

Amblyopia in the pediatric population – etiopathogenesis and current therapeutic approaches. A review of recent literature

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Summary:

Amblyopia is a visual development disorder defined as a reduction in best-corrected visual acuity. It is the most common cause of unilateral visual impairment in the pediatric population, affecting approximately 1% to 5% of children worldwide. According to current literature, the global burden of amblyopia may reach 221.9 million people by 2040.

The most common causes of amblyopia include strabismus (19%–50%), refractive errors (46%–79%), anisometropia, and optical media opacities. Therapeutic management involves stepwise refractive correction, occlusion of the better-seeing eye, or atropine penalization, complemented by selected optical or surgical approaches in deprivation-related cases. In recent years, binocular (dichoptic) therapies, such as digital platforms and eye-tracking systems aimed at reducing suppression and improving binocular function, have gained increasing attention. Early detection, individualized treatment plans, and systematic monitoring remain essential for achieving sustained visual improvement. This article reviews the 2020–2026 literature on the etiopathogenesis, diagnosis, and current management strategies for amblyopia in children.

Key words:

amblyopia, treatment, occlusion, atropine penalization, dichoptic therapy.

Introduction

Amblyopia is a visual development disorder defined as a reduction in best-corrected visual acuity (BCVA) in the absence of any underlying pathology that could account for the visual impairment [1]. According to the literature, the pathophysiology of the disorder involves abnormal visual cortex development during infancy or childhood [2], which may, in up to 90% of cases, be associated with conditions such as strabismus or anisometropia [3]. Amblyopia can also be secondary to organic ocular disease, such as congenital cataracts, ptosis, vitreous hemorrhage, or corneal opacities – disorders that obstruct the visual axis and prevent a clear image from reaching the retina [4].

Amblyopia has been a global health issue for many years. According to current literature, the global burden of amblyopia may reach 221.9 million people by 2040 [2, 3].

Periodic screening in children is essential for early diagnosis. During the first four years of life, three routine examinations in primary care settings are recommended: typically at 6–9 weeks of age, 6–9 months of age, and between 3 and 4 years of age [5]. Subsequent assessments are most often performed during elementary school as part of routine health check-ups (at ages 6–7 and 12–13) [6].

Treatment methods for amblyopia can be divided into traditional and alternative approaches. Traditional therapies include complete correction of refractive errors, treatment of the underlying condition, e.g., strabismus surgery or the use of prisms, occlusion of the better-seeing eye (considered the gold standard), and the use of atropine in the dominant eye [7]. Alternative methods include pharmacological options – such as levodopa, citicoline, selective serotonin reuptake inhibitors (SSRIs), and donepezil – as well as games designed to stimulate both eyes, which are currently undergoing clinical trials [7, 8].

Amblyopia represents a significant challenge for pediatric ophthalmology departments worldwide. The authors conducted an updated literature review using databases such as PubMed and

Google Scholar, covering the last five years (2020–2026), to evaluate the latest treatment modalities for amblyopia. This article presents both traditional and modern methods and compares their therapeutic efficacy.

Epidemiology and diagnosis of amblyopia

Amblyopia is a common pediatric visual disorder, affecting 1% to 5% of children worldwide [9]. On average, 2 to 3 out of every 100 children are diagnosed with the condition [10]. The highest prevalence rates are reported in Europe (2.90%) and the United States (2.41%), with males diagnosed more frequently than females (1.40% vs. 1.24%). According to current literature, the global burden of amblyopia may reach 221.9 million people by 2040 [2, 3]. The most intensive period of visual system development occurs during the first three years of life, and the entire first decade is considered particularly important for the establishment of normal vision. Any abnormalities during this time may disrupt visual development and result in irreversible deficits [11, 12].

The most common causes of amblyopia include strabismus (19%–50%), refractive errors (46%–79%), anisometropia (differences in refractive errors between the eyes), and opacification of the optical media [13–15].

In strabismus, in which the eyes are misaligned, the ability to fuse the images from both eyes is lost. As a result, one eye becomes dominant, while suppression develops in the other. In anisometropia, differences in the size of the retinal images disrupt binocular vision, giving rise to dominance of one eye. Other factors, such as ptosis or cataracts, can physically limit the amount of light reaching the eye, preventing normal visual development. In each of these situations, dominance of one eye and functional suppression of the other become established, ultimately culminating in the development of amblyopia. For this reason, early diagnosis and prompt initiation of treatment are essential [11, 12].

