorización de nuevos servicios.*

**Palabras clave:** *Radioterapia. Geografía. Accesibilidad a los servicios de salud. México.*

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## Introduction

Distance has been consistently identified as an important barrier to cancer treatment[1-4]. A single radiotherapy (RT) session usually takes < 30 min, but treatment can range from as little as one session to as many as five per week for 10 weeks. For people who live far away, every session means: driving for hours, staying all day in an unfamiliar city, and neglecting other responsibilities.

In 2022, Mexico had over 200,000 new cases of cancer and 96,000 deaths related to it. The most common types were prostate, breast, colorectal, thyroid, and cervical[5]. It is estimated that about half of all cancer patients will need RT at some point during treatment[6,7]. Meeting this demand is a question not only of resources but of distribution.

Mexico's tertiary healthcare has typically been clustered around the largest cities in each state and, even more so, around Mexico City. This centralization of healthcare restricts access to specialized services for those who do not live in those cities; something similar happens in radiation oncology.

This paper examines the geographic distribution of RT services in Mexico: where the clinics are and how far would a patient need to travel to receive care. Understanding the general distribution of people and RT centers could help identify regions where a new clinic or expansion of existing services would have the biggest impact.

## Materials and methods

I conducted an observational, cross-sectional geospatial analysis to examine the geographic distribution of RT services in Mexico and patient access to them. This study was reported in accordance with the STROBE guidelines[8].

This study is a geographic analysis of the distribution of RT services in Mexico, intended as a tool to inform policy interventions. For this reason, this analysis is primarily descriptive.

### *Population and RT facilities data*

The population data of the 2020 census were extracted from the consultation system of the National Institute of Statistics and Geography of Mexico (INEGI)[9]. For each state, the following information was obtained: the names of all the municipalities, the population of each municipality, and the coordinates of the centroid of the municipal seat.

Mexico has 2,478 municipalities; the study analyzed 2,453 municipalities, excluding the 16 boroughs of Mexico City and 9 municipalities established after 2020.

Mexico City is a special case: while not technically a state, it functions as one. In this paper, it is modeled as a single "municipality," since its boroughs are concentrated in a small geographical area, and it houses almost 20% of the RT clinics in the country. This means a resident of Mexico City is never considerably far from a RT clinic.

The International Atomic Energy Agency (IAEA) keeps a database of RT resources called the Directory of RT Centers (DIRAC)[10]. Information from this directory was retrieved to establish which cities have external beam RT (EBRT) and brachytherapy capabilities. A web search to determine whether the center is public or private was done.

### *Distance measurement and visualization*

Three approaches were considered to calculate the distances between the municipalities and the RT centers: great-circle distance, the straight-line distance between two points on a 3D sphere; Euclidean distance, the straight-line distance between two points on a 2D map; and real road distance.

Great-circle distance considers the curvature of the Earth. For small distances, the difference between great-circle and Euclidean distance is minimal – the largest distances in this study are around 400 km. The average percent error of the Euclidean distance is 0.18% (standard deviation [SD] = 0.02%), indicating that, for the purpose of this study, there is no difference in using either distance.

A paper published in 2012 suggests that Euclidean distance is a good predictor of real travel in the United States[11]. No similar study for Mexico was identified, so the same conclusions could not be applied. Mexico has a higher terrain ruggedness index, a measure of the change in elevation across the landscape[12]; uneven terrain and the lack of a previous study mean neither Euclidean nor great-circle distance could be relied on blindly.

For each municipality, great-circle and Euclidean distances were calculated from the centroid of its municipal seat to the nearest municipality with a RT center. Each municipality was assigned the nearest RT clinic based on the minimum distance. To account for real-road variation and geography, all other eligible municipalities within 20 km of that result were also recorded. Sensitivity checks showed some variation between 10 and 20 km, but no variation between 20 and 30 km. This analysis was made using the PANDAS library in Python[13].

Real road distances were manually obtained using Google Maps, and the shortest distance was selected and rounded to the nearest integer[14]. The municipalities were categorized by distance to the nearest service: 0 km, where the clinic is within the municipality; < 25 km, usually in the outskirts or in the same metropolitan area; ≥ 25 km and < 50 km; ≥ 50 km and < 100 km; ≥ 100 km and < 200 km; and ≥ 200 km. These categories were visualized in choropleth maps created with Mapchart.net (Fig. 1).

The dataset containing distances and their categories was used primarily as a descriptive tool. Descriptive statistics – mean, median, range, outliers – were calculated using Excel. Variations across Mexico's eight main regions were assessed with a $\chi^2$ test, and population proportions were calculated with 95% confidence intervals (CIs).

