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Original Article

Evaluation of Behavioral Characteristics in Response to Visual Stimuli in Infants with Cerebral Visual Impairment

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Abstract

Objectives: To evaluate the behavioral characteristics of infants with cerebral visual impairment (CVI) in response to visual stimuli and the frequency of these features.

Materials and Methods: In this retrospective study, 32 infants aged 8-37 months who were referred to the low vision unit in 2019-2021 and diagnosed with CVI based on their demographic characteristics, systemic findings, and standard and functional visual examinations were evaluated. The frequency of ten behavioral characteristics exhibited by infants with CVI in response to visual stimuli as defined by Roman-Lantzy was examined in the patients.

Results: The mean age was 23.46±11.45 months, the mean birth weight was 2,550±944 g, and the mean gestational age at birth was 35.39±4.68 weeks. There was hypoxic-ischemic encephalopathy in 22%, prematurity in 59%, periventricular leukomalacia in 16%, cerebral palsy in 25%, epilepsy in 50%, and strabismus in 68.7% of the patients. Color preference for fixation was observed in 40% and visual field preference was observed in 46% of the patients. The most preferred color was red (69%) and the most preferred visual field was right visual field (47%). Difficulty with distance viewing was observed in 84% of patients, visual latency in 72%, need for movement in 69%, absence of visually guided reach in 69%, difficulty with visual complexity in 66%, difficulty with visual novelty in 50%, light-gazing/non-purposeful gaze in 50%, and atypical visual reflexes in 47%. There was no fixation in 25% of the patients.

Conclusion: Behavioral characteristics in response to visual stimuli were observed in most infants with CVI. Knowing and recognizing these characteristic features by ophthalmologists will assist in early diagnosis, referral to visual habilitation, and planning habilitation techniques. These characteristic features are important in order to not miss this critical period in which the brain is still plastic and good responses to visual habilitation can be obtained.

Keywords: Cerebral visual impairment, cortical visual impairment, low vision, visual habilitation, visual impairment

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Introduction

Cerebral visual impairment (CVI) is functional visual impairment resulting from damage to the retrochiasmal visual pathways.[1,2,3] It is the most common cause of low vision in children in developed countries, and its prevalence is increasing steadily in developing countries.[2,4,5,6,7] Various factors are believed to have increased the incidence of CVI, such as increased neonatal care services, improved survival of preterm infants, and higher rates of multiple pregnancy due to infertility treatment.[2,3,8]

Although the terms "cerebral" and "cortical" visual impairment are often used interchangeably in the literature, involvement is not limited to the cortex in most cases of CVI. Therefore, the expression "cerebral visual impairment" is thought to be more accurate.[1,3,8,9] In addition, because almost all patients have some vision, it has been noted that the term "cortical visual impairment" would be more appropriate than "cortical blindness."[10]

Perinatal and postnatal hypoxic ischemic encephalopathy is the most common cause of CVI.[1,2,3,9,11] There are insults to the postgeniculate visual pathways in the brain.[1,2,3] This affects the perceptual visual system; i.e., the ability to understand what is seen. Damage may be present in the visual pathways and visual information processing centers of the brain. Of the visual information processing centers, the dorsal stream (occipitoparietal pathway) is known as the "where" pathway and the ventral stream (occipitotemporal pathway) as the "what" pathway. Defects in these pathways cause disturbances in object recognition, object detection in complex environments, orientation in space, and perceptual visual disorders.[2,3,12]

Features suggestive of CVI are bilateral visual impairment, generally normal ocular structures or no detectable pathology explaining deep vision loss on standard ophthalmologic examination, and the presence of an underlying cerebral pathology.[1,2,3] There is no standard protocol for making a diagnosis. The brain is more affected than the eye, and patients often have additional systemic problems other than visual impairment.[2,3,10] Standard structural brain imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) demonstrate cerebral damage, aiding in the diagnosis of CVI. In the assessment of functional vision, new imaging methods such as functional brain imaging methods and diffusion tensor MRI can provide more information about the structure-function relationship in the brain.[11]

Patients with suspected CVI should undergo standard ophthalmological examination at initial evaluation, and refractive error and lack of accommodation should be corrected if needed.[2] However, a standard vision examination is not always possible and is insufficient to determine the severity of CVI.[13] Observing visual and behavioral responses in these cases is considered the most appropriate method of evaluating the visual system, especially in patients who are pre-speech or have limited speech abilities.[14]