Bilateral refractive amblyopia (isoametropic amblyopia) is a less common form of refractive amblyopia and is characterized

by reduced visual acuity in both eyes. It is thought to result solely from the formation of bilaterally blurred retinal images (i.e., chronic image degradation in both eyes). Occlusion amblyopia (reverse amblyopia) is a distinct, transient form of deprivation amblyopia that may develop after approximately six months of therapy involving patching of the non-amblyopic eye or pharmacological cycloplegia in the non-amblyopic eye, most commonly with atropine [16, 17].

Until 3 years of age, regular examinations in primary care offices are recommended. The following ophthalmic examinations are performed: a general external eye examination, assessment of the red reflex and fixation, and visual acuity testing (using LEA Symbols/HOTV charts or age-appropriate optotypes) adjusted to the child's age (at 6–9 weeks, 6–9 months, and 3–4 years of age) [5]. Subsequent assessments are most often performed during elementary school as part of routine health check-ups (at ages 6–7 and 12–13) [6].

Amblyopia and its risk factors are more common among children born prematurely, those who are small for gestational age, children with psychomotor developmental delays, and those with a first-degree family history of amblyopia. Some studies have also demonstrated an association between prenatal environmental factors, such as maternal smoking, drug use, or alcohol consumption during pregnancy, and an increased risk of amblyopia or strabismus. Conversely, other population-based studies have failed to confirm a significant association between maternal smoking during pregnancy and amblyopia, highlighting the inconsistency of the available epidemiological data [18].

Untreated or undertreated amblyopia can limit future career opportunities, as many professions have strict standards regarding visual acuity and binocular vision, including stereopsis. This is particularly relevant to fields such as the military, law enforcement and public safety, aviation, and working at heights [18, 19].

At the same time, available scientific reports do not provide clear evidence that unilateral amblyopia itself constitutes a substantial barrier to education or general job performance. Maintaining normal visual function in each eye through appropriate treatment of amblyopia is a key component of effective strabismus management. If the visual system is anatomically well developed, every child with amblyopia, regardless of age, should be offered treatment [18]. Table I presents the diagnostic criteria for amblyopia.

Examination	Diagnostic criteria
Unilateral amblyopia	
Patching test (occlusion test)	Markedly asymmetric response of the child (resistance to covering the better-seeing eye)
Fixation preference	Inability to initiate or maintain fixation, or a definitive preference for one eye
Preferential looking test (Teller Acuity Cards)	Interocular visual acuity difference ≥ 2 octaves*
Best-corrected visual acuity (BCVA)	Interocular visual acuity difference ≥ 2 lines, with normal acuity in the better-seeing eye†
Bilateral amblyopia	
Best-corrected visual acuity (BCVA) in each eye†	Age 3 to <4 years: visual acuity < 0.4 ($\leq 20/50$) in both eyes
	Age 4–<5 years: visual acuity < 0.5 ($\leq 20/40$) in both eyes
	Age ≥ 5 years: visual acuity < 0.7 ($\leq 20/30$) in both eyes

Tab. I. Diagnostic criteria for amblyopia [18].

Legend:

The diagnosis of amblyopia requires the presence of an amblyogenic factor (e.g., strabismus, anisometropia, bilateral ametropia, visual deprivation) along with a corresponding reduction in visual acuity. BCVA (best-corrected visual acuity); visual acuity values are presented in decimal notation and (in parentheses) on the Snellen scale.

* A difference of 2 octaves in the preferential looking test corresponds to a 4-card difference in the full Teller Acuity Cards set. The Teller Acuity Cards test evaluates visual acuity based on the resolution of stripes of varying widths (spatial frequencies). The child spontaneously looks toward the patterned stimulus if it is visible to them. An "octave" represents a two-fold difference in grating frequency – that is, if the interocular difference is 1 octave, one eye can resolve stripes that are twice as fine as the other.

† In bilateral amblyopia, visual acuity is not necessarily symmetrical in both eyes.