The same procedure was repeated with the nearest clinic that offers brachytherapy. An overview of the analytical workflow has been provided as Supplementary figure 1.

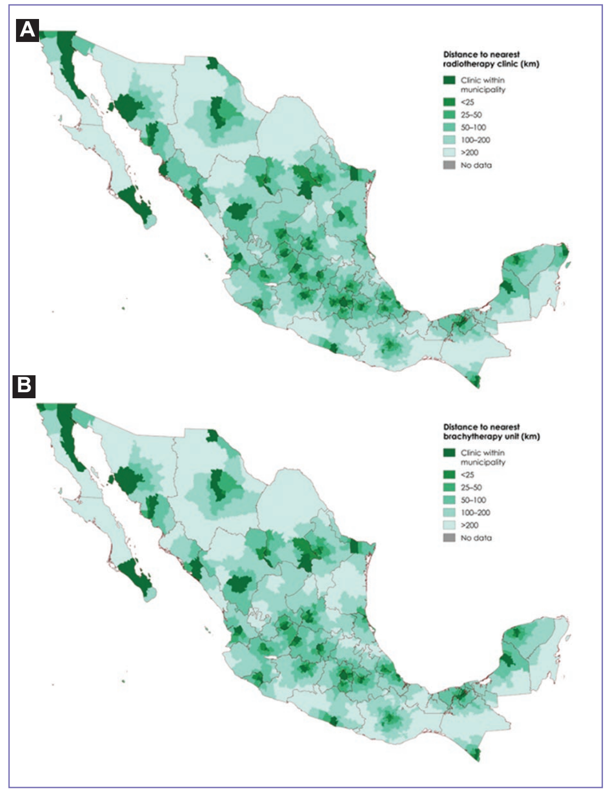


**Figure 1.** Geographic distribution of radiotherapy clinics in Mexico. Municipalities are colored according to the road distance from the centroid of each municipal seat to the nearest radiotherapy center. **A:** centers that offer external beam radiotherapy. **B:** centers that offer brachytherapy. *Maps generated with MapChart (mapchart.net), used under CC BY-SA 4.0.*

## *Complementary regional overview*

A visual analysis of the access maps (Fig. 1) showed clusters of municipalities with low geographic access (distance > 200 km). The clusters were manually defined from continuous groupings of ≥ 3 municipalities. Cross-border clusters were permitted; however, the largest one – encompassing eastern Oaxaca and all central Chiapas – was separated in two. Populations were obtained from the EBRT dataset. The five most populated clusters were selected for visualization (Fig. 2). A repeat of the analysis using the brachytherapy subset showed no differences in the selection.

## Results

In Mexico, there are 114 radiation oncology clinics registered in the IAEA's DIRAC database, housed in 44 municipalities. Sixty of these clinics (53%) are public. At the time of writing this paper, Tlaxcala was the only state in the country without any RT facilities.

Geographic access to RT was assessed by calculating the real driving distance from 2,453 municipalities to the nearest clinic that offers EBRT. The median distance, weighted by population, was 28 km (interquartile range: 0-94 km; range: 0-551 km). The average distance, also weighted by population, was 63.38 km. Two municipalities, totaling 4,000 people, had no road information available.

The choice of real drive distance over Euclidean was supported by the data: the mean of the detour index, the ratio of real to straight-line distance, is 1.47 (SD = 0.35). On average, real routes were 47% longer than what the straight-line distance suggested, with 79% of observations being within one SD (12-82% longer).

The distances were grouped into six categories (Table 1). Overall, 32.04% of Mexico's population lives in a municipality with an RT facility (distance = 0 km, 95% CI: 32.03-32.05%). Population access is shown in a choropleth map, with municipalities colored by distance category (Fig. 1A).

Using cumulative distance thresholds, 61.05% (95% CI: 61.04-61.06%) of the population lives within 50 km of the nearest RT facility, and 76.61% (95% CI:

