One-stage transanal endorectal pull-through for Hirschsprung disease: experience with 229 neonates

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Abstract
Objective To evaluate the safety and efficacy of transanal endorectal pull-through (TEPT) and the long-term outcomes in newborns with Hirschsprung disease (HD).
Methods A total of 229 newborns with HD underwent one-stage TEPT between 2007 and 2020, and the diagnoses were confirmed by rectal biopsy. The perioperative clinical course for all patients was reviewed, and the postoperative short- and long-term outcomes were assessed.
Results A total of 229 neonates (187 male and 42 female) had a median age at TEPT of 17 days (range 6–28 days). Sixty-eight patients (29.7%) underwent TEPT combined with an abdominal approach or laparoscopy. Early postoperative complications (using the Clavien–Dindo grading system) were documented in 36 patients (15.7%), and late postoperative complications were noted in 9 patients (3.9%). The follow-up period in the remaining 165 children ranged from 1.2 to 14.0 years (median 5.0 years). A total of 106 of the patients older than four years old took part in an interview about bowel function, and 85 patients (80.2%) had bowel function scores (BFS) ≥ 18.
Conclusion TEPT is effective and safe for HD in the neonatal period and presents with a low rate of complications and an acceptable outcome.

Keywords Hirschsprung disease · Transanal endorectal pull-through · Newborn · Follow-up

Introduction
Hirschsprung disease (HD) is a congenital disorder characterized by the absence of ganglion cells in the submucosal and myenteric plexus of the bowel, which results in functional obstruction. HD affects approximately one in 5000 live-born infants [1]. The usual presentation of neonates with HD is delayed passage of meconium, abdominal distention, constipation, and vomiting [2].

In the past several decades, increasing numbers of pediatric surgeons have abandoned the historical multistage procedure in favor of a single-stage technique due to its safety and efficacy [3, 4]. Since then, multiple series have reported that transanal endorectal pull-through (TEPT) is especially suitable for newborns and young infants [5, 6]. Some surgeons recommend that surgery be performed in infants > 3 months old because there were lower rates of accurate and conclusive diagnostic results and poorer postoperative outcomes in younger infants [7, 8]. However, some surgeons believe that delaying surgical treatment might lead to persistent colorectal obstruction, malnutrition, and enterocolitis [9].

The purpose of this study was to evaluate the short- and long-term results of primary TEPT during the newborn period. We collected the data of neonates who were treated for HD by TEPT in our hospital within the past 14 years.
Materials and methods

Patients

We retrospectively reviewed the medical records of all newborns who underwent a one-stage TEPT for HD between 2007 and 2020 at Beijing Children’s Hospital (BCH). The inclusion criteria were as follows: (1) preoperative diagnosis of HD based on the results of suction rectal biopsy (SRB), and (2) ≤ 28 days old at the time of one-stage TEPT. The exclusion criteria were as follows: (1) staged enterostomy performed, or (2) > 28 days old at the time of one-stage TEPT. The criteria of pathological diagnosis were as follows: (1) a biopsy specimen was at least 3 mm in diameter, and a minimum of one-third of the sample should include the submucosa; (2) representative tissue sample should show the absence of ganglion cells and/or hypertrophic nerve fibers; and (3) other ancillary methods should support the diagnoses of HD at least, including immunohistochemistry staining of calretinin, CD56, and S100.

The demographic information, details of surgery, length of aganglionosis, early postoperative complications and follow-up data, including late postoperative complications, bowel function and development condition, were documented. Early postoperative complications were evaluated by the Clavien–Dindo grading system [10]. Follow-up information was obtained in the form of telephone inquiries or outpatient reviews, and the follow-up process of patients during the study is shown in Fig. 1. In addition, the bowel function scores (BFS) were used to assess the bowel functional outcomes in children older than 4 years of age, which consists of questions on urgency, rectal sensation, stool frequency, soiling, fecal continence, and social impacts of bowel habits [11]. The maximum score is 20. In individuals considered healthy, the mean (± SD) score was 19.1 ± 1.3, and the 10th percentile was 18 [12]. The development condition of children was evaluated by the Z score calculated for all 3 growth indicators (height for age, weight for height, and body mass index for age) using the World Health Organization’s Anthro Software (Version 3.2.2, WHO, Geneva, Switzerland). This retrospective study was approved by the Medical Ethics Committee of the BCH (2020-Z-082), and the patient informed consent requirements were waived.

