Raven Neurology Review
Neuroimaging
Free e-book

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Imaging is becoming increasingly important in the diagnosis and management of many neurologic illnesses. The neurologist and neurology student must be competent in understanding when to order imaging tests, know the utility and limitations of such tests, be capable of interpreting radiology reports, and be able to independently evaluate common neuroimaging studies.

The four primary types of neuroimaging that you should be familiar with are computed tomography (CT), magnetic resonance imaging (MRI), catheter angiography and ultrasound. We will briefly review the relevant information for each of these modalities.

**Computed Tomography**

The head CT is easily the most frequently obtained neuroimaging study. It is widely available, rapidly acquired and relatively inexpensive. If no IV contrast is used, it is a non-invasive study. The CT machine essentially uses a series of X-rays to reconstruct an image of the brain. X-rays are sensitive to the density of materials, so bright structures on CT are ‘hyperdense’ and darker structures are referred to as ‘hypodense.’

The head CT is very good at quickly identifying abnormal hyperdense lesions, such as blood (which is ‘dense’ because the hemoglobin in blood contains iron), foreign objects, calcified structures and bone fractures. It can also quickly identify very hypodense structures, such as free air in the brain, as sometimes happens following trauma or neurosurgery, or encephalomalacia.

Gross anatomy is moderately well visualized on head CT. Large abnormalities, such as prior areas of stroke that have had time to evolve into empty, cystic spaces are typically well visualized. Large tumors may be seen if they distort the shape of the brain, bleed or are calcified. However many tumors will not be obvious on head CT. Smaller, more subtle injuries in the brain, including most acute ischemic strokes, are also not well seen on CT. These cases may require brain MRI for better visualization.

A primary use of the head CT in the emergency room is to evaluate for hemorrhage – either within the brain tissue (intraparenchymal hemorrhage), between the brain and the dura matter (subdural hemorrhage), or between the brain and its immediate covering the pia matter (subarachnoid hemorrhage). An important point to remember is that in very early ischemic stroke, the head CT will usually be normal – it takes up to 6 hours for ischemic stroke changes to be reflected on a head CT. The main utility of the head CT in acute stroke is to rule out hemorrhage.
Drawbacks of head CT include the use of radiation, an especially important consideration in children or for those who may be pregnant. In addition, CT is prone to streak artifacts from very dense materials, such as the metal in dental fillings, EEG leads or the metal clips used to treat intracranial aneurysms. Although CT is rapidly acquired, motion artifact is also possible.

Common uses of head CT include evaluating for hemorrhage or fracture, tracking post-operative changes, evaluating for brain swelling in ischemic stroke and as a rapid screening test in patients with sudden neurologic changes. Keep in mind that many inflammatory conditions, tumors and early strokes will be missed by a non-enhanced head CT.

A note on CT of the spine- although generally good at evaluating the vertebral bones for fractures or misalignment, the spinal cord itself is not well seen. For suspected spinal cord pathology, MRI is generally a better choice.

One other important aspect of CT is the ability to obtain reformats in different planes. Upon request, the radiology technologist can reform the head CT into coronal or sagittal views. This is done by the computer, and doesn’t require any additional scanning or radiation for the patient, unlike brain MRI as we will see.
A) Normal non-contrast head CT. Note the calcified pineal gland in the center (short arrow). B) Intraparenchymal hemorrhage (arrow) in the right thalamus – this is a classic location for a hypertensive bleed. C) Small subarachnoid hemorrhage on the left (arrowhead). Subarachnoid and subdural hemorrhages are sometimes seen best in the coronal plane. D) A small left hemisphere subdural hematoma (arrow). See how it does not go into the brain sulci, whereas the subarachnoid hemorrhage did?
A) Left temporal epidural hematoma (short arrow), with some mass effect – note the bulging, convex appearance. B) Right subdural hematoma (arrow) – as the blood ages the density becomes increasingly similar to that of the brain tissue. C) Right caudate head intraparenchymal hemorrhage (arrowhead), likely from hypertension. D) Left temporal ischemic stroke with hemorrhagic conversion (arrow) – this represents bleeding into the dead tissue, and is much more likely to occur in embolic type strokes.
CT Angiography

An important variation of the head CT is the CT angiogram, which uses intravenous iodinated contrast to visualize the arteries in the head and neck. This can be extremely helpful in identifying vascular lesions such as carotid stenosis or dissections, acute arterial occlusion, aneurysm or vascular malformations. It is commonly used during acute stroke to evaluate for culprit vascular lesions or large vessel occlusions that may be amenable to intra-arterial thrombectomy. In addition, contrast may leak out of inflamed or fragile blood vessels in the brain, showing enhancement in inflammatory lesions such as brain abscesses or brain tumor.