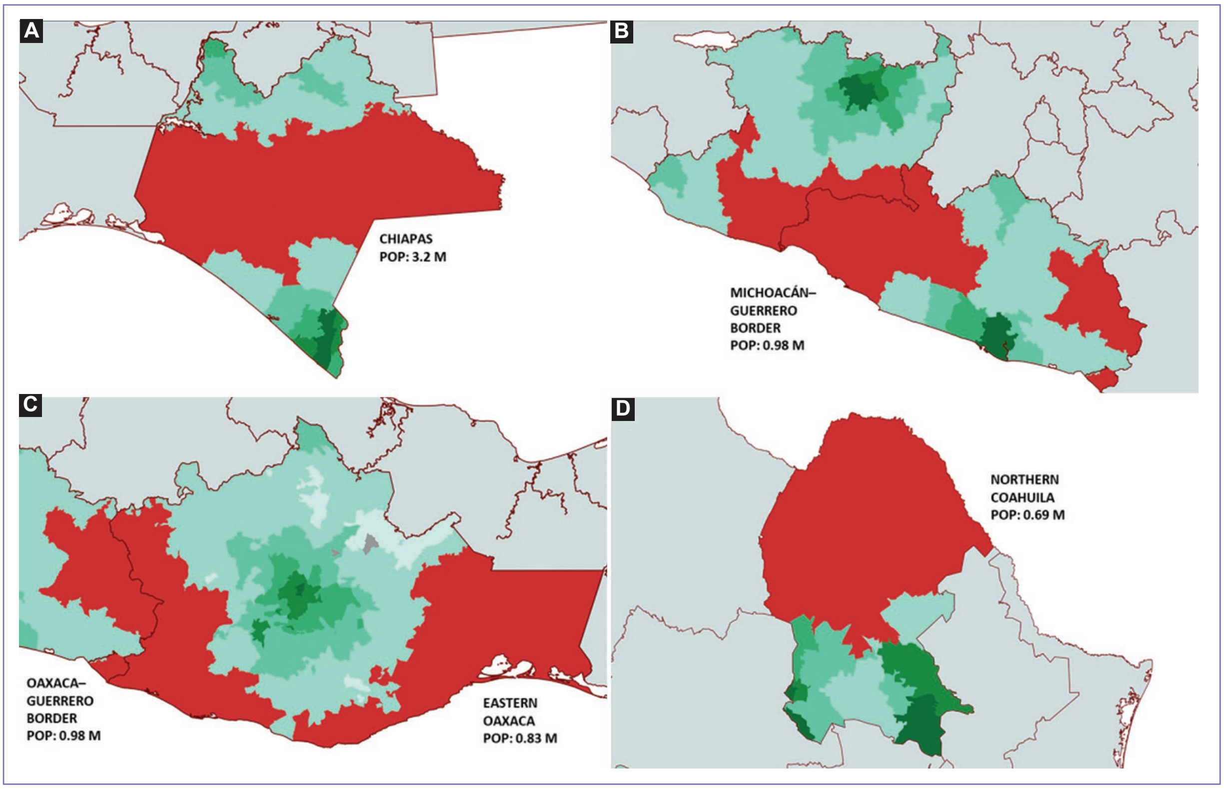


**Figure 2.** The most populated contiguous clusters (≥ 3 municipalities) located > 200 km from the nearest radiotherapy clinic in Mexico; colored in red, with total population estimates indicated. **A:** Chiapas. **B:** Michoacán-Guerrero border region. **C:** Oaxaca-Guerrero border (left) and eastern Oaxaca (right). **D:** Coahuila. *Maps generated with MapChart (mapchart.net), used under CC BY-SA 4.0.*

**Table 1.** Population distribution by distance to the nearest RT center for EBRT and brachytherapy

| Distance to nearest RT center | EBRT (n = 126,002,677) (%) | Brachytherapy (n = 126,002,677) (%) |
|---|---|---|
| 0 km (within municipality) | 40,371,484 (32.04) | 35,999,496 (28.57) |
| < 25 km | 20,563,969 (16.32) | 18,197,274 (14.44) |
| ≥ 25 km and < 50 km | 15,988,132 (12.69) | 13,899,387 (11.03) |
| ≥ 50 km and < 100 km | 19,636,053 (15.57) | 19,887,746 (15.77) |
| ≥ 100 km and < 200 km | 17,978,389 (14.28) | 22,648,629 (17.99) |
| ≥ 200 km | 11,460,666 (9.10) | 15,366,161 (12.20) |

n is the total population included in the study. Percentages are a proportion of total population n.
RT: radiotherapy; EBRT: external beam radiotherapy.

76.61-76.63%) within 100 km. Conversely, 23.38% (95% CI: 23.37-23.39%) of the population resides more than 100 km from the nearest RT center.

The same analysis was made for RT clinics with brachytherapy units, which are a little more than half (n = 61, 53.51%). Across distance categories, population access distribution mirrors that of EBRT, with a maximum difference of < 4% (Table 1). Population access is shown in figure 1B.