Amblyopia – definition [20]

Amblyopia is a developmental visual disorder characterized by reduced best-corrected visual acuity (BCVA) in one or both eyes that is not attributable to identifiable pathology of the ocular structures, but rather results from abnormal visual stimulation during the critical period of visual system development. In clinical studies (MEPEDS), amblyopia is most commonly defined as follows [20]:

1. Unilateral amblyopia:
 - a difference in visual acuity between the eyes of ≥ 2 lines, with reduced BCVA of ≤ 0.8 in one eye and at least one of the following factors:
 - ✓ strabismus,
 - ✓ anisometropia with refractive error in the poorer-seeing eye:
 - ≥ 1.00 D of hyperopia (anisohyperopia)
 - ≥ 3.00 D of myopia (anisomyopia)
 - ≥ 1.50 D of astigmatism (anisoastigmatism),
 - ✓ Sensory deprivation (cataract, corneal opacities, ptosis, maculopathy, eyelid tumors).
2. Bilateral amblyopia:
 - bilateral BCVA of ≤ 0.8 since childhood, with a history of a previous bilateral visual axis obstruction or bilateral significant refractive error (ametropia)
 - ≥ 4.00 D of hyperopia,
 - ≥ -6.00 D of myopia,
 - ≥ -2.50 D of astigmatism.

The grades of amblyopia and their corresponding visual acuity are presented in Table II.

Amblyopia severity	Visual acuity in the amblyopic eye (Snellen chart)	Visual acuity in the amblyopic eye (LogMAR)
Mild	20/30–20/40	~0.18–0.30
Moderate	20/40–20/80	~0.30–0.60
Severe	20/100–20/400	~0.70–1.30

Tab. II. Amblyopia severity and corresponding visual acuity.

Treatment methods for amblyopia

Treatment for amblyopia in children includes the following modalities:

- ✓ optical correction of significant refractive errors,
- ✓ occlusion (patching the dominant eye),
- ✓ pharmacological treatment (atropine),
- ✓ optical treatment (e.g., the use of overplussed lenses),
- ✓ bangerter filters (semitransparent) (Ryser Optik AG, St. Gallen, Switzerland),
- ✓ digital binocular (dichoptic) therapy,
- ✓ surgical treatment of media opacities causing deprivation amblyopia (e.g., cataract, ptosis),
- ✓ refractive surgery.

The prognosis for achieving normal visual acuity in the amblyopic eye depends on several factors, including the age of onset, underlying etiology, severity and duration, clinical course and response to prior therapy, adherence to treatment, and coexisting medical conditions. Close collaboration between the ophthalmologist, the child, and their caregivers is essential, as is a clear explanation of the nature of the condition and the potential consequences of not initiating treatment or not adhering to the recommended therapy. It is also important to choose not only an effective treatment method, but one that is best accepted by the patient, as this influences adherence to medical recommendations and the overall therapeutic outcome.

Full correction of refractive error is the starting point for amblyopia treatment

Treatment consisting solely of refractive correction is the first and fundamental step in the therapeutic management of children and adolescents aged 0 to 17 years with diagnosed amblyopia [21, 22].

In children aged 3 to 7 years with isoametropic amblyopia, spectacle correction alone has been shown to yield a mean improvement of 2.9 lines in visual acuity in the amblyopic eye. Compared with baseline, an improvement of at least 2 lines of visual acuity was observed in 77% of patients, while an improvement of 3 lines was observed in 60% of participants. Complete resolution of amblyopia was observed in 27% of children during the study. Additionally, in a subsequent randomized phase of the study, in the control group that continued treatment with spectacles alone, resolution of amblyopia was observed in 6 of 34 children (18%) who had previously had residual amblyopia. The observed mean improvement of 2.9 lines in visual acuity was significantly greater than would be expected from the learning effect associated with repeated testing or from normal age-related changes [23].

According to the PEDIG approach, full correction of the refractive error determined by cycloplegic refraction may produce a clinically meaningful improvement in visual acuity in the amblyopic eye (on the order of several lines) and, in some patients, may even lead to resolution of amblyopia. The observed improvement in visual acuity exceeded the level that could be attributed solely to the learning effect associated with repeated visual acuity testing during follow-up visits, indicating that refractive correction itself exerts a genuine therapeutic effect rather than merely reflecting better cooperation of the child during examination [24].