The main limitation to using CT contrast is in individuals who have poor renal function. In general, CT contrast is not used in people who have a GFR less than 30 mL/min, although some exceptions do exist, such as dialysis dependent patients who can undergo dialysis after the study. Patients may also have allergic reactions to the contrast agent.

Radiologists will often report on any flow limiting areas of stenosis (narrowing) on the study, including the degree of narrowing of the proximal internal carotid artery (ICA). ICA narrowing is often measured using the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria. The NASCET study indicated that in patients with minor stroke or TIA whose stroke was likely due to ipsilateral carotid artery disease, those with narrowing of 70% or more were likely to benefit from carotid endarterectomy.

Magnetic Resonance Imaging

MRI provides excellent visualization of the brain tissue, inflammation and stroke. Unlike CT, the MRI uses no radiation and does not measure tissue density. Instead, it depends on the magnetic property of the tissue – some people have called MRI a ‘water map’ of the brain because water creates such a strong signal. The MRI can be configured to highlight different properties of the brain, depending on the sequence used. Because you are not measuring density, we use the terminology “hyperintense” for bright structures and “hypointense” for darker structures on MRI. A major part of learning to interpret brain MRI is learning what brain features each distinct sequence is intended to highlight.

Unlike the head CT, brain MRI is very time intensive to acquire. Each individual sequence is obtained separately. So, the more information you need from the study, the longer it takes. Patients are required to stay very still, which can be challenging given the long duration of the study – often 30 to
60 minutes. It can also be difficult for claustrophobic patients, as the opening in the magnet is very small and the machine is loud.

In addition, the MRI is prone to artifact from any ferromagnetic material, which may include braces, metal screws, pins or clips and other material.

Let’s review the most common brain MRI sequences. Bear in mind that individual hospitals and MRI machines may slightly differ in the names of some sequences. Use this section as a reference when needed.

**T1-Weighted** sequences typically give good anatomical representation of the brain. The cerebrospinal fluid (CSF) is dark, white matter appears white and grey matter appears grey. Inflammation and acute stroke do not show up well, but gadolinium based contrast will appear bright.

![T1W brain MRI, providing a good view of the structural anatomy of the basal ganglia (arrow) and the internal capsule (arrowhead). Recall that the basal ganglia is made of the putamen and globus pallidus.](image)

**T2-Weighted** is a fluid bright sequence. This means, unlike T1W, the CSF appears bright. Areas of inflammation or injury will also be bright, although it can be hard to pick these out given the presence of bright CSF as well. In T2W images the white matter appears darker, and the grey matter appears brighter.

![T2W brain MRI demonstrating ‘bright’ CSF. Notice that the white/grey matter are reversed compared to the T1W image above.](image)
**T2W FLAIR** is meant to make it easier to see pathology on a T2W sequence. Essentially, the bright signal from CSF is removed, leaving the pathologic signal from injured tissue clearly visible. This is often considered a “go-to” sequence for looking at pathology. Signs of chronic white matter disease (microvascular disease) is also readily apparent on T2W FLAIR.

