RESULTS OF HEMIVERTEBRA EXCISION THROUGH COMBINED, POSTERIOR AND TRANSPEDICULAR APPROACHES: SYSTEMATIC REVIEW

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The paper presents a review of 28 domestic and foreign publications with the level of evidence of not less than 2 reporting the treatment results in children with congenital monosegmental anomalies of the spine over the past 15 years. A total of 657 clinical cases were analyzed, including 593 literature cases and 64 cases from authors' experience. Results of hemivertebra treatment in children using combined approach, extended posterior approach and local posterior approach with transpedicular excision of hemivertebra were analyzed. The following criteria were used for analysis: patient's age at the time of treatment, magnitude of the local (segmental) curvature before and after surgery, percentage of correction, blood loss volume, duration of surgery, type and length of fixation, and nature and structure of complications. The advantages of transpedicular excision of abnormal vertebra through posterior approach were noted in terms of surgery duration, intraoperative blood loss, risk of neurological complications after comparable correction of deformity, and time required for patient activation and rehabilitation as compared with combined approach, as well as in terms of blood loss volume and correction of kyphotic component as compared with extended posterior approach.
Key Words: congenital scoliosis, congenital kyphosis, monosegmental anomalies of the spine, hemivertebrae, posterior approach, transpedicular excision, deformity correction.

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During the last 10–15 years, surgical resection of hemivertebrae have become the standard treatment of this pathology in young children. Early intervention (within the period from 2 to 5 years) maximizes deformity correction, prevents the development and progression of secondary curves, minimizes the number of fixed segments and preserves the correct axial growth of intact spinal segments [1, 4, 6, 8, 9, 15, 22, 24 29].

Hemivertebra excision (extirpation) first described by Royle in 1928 [23] is one of the main methods of surgical treatment of congenital monosegmental deformity caused by hemivertebra or hemivertebrae. At the early stages, this operation was carried out alone through the anterior approach without additional stabilization or fixation. The high incidence of poor outcomes due to progressing kyphoscoliosis with underlying pseudarthrosis necessitated the use of metal fixation (plates, rods, cerclages) [10]. Subsequently, posterior instrumented fixation along with extirpation of hemivertebrae through the combined anterior and posterior approach has become more popular, and improvement of metal structures provided more reliable fixation of segments and improved deformity correction outcomes. Widespread implementation of the third generation instrumentation (CD) has led to formation of two opposing camps of pediatric spinal surgeons, who mainly discuss, which fixators, hook or screw, should be favored after hemivertebra excision. At the same time, the issues of hemivertebra excision methods, which have also improved with the development of new techniques, are beyond the discussion. The latter fact determined the objective of our review.

Evidence level 2++.

Material and Methods

We analyzed 28 Russian and foreign articles published over the last 15 years, which describe the treatment outcomes of children with congenital monosegmental abnormalities of the spine.

Thematic sources were searched in the PubMed (NCBI), Cochrane Library, The Cochrane Database of Systematic Reviews, and eLIBRARY databases, according to the following inclusion criteria:

1) surgical resection of monosegmental defects using transpedicular or hook fixation of the spine in children;

2) case series or cohort studies with the level of evidence 2+, 2-, 3;

3) postoperative follow-up more than 2 years;

4) age of the patients at the time of operation from 1 to 8 years;

5) available information about the magnitude of the deformity before and after surgery, volume of blood loss, duration of surgery, type and extent of fixation, the nature and structure of complications.

Patients described in 22 publications had deformities with underlying local isolated or unsegmented hemivertebra. Three articles describe treatment of patients with hemivertebra or asymmetric butterfly-like vertebra as the leading component of the spine deformity in combination with the neutral form of segmentation disorder at another level [12, 16, 18]. Result duplication could not be ruled out in three publications and therefore they were not included in the final data analysis [3, 4, 25]. When the authors had similar studies discussing similar clinical material [1, 3, 4, 6, 25, 26], we analyzed data from only one publication of these authors, which included the largest number of cases (Table 1).

A total of 657 cases of monosegmental defect treatment in children were analyzed, including 593 cases found in the literature and 64 cases from the experience of the authors of this review obtained at the clinic of the Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics. The cases of hemivertebra excision through the combined approach were analyzed in 10 articles, through isolated posterior — in 18. Treatment outcomes were compared taking into account the approaches used for extirpation: combined, extended posterior and local posterior with transpedicular excision.