Surgery

All patients underwent TEPT. The mucosal incision was made 5 mm proximal to the dental line, and a submucosal dissection was carried proximally. The rectal muscular cuff was 3 cm long. Then, it separated upward along the rectum wall to the level of the peritoneal reflection. The transition zone was confirmed by frozen section analysis of the intraoperative biopsy sample. In some cases, we identified the pathological transition zone by laparoscopy or laparotomy to undergo a seromuscular biopsy because of the atypical colon appearance, such as long-segment HD (the proximal aganglionic bowel segment extends to the transverse or descending colon) and total colonic aganglionosis (TCA). The bowel was then transected, and an anastomosis was performed.

Fig. 1 Flowchart of follow-up process
Statistical analysis

We analyzed all the data using SPSS 26.0. Continuous variables were presented as the mean with standard deviation or median and interquartile range if the normality hypothesis test rejected the null hypothesis of normal distribution. Categorical variables were reported as counts and percentages. The two independent samples t tests and Mann–Whitney U test were used to compare BFS, and the Kruskal–Wallis H test was used to compare the operating time. $P < 0.05$ was considered statistically significant.

Results

Patient characteristics

A total of 229 neonates (187 male and 42 female), with a median age of 17 days when receiving TEPT, were included in the study analysis. The patient characteristics are listed in Table 1. There were only four premature infants (1.7%). The median birth weight was 3490 g, and the median weight at the time of surgery was 3375 g. There was a case of Waardenburg syndrome. In addition, other associated anomalies were found in 31 patients (13.5%), including 18 cardiac anomalies, 11 urogenital anomalies and 2 polydactylisms. Nine patients (3.9%) had a specific family history of HD.

The presenting symptoms included abdominal distention (96.9%), vomiting (75.1%), and diarrhea (8.7%). Thirty-one patients (13.5%) passed meconium within 24 h. Thirty-two patients (14.0%) passed meconium between 24 and 48 h, and fifteen patients (6.6%) passed meconium after 48 h. Furthermore, 151 patients (65.9%) were unable to discharge the meconium after birth and required irrigation or rectal stimulation to relieve their discomfort. The rectal examinations of 198 of the 215 patients (92.1%) who underwent the study demonstrated a tight anal sphincter or explosive discharge of stool and gas.

Contrast enema examination was diagnostic in 167 of the patients (72.9%). However, 62 patients (27.1%) did not demonstrate a radiological transition zone and were finally confined to the lower rectum (22, 35.5%), sigmoid colon (26, 41.9%), and long-segment (14, 22.6%).

Surgical course

The patients were determined to be the lower rectum (24.0%), sigmoid colon (52.0%), long-segment (22.3%), and TCA (1.7%), and the average distances of the transition zone from the dentate line in the lower rectum, sigmoid colon, and long-segment were 3.6 ± 0.7, 8.3 ± 3.5, and 21.5 ± 8.2 cm, respectively. The aganglionosis segment that was removed in the TCA included the entire colon with additional small intestine (Table 2).

The treatment process of the sigmoid colon is similar to that of the lower rectum, so we sometimes combine them into one category called short-segment HD. In the short-segment group, 161 patients underwent TEPT, and 13 patients underwent TEPT combined with an abdominal approach or laparoscopy. Among these, 11 patients needed to have the pathologic transition zone identified before initiating the anal dissection. In the long-segment and TCA groups, 38 patients underwent TEPT combined with the abdominal approach, and 17 patients underwent TEPT combined with laparoscopy.