In some states, more than a million people live over 100 km from the nearest clinic – totaling 20.5 million people (Table 2).

Access is not uniform across the country; the proportion of the population living ≥ 100 km from the nearest RT facility differed significantly by region ($\chi^2$ test, $p < 0.001$). A complementary analysis of contiguous clusters of ≥ 3 municipalities located more than 200 km from an RT clinic found highly populated areas all around the country.

The cluster with the largest underserved population is in Chiapas (Fig. 2A), with an estimated 3.2 million people. Other large populations are also present along the Michoacán-Guerrero border (Fig. 2B; 984,000), the Oaxaca-Guerrero border (Fig. 2C; 981,000), eastern

**Table 2.** States with > 1 million people living ≥ 100 km from nearest RT clinic

| State | Population ≥ 100 km from nearest RT service (n) | Percentage of total state population (%) |
|---|---|---|
| Chiapas | 4,465,762 | 80.55 |
| Veracruz | 3,698,004 | 45.87 |
| Oaxaca | 2,770,254 | 67.04 |
| Michoacán | 2,487,805 | 52.39 |
| Guerrero | 2,236,678 | 63.17 |
| Puebla | 1,468,110 | 22.30 |
| Jalisco | 1,153,665 | 13.82 |
| San Luis Potosí | 1,153,374 | 40.87 |
| Coahuila | 1,083,528 | 34.43 |

RT: radiotherapy.

Oaxaca (Fig. 2C; 836,000), and northern Coahuila (Fig. 2D; 687,000).

A full population breakdown of each state by distance category has been added as supplementary material (Table S1).

## Discussion

To the best of our knowledge, this is the first detailed assessment of the geographic distribution and accessibility to RT services in Mexico, for both EBRT and brachytherapy. This study intends to serve as a diagnostic tool for policy planning and infrastructure development to expand access by identifying potential areas for intervention.

Overall, about a third of Mexico's population (~40 million people) can access EBRT locally; 61% live < 50 km from the nearest EBRT clinic. However, almost a quarter of the country (~29.5 million people) must travel 100 km or more. Brachytherapy has slightly worse geographic access, with a difference of around 4% from the EBRT numbers. Long distances for specialized care can turn into delayed diagnoses, worse patient outcomes, and unequal survival rates[15].

About three-quarters of all RT clinics are in a state capital or in Mexico City. While these major cities house a large part of the country's population, there is a strong need for new services outside of them so patients can get care closer to home.

### *States, regions, and underserved clusters*

In this paper, the absolute population instead of relative proportions creates a fuller picture, since the aim is to identify the major nationwide gaps. For example, 15% of Jalisco's population is 1.1 million people, but Durango's population is 280 thousand.

Table 2 shows the states where more than a million people live over 100 km from the nearest RT clinic. These states are, naturally, some of the most populated. State comparisons could be useful for future planning, but they may not be the only lens worth looking at.

Since geographic access might not align with state borders, examining continuous areas provides a complimentary perspective. A state-focused analysis will show that there are 350,000 people living more than 200 km from an RT clinic in southern Michoacán. However, a simple look at the adjacent area in western Guerrero – on the border between both states – will show a contiguous area close to a million people (Fig. 2B).

Using this perspective, figure 2 shows the five most populated clusters of ≥ 3 municipalities located > 200 km from the nearest RT clinic. The four most populated regions (Fig. 2A-C) are in the southwest region – Chiapas, Oaxaca, and Guerrero – making it the most geographically disadvantaged region in the country. Notably, it is also the poorest region in Mexico[16].

### *Mexican access in an international context*

Since 1999, the World Health Organization and the IAEA have recommended different RT machines-to-population ratios, from 1 machine per 2.5 million people to the optimal 5 per 1 million[17]. Mexico has an estimated 1.59 machines per million people: which makes it the lowest ranked in North America (United States: 11.39; Canada: 7.49) and the 6$^{th}$ lowest in Latin America, despite having the second highest number of RT centers in both regions[10].

Recent studies have looked at the geographic access to RT in the United States and Canada[18,19]. Every country has been studied with different methodologies and thresholds, so any comparative is illustrative rather than formal.

The United States has the broadest access in the region: 78% of their population lives ≤ 20 km from the nearest RT center, and < 2% lives > 80 km away[18]. Comparatively, in Mexico, 44.71% of the population lives ≤ 20 km (95% CI: 44.70-44.72%), and 28.90% of the population lives > 80 km from the nearest clinic (95% CI: 28.90-28.91%).