The following parameters were analyzed: location of abnormal vertebra, age of patients at the time of treatment, local (segmental) curve magnitude before and immediately after surgery (Cobb angle, degrees), correction percentage, volume of blood loss, duration of surgery, fixation type and length, as well as the nature and structure of complications.

Statistical Package for the Social Sciences (SPSS) version 22.0 (SPSS Inc., Chicago, IL, USA) software was used.

T-tests:

1) comparison of the mean values of the angular scoliotic deformity before and after the operation;

2) comparison of the mean values of the angular kyphotic deformity before and after the operation;

3) comparison of intraoperative blood loss volume and operation time.

The differences were considered as statistically significant at $p < 0.05$. Pairwise correlation analysis with rank-based Kruskal-Wallis test for independent samples showed insignificant correlation: $p < 0.5$ — weak correlation; $0.5 < p < 0.7$ — intermediate correlation; $p > 0.7$ — strong correlation.

Results

Summary of the results of analysed publications are shown in Table 2. Authors' experience ranged from several tens to hundreds of clinical cases.

Summary analysis of the publications enables some generalizations:

– hemivertebrae were most frequently located at the thoracolumbar junction T10–L2, 56 % (354 cases), which is fully consistent with the data of one of the first Russian publications in 1936, which focused on the spinal deformities [5]; the thoracic spine T1–T9 is the second most common location, 25 % (152 cases); lumbar spine L3–L6 is the third, 19 % (121 cases; Fig. 1);

– hemivertebrae are more common in girls than in boys (56 and 44 %, respectively);

– the average age of patients ranged from 5 to 6.5 years in all comparison groups;

– scoliotic deformity component was 37–40° ($p = 0.297$) before surgery and 10–11° ($p = 0.722$) after surgery, correction ranged from 71 to 74 %;

– kyphotic component of the deformity was 22 to 42° ($p = 0.218$) before surgery and 7–10° ($p = 0.214$) after surgery, kyphosis correction was 62–83 %;

– the volume of intraoperative blood loss ranged from 345 to 588 ml ($p = 0.348$), the volume of blood loss as a percentage of the total blood volume could not be calculated, since morphometric data are missing in many articles;

– operation time was 217 to 284 minutes ($p = 0.211$).

Monosegmental unilateral fixation was used in 53 cases, monosegmental bilateral – in 306, polysegmental bilateral – in 209. The average age of children who were operated on through the combined approach was 5 years 3 months, through posterior approach – 6 years 1 month, and using transpedicular excision – 6 years 6 months.

Correlation analysis of the preoperative and postoperative magnitude of local spinal deformity shows linear relationship between the residual deformity and its initial magnitude (Fig. 2a). However, the low value of the coefficient of determination indicates that the relationship is affected by random factors, which cannot be taken into account based on the information provided in the literature. This is also confirmed by the results of approximation of similar data for kyphotic component of the deformity, where the data are even more scattered. When considering the volume of blood loss as a factor limiting surgery duration in different hospitals, it was shown that increase in the blood loss volume often forced surgeons to limit the extent of surgical intervention (Fig. 2b).

The patients were divided into three groups based on the operative approach used for hemivertebra excision: I – combined approach (203 patients), II – posterior (390 patients), and III – transpedicular (64 patients).

The average preoperative magnitude of scoliotic component and its correction were almost equal in all the groups and amounted to 38° and 71 % in group I, 40° and 74 % in group II, 37° and 72 % in group III, respectively. However, preoperative value of local kyphosis and its correction (42° and 83 %, respectively) were significantly higher in group III compared to groups I (22° and 64 %) and II (28° and 62 %).