| Table 1 Patient characteristics |
|--------------------------------|
| Variables | Results |
| Gender ($n$, %) | |
| Male | 187 (81.7) |
| Female | 42 (18.3) |
| Gestation ($n$, %) | |
| Mature ($\geq$ 37 weeks) | 225 (98.3) |
| Premature (<37 weeks) | 4 (1.7) |
| Birth weight (median, range, g) | 3490 (2100–4500) |
| Surgery weight (median, range, g) | 3375 (1900–4500) |
| Age at surgery (median, range, day) | 17 (6–28) |
| Presenting symptom ($n$, %) | |
| Abdominal distention | 222 (96.9) |
| Vomiting | 172 (75.1) |
| Diarrhea | 20 (8.7) |
| Delayed meconium discharge | 198 (86.5) |
| Tight anal sphincter with an empty rectum or explosive discharge | 198 (198/215, 92.1) |
| Preoperative HAEC ($n$, %) | 15 (6.6) |
| Associated anomalies ($n$, %) | 31 (13.5) |
| Associated syndrome ($n$, %) | |
| Waardenburg syndrome | 1 (0.4) |
| Family history ($n$, %) | 9 (3.9) |
| Barium enema ($n$, %) | |
| Radiological transitional zone | 167 (72.9) |
| No radiological transitional zone | 62 (27.1) |

| Table 2 Level of aganglionosis and distance of the transition zone from the dentate line |
|--------------------------------|
| Level of aganglionosis | $N$ (%) | Distance of the transition zone from the dentate line (mean ± SD, range, cm) |
|------------------------|--------|------------------------------------------------------------------|
| Lower rectum | 55 (24.0) | 3.6 ± 0.7 (1.5–5.0) |
| Sigmoid colon | 119 (52.0) | 8.5 ± 3.5 (4.5–20.5) |
| Long-segment | 51 (22.3) | 21.5 ± 8.2 (9.0–47.5) |
| TCA | 4 (1.7) | Entire colon |

HAEC Hirschsprung-associated enterocolitis
The median operation time (including the time needed to wait for the frozen biopsy results) of the short-segment, long-segment, and TCA was 75 min (range 43–156 min), 161 min (range 90–263 min), and 190 min (range 188–385 min), respectively, and there was a significant difference in operation time among the short-segment, long-segment, and TCA groups (p < 0.001). No patients required a blood transfusion. There were no intraoperative complications.

Postoperatively, the median time of initial oral nutrition was 2 days (range 1–15 days), and the median postoperative hospital stay of the patients in the short-segment group was 7 days (range 6–36 days), while that of the long-segment group was 10 days (range 6–44 days).

### Complications

Patients who had postoperative complications within 30 days of TEPT were graded using the Clavien–Dindo grading system. A total of 36 (15.7%) patients had postoperative complications, 3 of whom (1.3%) had a Grade I complication, 28 (12.2%) had a Grade II complication, 2 (0.9%) had a Grade IIIb complication, 2 (0.9%) had a Grade IVa complication, and 1 (0.4%) had a Grade V complication (Table 3). All three grade I complications were related to postoperative mild wound infections that required physiotherapy. Twenty-four patients had a Grade II complication because of parenteral nutrition, while the 3 others required antibiotics because of infections. One patient had a Grade II because of intestinal obstruction that improved after conservative treatment. Two patients had a Grade IIIb complication caused by enterostomy under general anesthesia, one of whom had anastomotic leakages, and the other had severe enterocolitis. Two patients had Grade IVa because of severe infection after surgery. One patient with long-segment disease had a Grade V death after surgery because of sepsis and multiorgan dysfunction. Postoperative enterocolitis occurred in 15 children (6.6%) within 30 postoperative days, of which 1 patient underwent a transient ileostomy to relieve the condition and underwent a stoma closure surgery after 2 months.