Patching

Occlusion (covering the dominant eye) is an appropriate treatment for amblyopia in children in whom refractive correction alone does not lead to improvement, or in those who continue to show incomplete correction of the visual acuity deficit after this stage of management [25]. The most effective form of occlusion is the application of an opaque, adhesive patch placed directly onto the skin surrounding the better-seeing eye. Prescribed corrective spectacles should be worn over the patch. A fabric patch attached to the spectacle frame is a possible alternative. However, this method is less preferred, as the child may peer around the frame, thereby reducing occlusion efficacy [26]. Randomized clinical trials (RCTs) have demonstrated that the duration of occlusion should be tailored to the severity of amblyopia to ensure that the clinical effect is maintained long term [17, 27]. (Data are presented in Table III).

Although the technique of patching the dominant eye is effective, disadvantages of the therapy include compliance difficulties among children and limited efficacy in older patients, which narrow its scope of application [23].

Pharmacological treatment

Topical 1% atropine applied to the fellow eye is an effective treatment for mild to moderate amblyopia in children after refractive correction and is comparable to occlusion, particularly in cases of hyperopia in the better-seeing eye. A twice-weekly atropine dosing regimen demonstrates similar efficacy to daily dosing [17, 28]. Treatment requires regular monitoring of visual acuity in both eyes because of the risk of transient visual deterioration and the rare occurrence of reverse amblyopia. More common adverse effects include photophobia (approximately 18%) and conjunctival irritation (approximately 4%), which may limit the use of atropine in regions with high sun exposure [16]. Systemic adverse effects may include dry mouth and skin, fever, delirium, and tachycardia. The use of 1% atropine in children under 3 years of age has not been evaluated in randomized clinical trials, and this age group may be more susceptible to systemic effects.

Multiple studies have demonstrated favorable outcomes with combined atropine and patching therapy (CAPT). The efficacy of CAPT has been shown to be substantially higher than that of patching as a monotherapy. Wang et al. showed that, at 6 months, the mean improvement in visual acuity of the amblyopic eye was 0.72 logMAR (7.2 lines) in the CAPT group versus 0.58 logMAR (5.8 lines) in the occlusion group [29].

Optical treatment options for amblyopia

Modification of the refractive correction of the better-seeing eye (most commonly by adding +1.00 to +3.00 diopters sphere to the values obtained by cycloplegic refraction in order to defocus distance vision) has been used as a method of treating amblyopia. However, the efficacy of this approach has been variable, and the technique has not yet been evaluated in randomized clinical trials, limiting the strength of the available evidence [30].

Bangerter foils

Bangerter foils (Ryser Optik AG) are semitransparent membranes adhered to the spectacle lens of the better-seeing eye. They

Amblyopia severity	Visual acuity of the amblyopic eye	Recommended duration of occlusion of the dominant eye	Findings from clinical trials
Moderate	20/40–20/80	2 hours	VA improvement comparable to 6 hours of occlusion
Severe	20/100–20/400	6 hours	efficacy of 6-hour daily patching comparable to full-day occlusion

Tab. III. Recommended duration of eye occlusion in amblyopia.

Feature analyzed	Atropine (pharmacological treatment)	Occlusion (eye patching)
Mechanism of action	cycloplegia of the fellow eye – optical defocus (particularly effective in hyperopia)	elimination of visual stimuli from the dominant eye
Timing of application	following unsuccessful refractive correction alone; alternative or replacement for occlusion	when refractive correction alone is unsuccessful
Optimal efficacy	when the fellow eye is hyperopic	independent of the type of refractive error
Efficacy (VA)	comparable to occlusion in RCTs	comparable to atropine
Dosage	1% atropine twice weekly or daily	2 h/day (moderate) or 6 h/day (severe)
Compliance	typically better (no patch)	frequently limited (social acceptance, discomfort)
Adverse reactions	photophobia (~18%), conjunctival irritation (~4%)	skin irritation, discomfort
Effect on binocular vision	may induce esotropia or improve it	neutral or improved control
Remarks	caution in children under 3 years of age – absorption may be reduced by applying pressure to the lacrimal puncta	requires proper patch placement

Tab. IV. Table comparing the use of two amblyopia treatment methods – atropine and occlusion.

represent a therapeutic option for **mild to moderate amblyopia**. Most commonly, they have been used as maintenance therapy following initial treatment such as occlusion or atropine. In a randomized controlled trial comparing the efficacy of the filters as first-line therapy with occlusion prescribed for 2 hours daily, children with moderate amblyopia achieved, on average, a similar improvement in visual acuity in both the filter group and the occlusion group [18].