Duration of operation was 284 min in group I, which significantly exceeded

Table 1
Comparative analysis of the results of hemivertebra treatment in children using the combined, extended posterior, and posteior with transpedicular excision approaches

Source	Patients, n	Age, months	Preoperative scoliotic/kyphotic component, degrees	Postoperative scoliotic/kyphotic component, degrees	Correction (scoliosis/ kyphosis), %	Blood loss, ml	Operation time, min	Monosegmental unilateral fixation	Monosegmental bilateral fixation	Polysegmental bilateral fixation
Combined approach										
S.V. Vissarionov et al. [1]	26	47.0	30.1/18.4	2.5/2.2	92/88	225	140	8	18	–
D.N. Kokushin et al. [6]	37	–	32.7/22.0	6.5/4.6	80/79	–	–	–	14	23
Wang et al. [28]	30	38.5	52.5/46.0	14.4/17.6	73/62	1290	451	–	–	–
Xu et al. [29]	34	145.2	45.3/10.1	14.9/-6.2	67/100	590	235	–	34	–
Bollini et al. [12]	33	41.0	34.8/20.0	17.4/8.6	50/57	–	280	–	33	–
Jalanko et al. [16]	12	38.4	30.8/0	7.4/0	76/0	258	258	–	12	–
Hedequist et al. [14]	18	38.0	40.0/0	9.0/0	78/0	159	308	18	–	–
Mladenov K. et al. [19]	13	69.0	40.0/0	18.0/0	55/0	–	319	–	–	–
Posterior approach										
С.В. Виссарионов с соавт. [2]	18	67.0	37.35/18.40	3.25/8.20	91/55	225	140	–	18	–
Wang L. et al. [28]	30	20.6	40.2/36.4	11.5/15.6	71/57	910	248.5	–	–	–
Ruf M. et al. [24]: группа с единичными полупозвонками	28	41.0	36.1/21.7	7.1/7.7	80/65	309	187	–	23	8
Ruf M. et al. [24]: группа с множественными аномалиями развития	13	–	69.2/23.9	23.3/9.1	66/62	723	272	–	–	13
Jalanko et al. [16]	11	–	32.6/0	8.8/0	73/0	401	228	–	11	–
Zhu et al. [32]	60	84.0	41.6/23.3	5.1/7.3	88/69	350.5	172.7	–	60	–
Li et al. [18]	12	204.0	43.8/11.8	16.5/6.2	62/47	312	155	–	–	12
Peng et al. [22]	10	39.6	35.21/19.61	13.11/4.31	63/78	114	142	10	–	–
Ocampo et al. [21]	7	38.4	35.0/42.0	20.0/29.0	43/31	312	225	–	–	7
Hedequist et al. [15]	10	51.0	44.0/0	9.0/0	80/0	270	–	–	10	–
Zhang et al. [31]	56	118.8	42.4/42.0	11.5/12.6	73/10	812.1	210.1	–	–	56
Chang et al. [13]	20	79.2	34.4/17.4	8.6/-1.3	75/100	472.5	158.0	20	–	–

Table 1 (Continued)

Source	Patients, n	Age, months	Preoperative scoliotic/kyphotic component, degrees	Postoperative scoliotic/kyphotic component, degrees	Correction (scoliosis/ kyphosis), %	Blood loss, ml	Operation time, min	Monosegmental unilateral fixation	Monosegmental bilateral fixation	Polysegmental bilateral fixation
Aydogan et al. [11]: — scoliosis group; — kyphosis group; — kyphoscoliosis group	3 5 11	84.0	40.3/0 0/53.4 38.2/49.4	10.7/0 0/8.5 7.5/12.0	73/0 0/84 80/76	375	312	—	3 5 11	—
Shono et al. [27]	12	168.0	49.0/40.0	18.0/17.0	63/58	600	260	—	12	—
Nakamura et al. [20]: группа с кифосколиозом	3	120.0	49.0/48.0	22.3/15.0	55/69	660	350	—	—	—
Nakamura et al. [20]: группа с кифозом	2	—	34.5/0	23.5/0	32/0	—	—	—	—	—
Ruf et al. [26]	25	40.0	45.3/21.8	14.4/9.8	68/55	496	225	15	13	—
Mladenov et al. [19]	12	68.0	39.0/0	16.0/0	59/0	—	272	—	—	—
Yaszay et al. [30]	42	60.0	35.0/18.0	10.0/14.0	71/22	455	255	—	—	—
Transpedicular excision method: S.O. Ryabych et al. [7]										
Monosegmental unilateral fixation	17	47.8	32.2/30.0	9.8/3.0	70/90	215.4	173.3	17	—	—
Monosegmental bilateral fixation	15	60.1	34.4/32.3	9.4/2.7	73/92	281.0	194.6	—	15	—
Polysegmental bilateral fixation	32	105.5	41.7/53.8	11.3/11.5	73/79	443.2	271.6	—	—	33

0 — conventional value, since one of the deformity components (scoliotic/kyphotic) was not considered by the authors of the aforementioned articles as a significant one.