Nine patients noted late complications beyond 30 days postoperatively that needed medical treatment. In one child, mild rectal prolapse developed, but he did not require additional surgery. Unfortunately, 1 patient who had TCA and had his entire colon removed during the surgery developed enterocolitis after discharge. Then, the severe diarrhea resulted in dehydration, and the patient died without treatment (the parents abandoned the baby for treatment). The remaining seven patients required additional surgery. One patient who had undergone laparoscopically assisted TEPT developed intestinal obstruction after discharge from the hospital, and then, an uneventful bowel enterolysis was performed after admission. Anastomotic strictures were observed in 2 patients (0.9%). Finally, they required a redo pull-through, but the postoperative pathology revealed ganglion cells in the resected bowel. Rectoanorectal fistulas, rectourethral fistula and anal fistula occurred in 2 patients (0.9%), 1 patient (0.4%) and 1 patient (0.4%), respectively. All of them were readmitted and underwent repair surgery; they were followed up for more than 5 years, and there was no recurrence.

Therefore, the rate of early and late complications in the short-segment, long-segment, and TCA was 10.9% (19/174), 21.6% (11/51), and 50% (2/4), respectively (Table 4). This table only recorded HD-specific complications and did not exactly match the Clavien–Dindo grading system shown at Table 3.

### Table 3 Clavien–Dindo classification of surgical complications

| Postoperative complication < 30 days of TEPT n (%) | Short-segment n=174 | Long-segment n=51 | TCA n=4 | Total N=229 |
|-----------------------------------------------|---------------------|------------------|--------|-------------|
| Clavien–Dindo classification n (%)             |                     |                  |        |             |
| Grade 0                                       | 162 (93.1)          | 30 (58.8)        | 1 (25.0) | 193 (84.3) |
| Grade I                                       | 1 (0.6)             | 2 (3.9)          | 0 (0)  | 3 (1.3)    |
| Grade II                                      | 9 (5.2)             | 16 (31.4)        | 3 (75.0) | 28 (12.2)  |
| Grade IIb                                     | 1 (0.6)             | 1 (2.0)          | 0 (0)  | 2 (0.9)    |
| Grade IVa                                     | 1 (0.6)             | 1 (2.0)          | 0 (0)  | 2 (0.9)    |
| Grade V                                       | 0 (0)               | 1 (2.0)          | 0 (0)  | 1 (0.4)    |
| Wound infection n (%)                         | 1 (0.6)             | 2 (3.9)          | 0 (0)  | 3 (1.3)    |
| Anastomotic dehiscence n (%)                  | 1 (0.6)             | 1 (2.0)          | 0 (0)  | 2 (0.9)    |
| Postoperative HAEC n (%)                      | 11 (6.3)            | 4 (7.8)          | 0 (0)  | 15 (6.5)   |
| Early intestinal obstruction n (%)            | 1 (0.6)             | 0 (0)            | 0 (0)  | 1 (0.4)    |
| Severe sepsis n (%)                           | 1 (0.6)             | 2 (3.9)          | 0 (0)  | 3 (1.3)    |
| Reoperation within 30 days of TEPT            | 1 (0.6)             | 1 (2.0)          | 0 (0)  | 2 (0.9)    |
**Long-term outcomes**

The follow-up period in the remaining 165 children (72.1%) ranged from 1.2 to 14.0 years (median 5.0 years). Fifty-eight patients (25.3%) were lost to follow-up, and another two late deaths were noted, both of which were unrelated to the pull-through. One patient died of congenital cardiac disease, and the second died of encephalomenigitis.

A total of 106 of the patients above four years of age took part in an interview about bowel function. Eighty-five patients (80.2%) had a BFS ≥ 18, and 61 patients (57.5%) had a BFS of 20/20. In the individual items assessing bowel function, fecal soiling was observed in 22 patients (20.8%), of which 6 patients required protective aids due to soiling, 3 of whom had long-segment and others had sigmoid colon. Eleven patients (10.4%) had problems feeling the urge to defecate. Four patients (3.8%) had fecal accidents weekly, and 9 patients (8.5%) had fecal accidents less than one week prior. Constipation was noted in only 2 patients (1.9%), one of whom managed it with diet, and another managed it with laxatives. The frequency of defecation consisted of 92 children (86.8%) defecating every other day to twice a day, 12 children (11.3%) defecating more often and 2 children (1.9%) defecating less often. The children’s stool patterns were as follows: formed in 102 (96.2%), loose in 2 (1.9%), and dry in 2 (1.9%). Only 3 patients sometimes reported social problems.