Digital binocular (dichoptic) therapy

Binocular therapy has been used to treat amblyopia in children with either no strabismus or with small-angle strabismus who retain some degree of binocular visual function. Images are presented dichoptically. Typically, high-contrast images are presented to the amblyopic eye, and reduced-contrast images to the fellow eye. An example is shown in Figure 1.

In 2025, researchers compared dichoptic therapy with occlusion. In their conclusions, they reported that video-based therapy and conventional occlusion demonstrate comparable efficacy in improving visual acuity in children with amblyopia. They also noted that high compliance with dichoptic therapy may be associated with greater improvement in visual function [31].



Fig. 1. Dichoptic therapy [32].

Home-based dichoptic therapy administered for approximately 1 hour per day for 12 weeks was evaluated in a Phase III randomized clinical trial. The amblyopic eye showed an improvement in visual acuity of 1.8 lines in the intervention group, compared with 0.8 lines in the control group receiving optical correction alone,

with no serious adverse events reported [33]. A multicenter randomized trial protocol published in 2025 describes “gamified binocular therapy”, i.e., a binocular treatment delivered in the form of an interactive game designed to improve visual acuity and binocular function through appropriate modulation of visual stimuli. The study is designed to evaluate therapeutic efficacy as well as safety and patient adherence [34].

The advancement of digital technologies in dichoptic therapy is associated with increasingly favorable treatment outcomes in pediatric amblyopia. Randomized clinical trials have demonstrated that modern modalities of binocular therapy utilizing VR headsets or mobile devices yield significant improvements in visual acuity. Ongoing studies aim to define the optimal indications and treatment protocols for binocular therapy in amblyopia more precisely.

Therapy based on eye-tracking technology and anaglyph spectacles (color filters separating the visual input for each eye)

Therapy combining eye-tracking technology with anaglyph spectacles represents one of the best-documented approaches to home-based amblyopia treatment. This modality relies on dichoptic image presentation, where the system modifies the content viewed by the dominant eye in real time by blurring the central portion of the image while maintaining binocular video projection. In a multicenter RCT in which children were randomly assigned to binocular therapy or conventional occlusion, this approach was reported as an effective home-based treatment for pediatric patients [35]. Subsequently, a post-treatment follow-up observational study demonstrated that the achieved gains in visual acuity and binocular function can be maintained for one year following treatment completion [36].

Therapy using red-green spectacles

Red-green spectacles do not constitute a standalone therapy. Rather, they serve as a device that enables dichoptic stimulation. This stimulation involves the separate presentation of visual stimuli to each eye in such a way that the task can only be completed by integrating information from both eyes. In practice, one eye receives part of the visual elements while the other receives the remaining components. These inputs must be integrated through binocular vision, which may help reduce suppression of the amblyopic eye. In dichoptic approaches, the contrast between the eyes can be varied to achieve more balanced binocular activity and improve stereoscopic function [37].

Anaglyph spectacles are used in digital therapeutic programs based on the principles of binocular training, such as applications incorporating gamification, in which stimuli are presented in a manner that requires cooperation between both eyes [38]. Studies of binocular therapies indicate that the efficacy of such approaches depends on the overall therapeutic protocol and the manner in which visual stimuli are presented, rather than on the use of color filters alone [36, 38].

Pharmacological adjunctive treatment of amblyopia

Drugs such as levodopa, citicoline, SSRIs, and acetylcholinesterase inhibitors are being considered in the treatment of amblyopia because of their potential effects on central nervous system neuroplasticity mechanisms [39]. These substances modulate key neuromodulatory systems (dopaminergic, serotonergic, and cholinergic) that play an essential role in the processes of learning and attention, and synaptic reorganization within the visual cortex and the visual pathway. Consequently, they may facilitate functional adaptation of the visual system in response to therapeutic stimulation. However, this pharmacotherapy does not constitute a standalone treatment and does not replace standard vision-rehabilitation methods (such as refractive correction, occlusion, or orthoptic exercises), functioning only as a potential adjunct to active therapy. The largest, methodologically rigorous randomized, placebo-controlled clinical trial conducted in children aged 7–12 with residual amblyopia evaluated the efficacy of levodopa administered as an adjunct to occlusion. This study showed no clinically significant additional improvement in visual function compared with placebo, and the observed differences were of little practical relevance [40]. For both citicoline and SSRIs, the available literature includes reports indicating a potential therapeutic effect as well as studies yielding neutral results [39, 41, 42]. For donepezil, on the other hand, the data derive primarily from pilot studies and small clinical trials, precluding any definitive conclusions regarding its efficacy in the treatment of amblyopia [43].