Table 2
Average values of hemivertebra treatment outcomes in children through the combined, posterior approach, and transpedicular excision

Source	Patients, n	Age, months	Preoperative scoliotic/kyphotic component, degrees	Postoperative scoliotic/kyphotic component, degrees	Correction (scoliosis/ kyphosis), %	Blood loss, ml	Operation time, min	Monosegmental unilateral fixation	Monosegmental bilateral fixation	Polysegmental bilateral fixation
Combined	251	63.2	38.0/10.9	21.7/7.9	71.3/63.6	588.1	284.3	26	121	29
Dorsal	410	76.1	40.4/10.7	27.6/10.5	73.6/62.1	505.9	216.6	10	170	147
Transpedicular excision	64	79.5	37.5/10.4	42.5/7.2	72.2/83.1	344.7	227.5	17	15	33

this values in groups II (217 min) and III (227 min).

Transpedicular approach was the least traumatic in terms of the blood loss volume (average value 345 ml) as compared to the combined (588 ml) and posterior (505 ml) approaches, by 243 ml and 161 ml, respectively.

Extended bilateral polysegmental fixation was used in groups I, II and III in 16.5, 45.0, and 51.5 % of cases, unilateral monosegmental – 10.3, 2.4, and 26.6 % of cases, respectively (in absolute values, 26 out of 251, 10 out of 410, and 17 out of 64 cases).

Surgical complications are shown in Table 3.

According to the literature, when using combined and posterior approaches, implants fractures are among the most common complications, accounting for 23 % (17 cases), followed by superficial wound infection – 20 % (15 cases), and local deformity progression – 17 % (13 cases). When considering characteristics of approaches, another structure of complications was observed:

– in case of combined approach, persistent neurological disorders were observed in 4 (13 %) cases, pneumothorax – 3 (10 %); these complications were not observed in the case of the posterior approach;

– in case of posterior approach, vertebral arch fracture was the most common complication, 6 (13 %) cases; the incidence of transient neurological disorders was 11 % (5 cases); deep wound infection occurred in 3 (7 %) cases, which was not observed in the case of combined approach;

– in case of transpedicular excision, the most common complications included deformity progression, 6 (55%) cases and transient neurological disorders, 3 (27 %) cases; there was one case of metal fixator fracture and one case of superficial wound infections.

Discussion

In our opinion, the age of patients at the time of treatment, the severity of local deformity before and after correction, correction percentage, volume of blood loss, duration of surgery, type and extent of fixation are the key criteria to evaluate the results of different methods of hemivertebra excision in children. Meta-analysis is not available due to the low level of reproducibility of the material. The most complete randomized analysis of these factors could determine the advantages and disadvantages of the used treatment techniques. However, it is in some aspects limited or impossible due to the deficit or incomparability of the information provided by the articles, which necessitated exclusion of some data from evaluation of a certain parameter. S.V. Vissarionov et al. [1] did not report precise values of local correction associated with extirpation of the lateral hemivertebrae, and deformity value was measured at the level of vertebrae located three segments more craniad and more caudad from the apex, rather than at the apical angle. In some cases, Xu et al. [29] supplemented bilateral monosegmental system by screws above and below the instrumented region for higher fixation rigidity. In the article of Jalanko et al. [16], fixation options were defined only in the presented cases. Mladenov et al. [19] reported the data of the final follow-up examination without immediate postoperative results. Finally, Zhu et al. [32] analyzed the results of monosegmental bilateral fixation, as reflected in the title of the work, but provided bilateral polysegmental fixation as an illustration.

The volume of blood loss is described in the articles quite irregularly.