In the short-segment, the mean BFS was decreased among the patients who were 4–7 years old (18.84 ± 2.36) in relation to the patients who were 8–14 years old (19.06 ± 1.55). The data showed that the older group had better scores in all aspects, but there was no significant difference between the two groups (Table 5).

In the long-segment, the mean BFS of the patients who were 4–7 years old and 8–14 years old was 17.67 ± 3.18 and 17.44 ± 2.83, respectively. Of the individual factors assessing bowel function, the scores of the two groups were similar.

### Table 4  HD-specific complications

| Variable                        | Short-segment (n=174) | Long-segment (n=51) | TCA (n=4) | Total (N=229) |
|---------------------------------|-----------------------|---------------------|-----------|--------------|
| Wound infection n (%)           | 1 (0.6)               | 2 (3.9)             | 0 (0)     | 3 (1.3)      |
| Anastomotic dehiscence n (%)    | 1 (0.6)               | 1 (2.0)*            | 0 (0)     | 2 (0.9)      |
| Postoperative HAEC n (%)        | 11 (6.3)*             | 4 (7.8)             | 1 (25.0)* | 16 (7.0)     |
| Anastomotic stricture n (%)     | 1 (0.6)               | 1 (2.0)             | 0 (0)     | 2 (0.9)      |
| Anal fistula n (%)              | 1 (0.6)               | 0 (0)               | 0 (0)     | 1 (0.4)      |
| Rectovestibular fistula n (%)   | 1 (0.6)               | 0 (0)               | 1 (25.0)  | 2 (0.9)      |
| Rectourethral fistula n (%)     | 0 (0)                 | 1 (2.0)             | 0 (0)     | 1 (0.4)      |
| Rectal prolapse n (%)           | 1 (0.6)               | 0 (0)               | 0 (0)     | 1 (0.4)      |
| Intestinal obstruction n (%)    | 2 (1.1)*              | 0 (0)               | 0 (0)     | 2 (0.9)      |
| Sepsis n (%)                    | 1 (0.6)               | 2 (3.9)*            | 0 (0)     | 3 (1.3)      |
| Death n (%)                     | 0 (0)                 | 1 (2.0)             | 0 (0)     | 1 (0.4)      |
| Total n (%)                     | 19 (10.9)*            | 11 (21.6)*          | 2 (50.0)  | 33 (14.4)    |

*1 patient experienced intestinal obstruction and enterocolitis after the operation

* No treatment after diagnosis

*1 patient experienced anastomotic dehiscence and sepsis after the operation

### Table 5  BFS of the short-segment and long-segment

| Variable                        | Short-segment (n=79) | P | Long-segment (n=24) | P |
|---------------------------------|----------------------|---|---------------------|---|
|                                 | 4–7 y (n=44)         |   | 4–7 y (n=15)        |   |
|                                 | 8–14 y (n=35)        |   | 8–14 y (n=9)        |   |
| Urgency period                  | 2.84 ± 0.57          | 0.91 | 2.73 ± 0.70         | 0.82 |
| Sensation of the urge to defecate| 2.91 ± 0.29          | 0.58 | 2.80 ± 0.41         | 0.95 |
| Frequency of defecation         | 1.89 ± 0.32          | 0.16 | 1.67 ± 0.48         | 0.38 |
| Soiling                        | 2.48 ± 0.90          | 0.72 | 2.27 ± 1.03         | 0.48 |
| Fecal accidents                 | 2.89 ± 0.39          | 0.91 | 2.67 ± 0.72         | 0.96 |
| Constipation                    | 3.00                 | 1.00 | 2.80 ± 0.78         | 0.83 |
| Social problems                 | 2.84 ± 0.43          | 0.89 | 2.73 ± 0.46         | 0.48 |
| Total                           | 18.84 ± 2.36         | 0.94 | 17.67 ± 3.18        | 0.68 |
Compared with the short-segment patients, the patients who had long-segment disease scored worse on questions assessing urgent bowel movements, fecal soiling, constipation, uncontrollable stools, and social problems as well as on the total scores. However, there was not statistically significant in either the 4–7 age group or the 8–14 age group. Of the 3 TCA patients followed up, 2 patients had a BFS of 13 and 1 patient had a BFS of 12.