Roman-Lantzy[15] described 10 characteristic behavioral responses to visual stimuli in patients with CVI. The characteristic features of CVI may vary depending on the area of the brain that is affected. It has been reported that dorsal stream dysfunction resulting from damage to the occipitoparietal pathway and periventricular white matter causes impaired movement perception, difficulty seeing in complex environments, and difficulty with distance viewing,[16] whereas ventral stream dysfunction due to occipitotemporal pathway disorders affects visual memory and causes difficulty in object recognition and visual novelty.[17] Periventricular leukomalacia (PVL), which is especially common in prematurity, causes lateral ventricle enlargement, damaging the upper fibers of the optic radiations and leading to binocular lower visual field defects.[17,18] Visually guided stretch may indicate dysfunction in both the dorsal and ventral streams of the visual system.[3] Evaluating these features during assessment is important to avoid missing the diagnosis and to enable early intervention. However, there may be inconsistencies in the responses shown by patients with CVI, sometimes depending on the target shown, sometimes on the environment, and sometimes on infant-related factors.[2,3,15,19,20] Therefore, information related to these behavioral characteristics that is obtained by the physician through functional visual assessment should be evaluated together with information gleaned from parental observations.[2,3,11,15,19]

Vision is a sense that can be learned and developed because of the plasticity of the brain.[21,22] Functional vision and quality of life are reduced in CVI.[10,23] Therefore, diagnosis should be made and visual habilitation initiated as early as possible.[2,3] The visual potential of patients with CVI can be increased with early visual habilitation.[2,3,10,16,21,24] The planned visual habilitation should be multidisciplinary and individualized, and the methods used should be personalized according to the degree of impact.[2,3,19,25] Specifically, the preferred color and visual field for fixation, if any, should be determined.[3,19] It has been reported that the visual attention of patients with CVI can be increased through focusing and tracking exercises performed in a minimally crowded, simplified visual environment[1,3,26] and that using colorful, high-contrast, and moving objects can be used for this purpose.[3,25,26]

The aim of this study was to assess the behavioral characteristics observed in infants diagnosed with CVI and determine the incidence of these features. There are limited studies investigating behavioral characteristics in response to visual stimuli in CVI in the literature. To our knowledge, this is the first study on this subject in our country.

Materials and Methods

This cross-sectional retrospective clinical study was approved by the Clinical Research Ethics Committee of Adana City Training and Research Hospital (decision no: 02.12.2021/1655). All steps and procedures of the study were carried out in accordance with the principles of the Declaration of Helsinki and informed consent forms were obtained from the parents of the participants.

The study included 32 infants with CVI aged 8-37 months who presented to the low vision unit between August 2019

and May 2021. A detailed prenatal, perinatal, and postnatal history was obtained, followed by standard and functional ophthalmologic examinations. A pediatric neurology consultation was requested for all patients who were not referred by pediatric neurology but presented directly. CVI was diagnosed by a single ophthalmologist (D.A.) using all of the collected data. Parents were informed of the behavioral characteristics of CVI and were asked to come for follow-up after observing their infant for 1 week. The parents were questioned about these characteristics by the same ophthalmologist (D.A.).

In this study, the 10 characteristics of visual behavior specific to CVI defined by Roman-Lantzy[15] were assessed in patients with CVI. These characteristics are color preference for fixation, visual field preference for fixation, difficulty with distance viewing, atypical visual reflexes (incompletely developed blink and threat responses), difficulty with visual novelty, visual latency, need to move an object to initiate fixation, absence of visually guided reach, difficulty with visual complexity, light-gazing, and non-purposeful gaze. There is no age-specific standardized questionnaire to evaluate these 10 characteristics. Therefore, we asked some simple questions for each characteristic. For example, we asked the questions "Does your baby show more interest in any color when looking at toys or object?" for color preference, "Does your baby look from a different side when you show them a toy? Do they turn their head to the right, left, etc.?" for visual field preference, "From how far away does your baby notice you?" for difficulty with distance viewing, "When you buy a new toy, do they play with it immediately?" for difficulty with visual novelty, "Is there a delay in seeing a toy or bottle?" for visual latency, "When your baby doesn't see a toy, do they see it when you shake it?" for the need for movement, "Do they immediately reach for a toy you show?" for visually guided reaching, "When your house is crowded, when your relatives, neighbors, etc. come over, does your baby get fussy?" for difficulty with visual complexity, and "Do they look at the ceiling lamp or other light sources for a long time?" for the need for light.