Alternative therapies

Active therapeutic interventions, including anti-suppression exercises, vergence exercises, accommodative exercises, eye-hand coordination exercises, and perceptual learning, have been used in the treatment of amblyopia in both outpatient and home-based settings. Most commonly, these methods have been recommended as an adjunct to occlusion therapy rather than as a standalone treatment. However, there is currently insufficient compelling

scientific evidence to support their efficacy as a treatment for amblyopia [18, 44, 45].

Follow-up of patients with amblyopia

The purpose of follow-up visits is to evaluate treatment response and modify the therapeutic plan as needed. The primary component of the follow-up assessment is visual acuity testing of the amblyopic eye. However, obtaining an interim medical history is equally essential, with particular emphasis on treatment adherence, the occurrence of adverse effects, and visual acuity evaluation of the fellow eye. Measuring visual acuity in children can be challenging, which is why maintaining continuity of the care team, consistent testing conditions, and the same assessment method across consecutive follow-up visits is recommended. Using the same or comparable charts in a child-friendly environment enhances the reliability of the results. When a child transitions from symbol-based to letter-based charts for the first time, performing both types of assessment during the same visit is recommended to enable comparison with prior measurements, as scores obtained with symbols are typically higher [46, 47].

The initial follow-up visit should be scheduled **2 to 3 months** after initiating treatment. The measured visual acuity depends both on the true clinical response to therapy and on the child's degree of cooperation during testing and adherence to the prescribed therapeutic regimen. The treatment algorithm is presented in Table V.

Conclusions

Amblyopia involves a reduction in best-corrected visual acuity in one or both eyes, occurring in the absence of identifiable ocular pathology and resulting from abnormal visual stimulation during the critical period of visual system development. It most commonly results from refractive errors, strabismus, or visual stimulus deprivation. The efficacy of amblyopia treatment depends on its severity, the child's age, underlying etiology, and, above all, treatment compliance. Therefore, therapy selection should take into account the capabilities and preferences of both the child and their caregivers.

Management of amblyopia in children should follow a stepwise approach: from refractive correction to conventional therapy, through to adjunctive modalities in cases of limited efficacy or poor patient compliance. Frequent follow-up visits, visual acuity monitoring, and assessment of binocular visual function are essential to optimize treatment outcomes. In recent years, comple-

Response to treatment	Recommended modification of management
No improvement in visual acuity after 3 months of treatment	continue or modify (increase) the duration of occlusion, or initiate atropine penalization; consider an alternative treatment method
Severe skin irritation during occlusion therapy	switch to an alternative form of therapy
No improvement in visual acuity despite occlusion therapy	consider alternative treatment; gradually reduce or discontinue treatment if the current therapy has been continued for a sufficiently long period
Treatment ineffective due to an underlying condition (e.g., optic nerve hypoplasia)	gradually reduce or discontinue treatment
Development of strabismus and/or diplopia	temporarily discontinue treatment; monitor ocular alignment and visual acuity
Decrease in visual acuity in the fellow eye by ≥ 2 lines	temporarily discontinue treatment, reassess the diagnosis and monitor the patient; if reverse amblyopia is suspected, consider occlusion of the eye that was previously amblyopic
Visual acuity remains stable at a normal or near-normal level for ≥ 4 months, confirmed at least at two follow-up visits	gradually reduce or discontinue treatment

Tab. V. Amblyopia treatment algorithm [18].

mentary and alternative modalities, particularly digital binocular/dichoptic therapies, have advanced rapidly, opening new avenues for amblyopia treatment. Early diagnosis and appropriately tailored, stepwise intervention are essential to achieving sustained improvements in visual function in children.

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