Trends in the surgery for monosegmental vertebral malformations in children over the past 15 years suggest the expansion of transpedicular fixation, shift of emphasis towards posteior approach, and wider use of posterior vertebrotomy techniques. According to the researchers [8, 22, 31, 32], the main advantages of the posterior approach include possible extirpation of all columns of the abnormal hemivertebrae through one approach, reduced surgical aggression and duration of the operation, as well as postoperative patient's rehabilitation period. When implementing pediatric transpedicular fixation systems, the studies on the impact of screws on the development of vertebrae and vertebral canal proved the absence of adverse effects in infants and young children [16, 17, 25, 26, 33]. Preferences of vertebral surgeons were changed toward hemivertebra excision and deformity correction through the posterior approach under the influence of modern implants along with the use of power equipment, evolution of surgical instruments, and development of the implants that enable reposition maneuvers

Integrated analysis of the results of the use of various approaches showed advantages of transpedicular hemivertebra excision for correction of kyphotic component of the deformity, which suggests that it is a universal deformity correction technique, especially in infants and young children. It should also be noted that the profile and incidence of complications are comparable to those in other groups.

In terms of fixation length, monosegmental unilateral fixation was most often used in transpedicular excision. This fixation option enables operating young children due to minimal operative trauma [8]. However, it is associated with higher percentage of postoperative progression of the deformity.

The average volume of blood loss during transpedicular excision was 345 ml, which is significantly lower compared to the combined and posterior approaches with allowance for the fact that most patients (73.4 %) were operated on using bilateral approach and polysegmental fixation. The incidence and structure of complications of posteior and transpedicular approaches are comparable.

These results justified revision of fixation tactics: in early age patients and LBW infants (up to 10 kg), this operation is advantageous in term of surgical aggression (duration of surgery and blood loss), but may necessitate reoperation and system remounting at a later age. In younger patients with medium centile parameters of physical development, bilateral monosegmental or polysegmental instrumentation is the most adequate technique, since it is character-