The Canadian study reported distances as quartiles of their population: Q1 = 8 km, Q2 = 18 km, and Q3 = 48 km[19]. Mexico's quartiles are Q1 = 0 km, Q2 = 28 km, and Q3 = 94 km. For both countries, half their populations have a similar geographic access, with a difference of only 10 km. The other half is where the disparity is shown, with the upper quartile's distance in Mexico almost double that of Canada's.

While some countries in Latin America have better ratios of RT machines-to-population (Argentina: 2.87, Chile: 2.28, Uruguay: 6.79), geography-related studies are limited[10].

Many of the same challenges observed in Mexico were also reported in a Brazilian study, particularly the centralization of RT services and its consequences for rural and remote populations[20]. A different study found that the average travel distance for RT in Brazil is 120 km, compared to Mexico's 63 km. Travel was heavily influenced by the region, with averages of 442 km in the north and 71 km in the south[21].

## Financial inequities to RT access

Poverty exacerbates the effects of the geographic barriers to cancer treatment. A bit over half of all RT centers are public and free at the point of use. However, as they often have long wait times, patients and their families prefer to pay for private services instead of delaying care, even if it means severe financial strain[22].

Financial burdens go beyond the treatment itself: travel is a major cost of medical care. While those who live close to an RT center experience wait times and disruptions to their daily responsibilities, patients who live farther away – and their caregivers – face additional burdens like long commutes and the cost of transportation and accommodation.

## Hypofractionated RT as a mitigating strategy

RT is usually given in multiple sessions – once a day, Monday through Friday – during which a patient gets a fraction of the total dose. Treatments can last up to 10 weeks, which can be highly disrupting and may disproportionately affect patients who need to travel to receive care.

Hypofractionation is a strategy that increases the dose given during each fraction and reduces the total number of sessions needed. Hypofractionated RT has shown equivalent or improved efficacy for certain cancers like prostate, liver, and bladder[23,24]. Some treatments like radio surgery and brachytherapy are also available, where the patient may receive all the dose in a single day.

Hypofractionation improves patient compliance and reduces the overall length of the treatment in certain cases[25]. However, unless the treatment is one that can be given in a single session, hypofractionated RT still lasts several days, even several weeks. This strategy can mitigate some of the financial burden that patients who travel far may face, but the overall expense may still be prohibitive for many.

## Limitations

There are three main limitations in this study. The first one is that road distances are calculated between the geographical centroids of municipal seats. Regardless of location within the municipality or the size of the municipality itself, everyone is modeled as if they live in one single point. For most municipalities, this results in a difference of a few kilometers; however, for geographically large municipalities – like those common in northern states – it can exceed over 200 km. Some municipalities also include populated islands only accessible by boat or plane.

The second limitation is that road distance does not equate travel time – road conditions and mode of transport can affect the length of the commute. For example, while the route La Paz-Los Cabos and the route Oaxaca-Zapotitlán Palmas are both 186 km, Google Maps estimates that the route to Zapotitlán takes an hour more.

The third limitation is that this paper assumes that any hospital will take any patient. In reality, different hospital systems will have different requirements: state hospitals may only treat residents of their own state, private hospitals will only take those who can pay, and even some federal institutions – IMSS, ISSSTE, SEDENA – may only treat their affiliates.

Future studies could incorporate smaller geographic divisions, average travel time, and hospital eligibility to get a more realistic picture. This paper is an idealized version of current accessibility in Mexico – one where everyone lives at a fixed point, every road is the same, and every hospital can treat you.

Modeling the country under these constraints reduced considerably the computational and analytical labor of this paper. As a consequence, the estimates presented are conservative and optimistic: the geographic access to RT in Mexico is likely worse than what this study may suggest.

## Conclusion

Geography plays a major role in access to RT. In Mexico, close to 30 million people may experience barriers to accessing cancer care due to distance to the nearest RT clinic. Four large clusters where people live > 200 km from an RT clinic were identified in the southwest: making it the most underserved region in the country. These estimates are optimistic, but they provide an evidence base to support the prioritization of new RT services.

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## Conflicts of interest

The author declares no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The author declares that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** The author has obtained approval from the Ethics Committee for the analysis of routinely collected and anonymized clinical data; therefore, individual informed consent was not required. Relevant ethical recommendations have been followed.

**Declaration on the use of artificial intelligence.** The author declares that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

## Supplementary data

Supplementary data are available at DOI: 10.24875/j.gamo.26000141. This data is provided by the corresponding author and is published online for the benefit of the reader. The content of the supplementary data is the sole responsibility of the author.

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