![T2W FLAIR image, now with the bright CSF signal removed. This is an excellent sequence for looking at pathology – including subacute or chronic strokes, inflammation, white matter disease, etc. within the brain tissue.](image)

![This T2W FLAIR image shows several hyperintense lesions (arrows), which are not specific, but could represent subacute strokes or areas of inflammation, such as in multiple sclerosis. FLAIR may look similar to DWI (see below), but note that DWI tends to provide a ‘fuzzy’ image, while T2 FLAIR is a bit more ‘crisp’ with better resolution of detail.](image)

**Diffusion Weighted Imaging (DWI)** is best for visualizing acute stroke. A stroke will appear as a bright lesion, which fades slowly over about two weeks. There are a few other things which will cause bright signal (called diffusion restriction) on DWI, but these are much less common – the pus in a brain abscess may cause diffusion restriction, as will some tumors. The Apparent Diffusion Coefficient (ADC) map is a sequence in which acute strokes appear dark – a bright lesion on both ADC indicates a chronic lesion.
**T2** this category includes several types of sequence, such as GRE, SWI or SWAN. All are similar, and show both blood and calcification. They are very sensitive, and are often used to identify micro-hemorrhages. These micro-hemorrhages may be too small to be seen even on CT scan. Both blood and calcification will appear as dark circles, which are larger than the underlying lesion.

![Diffusion Weighted Imaging (DWI) on the left, showing an internal capsule stroke (arrow). The ADC map on the right shows the stroke as a dark spot (arrowhead), verifying its acute nature.](image1)

![This T2* image (the category includes GRE and the more sensitive SWI sequence), shows diffuse microhemorrhage (arrow, but seen diffusely) within the white matter tracts. Microhemorrhage is common after high speed head trauma or extensive time on cardiac bypass. Note there is also hemorrhage within the corpus callosum (arrowhead).](image2)

<table>
<thead>
<tr>
<th>Grey Matter</th>
<th>White Matter</th>
<th>CSF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1W</strong></td>
<td>Grey</td>
<td>Dark</td>
</tr>
<tr>
<td><strong>T2W</strong></td>
<td>White</td>
<td>Bright</td>
</tr>
<tr>
<td><strong>FLAIR</strong></td>
<td>White</td>
<td>Grey</td>
</tr>
</tbody>
</table>

![Appearance of brain structures in the most common MRI sequences.](image3)
MR Angiography

A quick note on angiography using MRI. As already mentioned, the contrast agent is gadolinium, not iodinated contrast (thus, safe for people with iodine allergies). Gadolinium is generally well tolerated, but has been known to cause a very serious, even lethal, condition known as nephrogenic systemic fibrosis in people with severe renal failure. Therefore, it should never be used in anyone with a GFR below 30 mL/min. It is also not safe to use gadolinium in pregnancy.

Gadolinium is often given when obtaining a brain MRI to evaluate for inflammatory conditions such as multiple sclerosis, or brain tumors. It is used for angiograms of the neck. However, for angiography of the head, gadolinium in not required. This is based on a neat trick based on MRI physics, because flowing blood is not well captured by the MRI scan, resulting in flow related absence of signal. These flow voids then are used to map out blood vessels. The results are best for angiography of the head; it can be done in the neck, but the results are poorer. This type of non-contrast angiogram is known as a “time of flight” study.

Conventional Catheter Angiogram

Another technique for imaging the vasculature of the head and neck is conventional catheter angiography, sometimes called digital subtraction angiography (DSA). This requires gaining arterial access with a microcatheter, usually through the femoral artery. The catheter is then guided to the cerebral vasculature, at which point contrast dye is injected through the catheter and a series of images are taken. The resulting images are high quality, and show the flow of contrast (and thus the flow of blood) through the arteries, capillaries and veins in real time. This endovascular technique can be used to remove occlusive blood clots in acute stroke (thrombectomy), place a stent for carotid artery stenosis, or place wire coils to occlude an aneurysm.

Catheter angiography provides the highest quality vascular imaging, but is an invasive technique and thus is done less frequently. It is not uncommon to have small, scattered micro-infarcts after catheter angiography due to the embolization of arterial plaque knocked loose by the catheter. However, symptomatic stroke as a result of catheter angiography is uncommon.
The most common ultrasound study used for neurology patients is carotid ultrasound, which is a non-invasive method of assessing for carotid stenosis. It can also be helpful in identifying carotid dissection, or tears in the wall of the artery. It is a relatively inexpensive test, but is performed less often now due to the frequency of obtaining CT angiograms.

Transcranial Doppler Ultrasound (TCD) is another common application of ultrasound. Specially trained TCD technicians can determine the direction and velocity of the flow of blood within the brain, carotid and vertebral arteries. It is especially useful following subarachnoid hemorrhage, where spasm of the cerebral arteries may cause significant increases in the velocity of blood flow in affected area. TCD can also be used to evaluate for active embolization, say from a symptomatic carotid artery plaque. However, the availability of TCD is limited and not readily available in all hospitals.