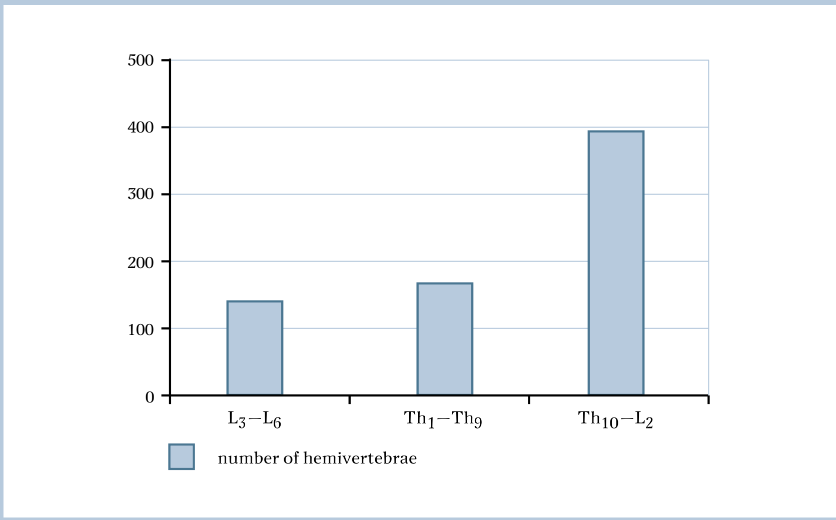

Fig. 1
Topical concentration of hemivertebrae

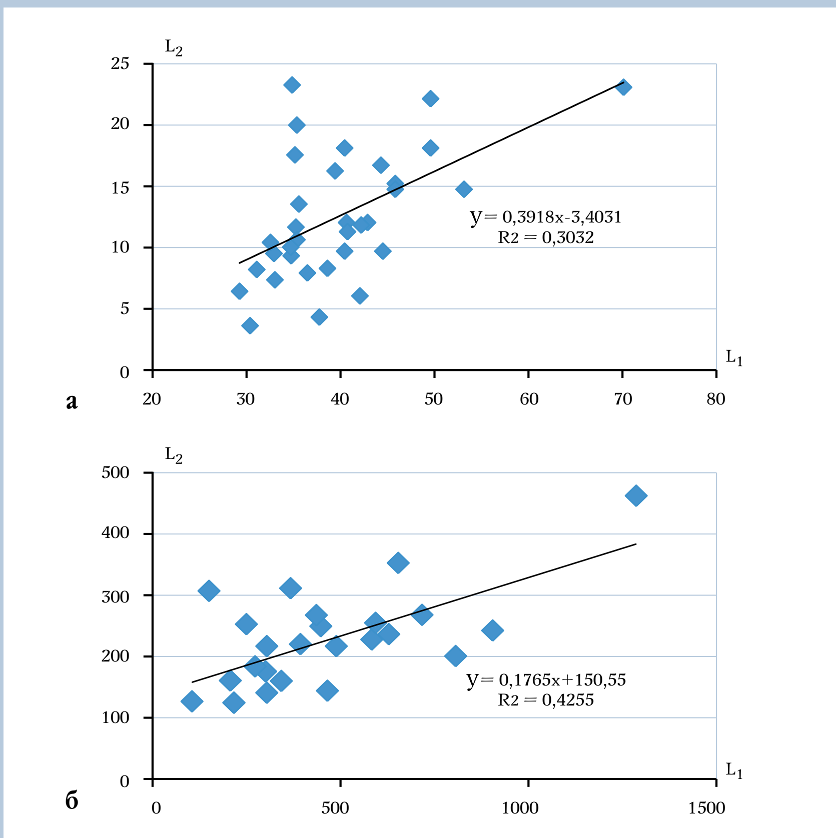

Fig. 2
The relationship between the magnitude of spine deformity before and after the operation **(a)**, blood loss and operation time **(b)**, wherein R2 is determination coefficient

ized by low risk of system instability and recurrent deformity.

This analysis shows that the available data are currently insufficient for comprehensive meta-analysis and conclusions, which could form the basis of high-evidence-level recommendations for doctors on the best way of hemivertebra resection followed by fixation of the spine. We should state that many articles either lack statistical analysis or provide not comparable data, which motivates further investigation of this issue with more strict compliance with the general analysis protocol.

Key provisions:

1) evolution of treatments for monosegmental vertebral malformations is clearly related to evolution of spinal fixation systems, manipulation tools, and intraoperative monitoring techniques;

2) the optimal age for hemivertebra excision and spinal deformity correction is 2–5 years;

3) literature data suggest middling results of deformity correction and fixation length regardless of the applied techniques of abnormal vertebra excision;

4) posterior transpedicular excision with bilateral transpedicular fixation is the method of choice in terms of apical deformity correction value, minimal surgical aggression, and comparable amount of postoperative complications.

Conclusion

Comparative analysis of therapies for monosegmental vertebral malformations showed that transpedicular excision of the abnormal vertebra through the dorsal approach reduces the time of surgery, intraoperative blood loss, risk of neurological complications, provides adequate deformity correction, facilitates early activation and rehabilitation of patients compared to the combined approach. It is superior to posterior approach in terms of the blood loss volume and correction of kyphotic component.

Of course, any conclusions are interim in a historical context, suggesting the need for further research.

Table 3

Integral structure of complications during surgical treatment for hemivertebrae in children through the combined and posterior approaches and transpedicular excision method

Sources	Deep wound infection	Superficial wound infection	Hemothorax	Pneumothorax	Vertebral arch fracture	Metal fixator migration	Metal fixator fracture	Deformity progression	Persistent neurological disorders necessitating metal fixator removal	Transient neurological disorders	Tracheospasm	Herniated abdominal wall	Atelectasis	Pleurorrhea
Combined approach														
S.V. Vissarionov et al. [3]					1									
Wang et al. [28]		1		1										
Bollini et al. [12]		3		2			5	6	3			1		
Hedequist et al. [14]						1								
Jalanko et al. [16]		1												
Xu et al. [29]						1					1			
Mladenov et al. [19]									1	1			1	1
Total		5	0	3	1	2	5	6	4	1	1	1	1	1
Posterior approach														
Wang et al. [28]		1								2				1
Ruf et al. [25]	1				1		2	2						
Ruf et al. [26]	1						3							
Ruf et al. [24]	1	1					3	2						
Jalanko et al. [16]		1	1							1				1
Hedequist et al. [15]		1								1				
Shono et al. [27]		1												
Zhang et al. [31]		1			2		2	1						
Chang et al. [13]		1						2						
Zhu et al. [32]		2			3		2							
Total	3	9	1	0	6		12	7		4				2
Transpedicular excision method														
Total		1					1	6		3				

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