Roman-Lantzy[19] divided CVI into three groups: phase 1, phase 2, and phase 3. Phase 1 is the first phase. It is called the gaze phase, where the child begins to use their vision to look at objects. The color, size, and shape of objects are very important in this phase. In phase 2, the gaze becomes more functional. The child uses their vision to reach for an object or light. In phase 3, visual resolution occurs. In this phase, the characteristic features are less pronounced and vision is improved.[19] A multidisciplinary approach and special training are required to identify the phases of patients with CVI. Therefore, the patients in our study were not grouped according to phase.

During the examination, care was taken regarding the absence of sensory stimulation other than vision; the selection of objects (balls in various colors) appropriate for age and CVI severity; inconsistencies in visual responses that may vary depending on the infant, environment, and object selected; and underlying neurological deficits. Some patients did not reach for objects not because they were unable to see the object, but because of loss of upper extremity motor function. Those who could not perform reaching movements due to concomitant conditions such as cerebral palsy or hemiplegia were excluded from the study. As there may be delayed fixation in CVI, the infants were given sufficient time (up to 3 minutes) during the examination to focus.

Standard objective visual acuity examination methods (e.g., preferential gaze tests, optokinetic nystagmus, visual evoked potential) are not sufficient and reliable to assess distance vision in CVI.[13] The ophthalmologist must also evaluate infants' behavioral responses to visual stimuli at a certain distance. In our study, infants with no fixation were accepted as having difficulty with distance viewing. Infants with fixation were shown colored balls (9-cm diameter ball first, in the preferred color if the infant has a color preference or red if no color preference) at specific distances (50 cm, 1 meter, 1.5 meters, 2 meters, and 3 meters) and assessed for fixation on and following of the target. Infants with fixation who could not track the target at distances closer than 3 meters were evaluated as having inadequate distance vision.[17]

Color preferences were identified using balls that were the same in terms of size, brightness, and shape and only differed in color.[2,15,19] A total of 8 hollow plastic balls 6 cm or 9 cm in diameter and colored red, yellow, blue, or green (two sizes for each color) were used for this purpose.

The study included 32 infants between the ages of 8 and 37 months who were described as having low vision by their parents or pediatric neurologists, had normal ocular structures or no ocular pathology severe enough to explain deep visual impairment on eye examination, had brain damage detected by pediatric neurology, and were diagnosed with CVI. Infants younger than 8 months and older than 37 months, those with ocular pathology that could explain their visual impairment, those who were not evaluated by pediatric neurology, those who had bilateral arm weakness due to brain damage and could not reach for objects because of motor deficits, and those who did not come for follow-up after 1 week of observation were excluded from the study.

Statistical Analysis

IBM SPSS Statistics version 20.0 package program (IBM Corp., Armonk, NY, USA) was used for statistical analysis of the data. Categorical variables were expressed as number and percentage, and numerical variables as mean and standard deviation. The level of significance was accepted as $p<0.05$ for all tests.

Results

The study included 10 female and 22 male patients. The mean age was 23.46±11.45 months, mean birth weight was 2,550±944 g, and mean gestational age at birth was 35.39±4.68 weeks. Nineteen (59%) of the patients were preterm (born at or before 37 weeks of gestation), 7 (22%) had hypoxic ischemic encephalopathy, 5 (16%) had PVL, 3 (9.4%) had hydrocephalus, 2 (6%) had intracranial hemorrhage, and 1 (3%) had neonatal hypoglycemia. Sixteen (50%) of the patients had epilepsy requiring medical treatment and 8 (25%) had cerebral palsy.

Eye examination revealed nystagmus in 8 patients (25%), strabismus in 22 patients (68.7%), including 19 (86.3%) with esotropia and 3 (13.7%) patients with exotropia, and optic disc pallor in 13 patients (40%). Eight patients (25%) had no fixation (Figure 1). Among those with fixation, the mean duration of fixation was 6.25±6.83 seconds. Fixation was longer than 5 seconds in 14 patients (43%) and longer than 10 seconds in 5 patients (15%).