▲ A conventional catheter angiogram of the right internal carotid artery, showing a proximal middle cerebral artery occlusion (left, arrow) followed by good perfusion after thrombectomy (right).
**Echocardiography**

Although not a neuro-diagnostic study per-se, echocardiograms are frequently ordered in people suspected of having ischemic strokes. The echocardiogram is used to evaluate for a number of stroke risk factors, such as presence of thrombus which could be the source of the stroke, for atrial
dilation indicating a high risk for atrial fibrillation, or patent foramen ovale (PFO) which could be a source of thromboembolism. The majority of stroke patients undergo transthoracic echocardiography only. Transesophageal echocardiography is more invasive, but is sometimes used when a cardiac source of stroke is suspected and transthoracic imaging is unrevealing.

**Venography**

Sometimes we want to take a close look at the veins, not just the arteries, around the brain. This is primarily to evaluate for dural sinus thrombosis – essentially a DVT surrounding the brain. It is also used for certain brain tumors, when they are in close proximity to the cerebral veins. Venography can be done with CT or MRI.

▲ *A conventional catheter angiogram in the venous phase, demonstrating the superior sagittal sinus (arrow), transverse sinus (arrowhead), and internal jugular veins (*).*

**All the rest**

There are many other imaging studies in the field of neurology, including nuclear medicine perfusion studies, DAT scans, CSF flow studies, other MRI sequences, CT myelograms and others. However, they are outside the scope of this book and uncommonly used.

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**“It be iddy biddy baby doo doo”**

The mnemonic ‘It be iddy biddy baby doo doo’ can be helpful when figuring out the age of blood on a brain MRI, as the pattern of intensity changes quickly as the blood products break down. The following table is a reference:

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Stage</th>
<th>T1W</th>
<th>T2W</th>
</tr>
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<tbody>
<tr>
<td>It Be</td>
<td>Hyperacute</td>
<td>Isointense (I)</td>
<td>Hyperintense (B)</td>
</tr>
<tr>
<td>IdDy</td>
<td>Acute</td>
<td>Isointense (I)</td>
<td>Hypointense (D)</td>
</tr>
<tr>
<td>BiDdy</td>
<td>Early Subacute</td>
<td>Hyperintense (B)</td>
<td>Hypointense (D)</td>
</tr>
<tr>
<td>BaBy</td>
<td>Late Subacute</td>
<td>Hyperintense (B)</td>
<td>Hyperintense (B)</td>
</tr>
<tr>
<td>Doo Doo</td>
<td>Chronic</td>
<td>Hypointense (D)</td>
<td>Hypointense (D)</td>
</tr>
</tbody>
</table>

(I) Isointense; (B) bright or hyperintense; (D) dark or hypointense. Table refers to age of BLOOD only.
Neuro-Imaging Cases

“I am Groot.”
Guardians of the Galaxy
A 15 year old boy fell off his bike with no helmet and struck his head. He felt fine for twenty minutes before becoming lethargic and difficult to arouse.

1. What is the diagnosis?
   A. Subdural hematoma
   B. Epidural hematoma
   C. Meningioma
   D. Abscess

2. This condition is typically caused by an injury to which blood vessel(s)?
   A. Temporal artery
   B. Middle cerebral artery
   C. Middle meningeal artery
   D. Bridging veins

3. What is the primary treatment of this condition?
   A. Steroids
   B. Mannitol or hypertonic sodium chloride
   C. Surgical drainage
   D. Blood pressure control
Case 1 – Neuro-Imaging

This is a classic epidural hematoma (arrows), usually associated with a skull fracture and damage to an artery – specifically, the middle meningeal artery. Blood accumulates between the skull and the dura, expands quickly, and causes brain herniation and possibly death if not treated emergently with surgical drainage.

Subdural hemorrhages can also cause significant mass effect, but are concave, not convex like an epidural bleed. Because subdural hemorrhages are caused by tears to lower pressure bridging veins they do not typically expand quickly, unless the patient has a coagulation disorder.