The patients' CVI-specific behavioral responses to visual stimuli are shown in Table 1. A color preference for fixation was observed in 13 patients (40%) and a visual field preference was observed in 15 patients (46%). For fixation, 9 patients (69%) preferred red, 3 (23%) preferred yellow, 7 (47%) preferred the right visual field, 5 (33%) preferred the left visual field, and 2 (13%) preferred the upper visual field. None of the patients had a lower visual field preference.

Discussion

Functional visual assessment and parental observations of patients with CVI provide guidance in the diagnosis of CVI, determination of its severity, and the planning of visual habilitation techniques to use.[2,3,13,15,19] In this study, the 10 behavioral characteristics in response to visual stimuli defined by Roman-Lantzy[15] were evaluated in infants with CVI and were observed at rates of 40-84% in these patients. We observed that 40% of the patients had a preferred color for fixation, with red being the most common color (69%), and 46% of the patients had a visual field preference for fixation, usually the peripheral visual field (80%). In 25% of the patients, no fixation was detected.

In the literature, perinatal hypoxia and ischemia have been reported as the most common causes of CVI.[9,11,24] The prevalence of hypoxic-ischemic encephalopathy in CVI was reported to be 22% by Huo et al.[24] and 25% by Chong and Dai.[9] Similarly, hypoxic-ischemic encephalopathy was the most common etiological factor in our CVI patients (22% of cases). Due to the underlying hypoxia and ischemia, CVI is frequently accompanied by neurological problems such as cerebral palsy and epilepsy.[3,10,11,24,27] The rate of cerebral palsy in patients with CVI has been reported to be between 26% and 47.7%.[24,28,29] Huo et al.[24] reported that chronic CVI was associated with epilepsy in 53% and cerebral palsy in 26% of their cases. In our study, 50% of the patients had epilepsy and 25% had cerebral palsy, consistent with the literature. Prematurity has also been implicated as an important risk factor for cerebral palsy.[30,31] This is supported by the fact that 59% of the patients with CVI in our study were preterm, and 75% of those with CVI and comorbid cerebral palsy were preterm. The mean gestational age at birth was 35.39±4.68 weeks among all patients and 32.35±5.44 weeks among those with cerebral palsy. Of the preterm patients, 26% had PVL due to prematurity. It has been reported that damage to the periventricular area during delivery causes PVL[8], particularly in premature infants at 24 to 34 weeks of gestation, affecting the upper fibers of the optic radiation and leading to CVI.[32,33]

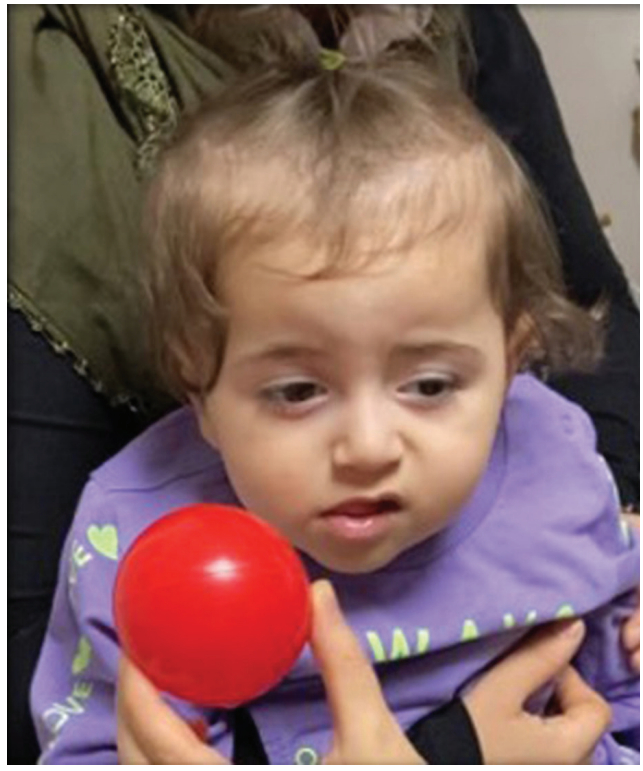

Figure 1. Absence of fixation in cerebral visual impairment

Table 1. The prevalence of characteristic responses to visual stimuli in patients with cerebral visual impairment

Behavioral characteristics	Number of patients	Percentage (%)
Color preference	13	40
Visual field preference	15	47
Difficulty with distance viewing	27	84
Atypical visual reflexes	15	47
Difficulty with visual novelty	16	50
Visual latency	23	72
Need for movement to initiate vision	21	69
Absence of visually guided reach	21	69
Difficulty with visual complexity	21	66
Light-gazing/non-purposeful gaze	16	50

Visual improvement in CVI is reported to be possible because of brain plasticity.[2,3,10,16,21,24] In their cohort study, Malkowicz et al.[34] gave a home program to 21 children aged 1-13 years with cortical vision loss, followed them for 4-6 months, and examined the effect of this program on the neuroplasticity of the brain with MRI and CT scans. As a result, they stated that there was visual improvement and reintegration in these children with cortical vision loss, that brain plasticity was preserved, and that visual skills could be improved with this plasticity. However, it should be noted that age is a prognostic factor in CVI. Diagnosis after the age of 3 years in particular adversely affects the prognosis.

Therefore, the diagnosis should be established as soon as possible and visual habilitation should be initiated in the early period.[16,24,35,36]

Training exercises to increase visual function are more efficient when planned according to the child's individual needs.[2,37] The behavioral characteristics observed in CVI facilitate this stage.[3,13,15,19,25] Based on the presence of these characteristics, the impact of CVI should be determined and vision should be improved using systematic visual stimuli planned according to CVI severity and age of the patient.[2,3] These characteristics should be assessed before planning visual habilitation, and any color or visual field preferences that are observed should be exploited during training.[3,19,25]

There are few studies in the literature on the behavioral characteristics observed in CVI.[15,18,19,25] In the absence of extensive cerebral damage, color vision-specific cortical areas are generally preserved and color vision is usually normal.[25,26] However, there are color preferences for fixation.[17] The ability to recognize colors is much stronger than the ability to perceive shapes.[1,20,25] This is because color perception, unlike shape perception, is represented bilaterally in the visual cortex and fewer neurons are needed for color vision.[20,38] In our study, color preference was observed in 40% of the patients and the most preferred color for fixation was red (69%), followed by yellow (23%). Roman-Lantzy[17] investigated the color preferences of 76 children aged 6 months to 15 years and reported that the most preferred colors were red (55%) and yellow (34%). Other studies have also shown that bright colors such as red or yellow are more preferred for fixation in CVI.[3,17,20,39,40] Preference for the colors red and yellow may be related to the presence of more photoreceptors for these colors in the human eye due to their long wavelengths.[3] It has been reported that infants and children with CVI are able to learn the names of colors and associate colors with objects.[25] Therefore, color perception can be used to teach vision during visual habilitation in such children with poor shape perception.[3,15,19,25]

Motion perception, which is one of the variables that helps process visual information, is usually preserved in CVI, like color perception. These patients can often perceive movement due to the preservation of the retinocollicular pathways or intact areas of the visual field.[20,41] If the object is motionless, they may have difficulty perceiving it. In most cases, the target must be moved to be seen.[17,25,42] In our study, we observed that 69% of the patients needed a moving target to engage vision. Cohen-Maitre and Haerich[25] reported that colors and moving the target for fixation in patients with CVI are important in maintaining the child's visual attention, and it may be beneficial to use these features to increase motivation for visual learning in these cases.

Visual field preference is also important in terms of planning visual habilitation techniques in patients with CVI.[3,14,17] There is usually a preference for the right or left visual field. In our study, 46% of the patients had a visual field preference and 80% preferred the peripheral visual field. None of the cases preferred the lower visual field. It has also been reported in the literature that the lower quadrant of the visual field was least preferred in CVI.[3,17] This has been attributed to the PVL-induced damage to the upper fibers of the optic radiation and the development of lower visual field defects, especially in preterm patients.[32,33] In our study, no visual field preference was observed in 54% of the patients. Dutton et al.[32] reported in their study that visual field preference was not observed in all cases and was not detected in approximately one-third of the patients.