Mannitol or hypertonic saline are used for stroke associated edema leading to herniation.

1. What is the diagnosis?
B. Epidural hematoma – Note the convex shape. These bleeds are contained by dural suture lines, unlike subdural bleeds.

2. Injury to which blood vessel is most commonly responsible?
C. Middle meningeal artery – a small extracranial artery that enters the skull at the temple

3. What is the primary treatment of this condition?
C. Surgical drainage – this is a surgical emergency
Case 2 – Neuro-Imaging

Answer the questions based on this patient’s brain MRI.

1. What MRI sequence is shown here?
   A. T2-Weighted FLAIR
   B. Diffusion Weighted
   C. T1-Weighted post-contrast
   D. T2-Weighted

2. In which vascular territory is the pathology?
   A. Anterior cerebral artery
   B. Middle cerebral artery
   C. Posterior cerebral artery
   D. Middle meningeal artery

3. Which best describes the patient’s most likely clinical symptoms?
   A. Loss of vision
   B. Loss of speech
   C. Hemiparesis
   D. Loss of sensation
Case 2 – Neuro-Imaging

This patient has a large stroke of the left occipital and medial temporal lobe (as well as a very small stroke in the right thalamus, shown by the arrowhead). This is in the posterior cerebral artery territory – recall that branches of this artery also supplies the thalamus. The occlusion of a large artery is suspicious for embolism. Stroke of the left lower occipital lobe will likely cause a right upper visual field loss in both eyes.

1. What MRI sequence is shown here?
   **B. Diffusion Weighted** – could be confused with T2 FLAIR, but the image is not as crisp

2. In which vascular territory is the pathology?
   **C. Posterior cerebral artery**

3. Which best describes the patient’s most likely clinical symptoms?
   **A. Loss of vision – it partly affects the occipital lobe**

► This patient’s formal visual field testing, demonstrating a right upper visual field cut, as expected.
Case 3 – Neuro-Imaging

Answer the questions based on this patient’s imaging shown above.

1. Which description best fits this CT scan?
   A. Normal non-enhanced head CT
   B. Abnormal non-enhanced head CT
   C. Normal post-contrast head CT
   D. Abnormal enhanced head CT

2. What abnormality, if any, is present?
   A. Normal head CT
   B. Subacute infarct present
   C. Subdural hematoma present
   D. Subarachnoid hemorrhage present
Case 3 – Subarachnoid hemorrhage

This is a non-enhanced head CT – there is no contrast in the blood vessels or sinuses. However, there is an abnormal hyperdense signal within the sulci of the left frontal lobe (arrow). Compare this to the opposite side, where you see dark CSF density signal within the sulci. This image is diagnostic of a small subarachnoid hemorrhage – they can be subtle. Compare to the subarachnoid in image C on page 42.

1. Which description best fits this CT scan?
   B. Abnormal non-enhanced head CT due to hemorrhage

2. What abnormality, if any, is present?
   D. Subarachnoid hemorrhage present. This might be seen well in a coronal reformat.
Answer the questions based on this patient’s imaging shown above.

1. Which MRI sequence is shown?
   A. T1-Weighted
   B. T1-Weighted post-contrast
   C. T2-Weighted
   D. T2-Weighted FLAIR

2. Which brain structure is represented by the *?
   A. Cerebellum
   B. Fourth ventricle
   C. Corpus callosum
   D. Occipital lobe

3. In this imaging sequence, the cortex is what color?
   A. White
   B. Black
   C. Grey
   D. Not visible
This is a T1-Weighted sagittal brain MRI. The corpus callosum (arrow) is a white matter tract – on T1W images the white matter appears white and the grey matter (i.e. the cortex) is grey. On T2W imaging this is inverted. The fourth ventricle is indicated with an arrowhead, the occipital lobe with a star.

1. Which MRI sequence is shown?
   A. T1-Weighted imaging

2. Which brain structure is represented by the *?
   A. Cerebellum

3. In this imaging sequence, the cortex is what color?
   C. Grey – and white matter appears white

**Teaching Point:** T1W images do a good job of showing brain anatomy, but T2W FLAIR is best for seeing pathology!
Case 5 – Neuro-Imaging

A 58 year old man is admitted to the stroke ward. His non-enhanced brain CT is shown above.