Gazing at light when there is a visual stimulus in the environment is a common and unique behavioral response in CVI that indicates delayed visual development.[17] In our study, light-gazing was observed in 50% of the patients. Jan et al.[18] reported that light-gazing was seen in 60% of 153 patients with CVI but detected no neuroanatomical differences between the groups with and without this behavior. Although the cause of this behavior is not fully understood, it is thought that light attracts visual attention and increases visual motivation.[2]

Most patients with CVI have difficulty perceiving objects in a complex environment and view objects at close range because they avoiding the crowding phenomenon.[20] van Genderen et al.[43] calculated the crowding rate for this characteristic (the ratio of single optotype visual acuity to linear visual acuity) and found this rate to be ≥2.0 in 41% of children with CVI and 4% of children without CVI. In support of this study, Little and Dutton[44] reported that the use of a plain monochrome tent during visual habilitation eliminated visual clutter and enabled children to focus on single stimuli presented in sequence, thereby helping to encourage visual attention and learning. In our cases, the prevalence of difficulty with vision in complex environments was 66% and the prevalence of difficulty with distance viewing was 84%. We believe that the prevalence we determined for difficulty with distance viewing may not reflect actual low visual acuity, but may in fact be related to difficulty in perceiving the object amid increasing complexity as it moves farther away and other objects enter the visual field.[43]

Children with CVI usually need time to visually focus and look. It can often be necessary to wait 15-30 seconds for fixation.[2] Fixation latency and fixation duration may show inconsistencies depending on the child, environment, and target.[2,3,15,19,20] The duration of fixation is short in most patients. Although sufficient time was given in this study, 25% of the patients did not fixate, and only 43% of patients had a fixation duration longer than 5 seconds.

In a comprehensive review of CVI, strabismus was reported at a rate of 31-94%, nystagmus at 11-92%, and optic atrophy at 16-42%.[11] Consistent with the literature, we observed strabismus in 68.7%, nystagmus in 25%, and optic disc pallor in 40% of the patients in our study. Rates of optic disc pallor may vary depending on the duration of hypoxia in the patients included in the studies. This is because the optic nerve is resistant to hypoxia in the perinatal period, and optic disc atrophy is an indicator of severe hypoxia and poor prognosis.[3]

Roman-Lantzy[19] proposed that CVI patients can be divided into 3 phases of progressively lower disease severity. Phase 1 is the initial phase, phase 2 is the intermediate phase, and phase 3 is the end phase. Behavioral characteristics guide the diagnosis of CVI and the planning of habilitation strategies. According to Roman-

Lantzy,[19] each phase is determined by a scoring the resolution of behavioral characteristics. As the visual improvement progresses, the characteristics resolve and the patient transitions from phase 1 to phase 2, and then to phase 3. However, scoring requires special training. Some studies have reported that the CVI phases and scoring system can be used to guide visual therapy and monitor treatment response.[15,19,45] However, it has also been stated that further research and evidence are needed to support the role of this scoring system in the clinic.[11]

Study Limitations

In this study, the behavioral characteristics seen in CVI were evaluated in patients who we diagnosed as having CVI. However, a similar study could be conducted by including age-matched subjects with ocular visual impairment and those without visual impairment in order to compare these characteristics between children with CVI, ocular visual impairment, and normal vision. For questions to be asked parents in future studies, a standardized questionnaire for 0- to 3-year-olds can be created. There are a limited number of studies on this subject in the literature, and this is a preliminary study conducted in our country. Therefore, more cases and studies are needed to determine the incidence and features of behavioral characteristics observed in CVI.

Conclusion

There is no standard treatment for CVI, but patients' quality of life can be increased with a multidisciplinary approach and early visual habilitation support. As standard vision examination is insufficient in these patients, performing functional vision assessment and evaluating functional vision and the behavioral characteristics of CVI are important for diagnosis and referral to visual habilitation in the early period, planning visual habilitation techniques, and promoting the visual and systemic development of the infant/child.

Ethics

Ethics Committee Approval: This cross-sectional retrospective clinical study was approved by the Clinical Research Ethics Committee of Adana City Training and Research Hospital (decision no: 02.12.2021/1655).

Informed Consent: Informed consent forms were obtained from the parents of the participants.

Peer-review: Externally peer reviewed.

Authorship Contributions

Surgical and Medical Practices: D.A., Concept: D.A., Design: D.A., Data Collection or Processing: D.A., İ.T., Analysis or Interpretation: D.A., Literature Search: D.A., Writing: D.A.

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