1. What is the most likely timing of this CT scan, in relation to the patient’s stroke?
   A. Within 60 minutes of stroke onset
   B. Within 6 hours of stroke onset
   C. Within 2-3 days of stroke onset
   D. Approximately 4 weeks after stroke onset

2. Which brain vascular territory is affected?
   A. Anterior cerebral artery
   B. Middle cerebral artery
   C. Posterior cerebral artery
   D. Basilar artery
Case 5 – Neuro-Imaging

This patient had a large left middle cerebral artery (MCA) territory stroke, due to untreated atrial fibrillation. A non-enhanced CT scan generally takes at least 6 hours to show evidence of acute ischemia. This much more frank infarct, with evidence of swelling and mass effect is more likely to be seen within 2-3 days after stroke onset. Notice the lack of sulci within the stroke bed, as compared to the normal side, which is due to swelling. The MCA vascular territory is clearly defined.

1. What is the most likely timing of this CT scan, in relation to the patient’s stroke?
C. Within 2-3 days of stroke onset, giving time for peak edema to develop

2. Which brain vascular territory is affected?
B. Middle cerebral artery – this image nicely demonstrates a stroke of the entire MCA territory
Use the above brain MRI sequences to answer the following questions.

1. Based on the MRI, how long ago did the patient’s stroke occur?
   A. Within the past 10 days
   B. Between 2-4 weeks ago
   C. More than 4 weeks ago
   D. Timing of the stroke cannot be determined from this MRI

2. Which brain region is affected by the stroke?
   A. Midbrain
   B. Pons
   C. Medulla
   D. Cerebellum

3. What symptoms do you expect this patient to have clinically?
   A. Inability to understand language
   B. Right hemiparesis
   C. Right visual field loss
   D. Loss of sensation in both legs
This patient has a left pontine stroke (arrowhead). The cause is likely atherosclerotic disease of a penetrating branch of the basilar artery. Notice how the stroke respects midline—separate basilar artery branches supply each side of the pons. We know the stroke is relatively recent, no more than 10-14 days old, because the ADC map remains dark (arrow). After 2 weeks this darkness will normalize and disappear. A pontine stroke will cause contralateral weakness. You would also expect to see cranial nerve dysfunction, possibly swallowing problems or eye movement abnormalities.

1. Based on the MRI, how long ago did the patients stroke occur?
   A. Within the past 10 days – the ADC normalizes after that time

2. Which brain region is affected by the stroke?
   B. Pons – this is the largest part of the brainstem

3. What symptoms do you expect this patient to have clinically?
   B. Right hemiparesis – remember that the left brain motor fibers cross to innervate the right side of the body. However, this patient may have left facial weakness as well, if the left facial nerve (CN VII) is affected as it leaves the pons.
Case 7 – Neuro-Imaging

The images above were obtained from a 35 year old man who had chronic headaches.

1. What type of images are these?
   A. Non-enhanced head CT
   B. CT with iodine based contrast
   C. CT with gadolinium contrast
   D. CT angiogram

2. Which of the following best describes the white structure indicated with an arrow?
   A. Benign calcification
   B. Tumor
   C. Hemorrhage
   D. Cannot be identified from these images

3. What is the major finding of these images?
   A. Normal study
   B. Hydrocephalus
   C. Ischemic stroke
   D. Hemorrhagic stroke
These are both normal non-enhanced head CT images from a young adult. There is calcification of the choroid plexus, which is common – a coronal view is shown here as well, to better visualize the calcified choroid (arrows). Recall that the choroid plexus is responsible for producing cerebrospinal fluid. Common areas for benign calcification include the dura, the basal ganglia and the pineal gland.

1. What type of images are these?
A. Non-enhanced head CT – there is no contrast in these images. Contrast is used to obtain a CT angiogram or CT venogram, in which case we would see enhancement within the vasculature

2. Which of the following best describes the white structure indicated by an arrow?
A. Benign calcification – this is benign calcification of the choroid plexus, which is common and the incidence increases with age

3. What is the major finding of these images?
A. Normal study – these are normal head CT images from a young adult. Note that the brain looks more ‘full’ than it might for someone several decades older
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