Growth was evaluated during the follow-up by recording the height and weight centiles of all 165 children. The mean (±SD) weight for age Z score (WAZ), height for age Z score (HAZ), and body mass index for age Z score (BAZ) were 0.53 ± 1.02, 0.45 ± 1.09, and 0.40 ± 1.22, respectively. < −2 SD Z scores were noted in 3 (WAZ, 3/166, 1.8%), 1 (HAZ, 1/165, 0.6%), and 4 (BAZ, 4/165, 2.4%) patients, respectively. Z scores > 2 SD were noted in 9 (WAZ, 9/165, 5.5%), 2 (HAZ, 2/165, 1.2%) and 11 (BAZ, 11/165, 6.7%) patients, respectively. The total numbers of patients who had < -2 SD Z scores and > 2 SD Z scores were 6 (6/165, 3.6%) and 22 (22/165, 13.3%), respectively.

Discussion

This study represents one of the largest series of patients at a single institution undergoing single-stage TEPT in the neonatal period. And our results show that HD patients might have favorable short-term and long-term outcomes.

Similar to previous reports [13], most HD patients show symptoms such as abdominal distention and vomiting during the neonatal period in our study. In the past, some researchers believed that the enteric nervous system was immature and was still developing in neonates [14]. However, in recent years, many studies have demonstrated that this conclusion might not be reliable [15–17]. Though there are some difficulties of pathological diagnosis in the neonatal period [18], experienced pathologists and auxiliary diagnostic methods such as immunohistochemistry can help us diagnose HD in newborn.

In our study, the positive rate of contrast enema examination was 72.93%, which was similar to previous studies [8]. However, in our experience, surgeons could improve the diagnosis rate of HD by combining the medical history and clinical manifestations with the imaging results. In addition, only 6.3% of patients with short-segment HD needed an abdominal approach or laparoscopic assistance during surgery to confirm the aganglionosis level. In the long-segment and TCA groups, no patients were diagnosed with lower rectum or sigmoid colon disease before the operation. Therefore, the accuracy of clearly formulating the surgical protocol before surgery can reach 95% after the patients diagnosed.

Since the advent of the TEPT procedure, it has been constantly discussed and improved by surgeons [3, 19–21]. Meanwhile, our department has adopted and optimized the surgical methods based on our own experience. The mucosal incision is made 5 mm proximal to the dental line, and the submucosal dissection is continued proximally. The rectal muscular cuff used is 2.5–3 cm long. Then, it is separated upward along the rectum wall to the level of the peritoneal reflection and proximally. This procedure is simple for neonatal patients because of their anatomical features. We usually choose the colon that is close to the normal colon diameter and texture to excise (intraoperative frozen pathology confirmed the presence of ganglion cells), instead of that at least 5–10 cm proximal to the first normal biopsy, which ERNICA recommends in rectosigmoid HD [7]. We found that the compensatory dilatation of the proximal colon was mild, and the transitional segment was short in neonatal HD. This can avoid excessively exciting the colon and thus affecting long-term colonic function, which is especially advantageous in patients with long-segment and TCA.

Compared with other scholars’ reports, the proportion of complications in our group was lower [16, 22]. It has been reported that the incidence of postoperative enterocolitis in the neonatal period is 40.2% [23], which was not consistent with our experience. We believe that this may be related to the long preoperative colon enema time (5–7 days) and the short muscular cuff preserved. Moreover, in our patients, routine placement of an anal draining tube through the anastomosis was unnecessary.

In the pediatric literature, several different questionnaires have been used to evaluate bowel function, but only the BFS questionnaire has data from the normal population [11], so we chose the BFS and compared it with the literature using the same scoring criteria. Björnland et al. reported a survey of long-term bowel function after TEPT in 200 patients with rectosigmoid HD, and the mean BFS in nonsyndromic patients was 15.7 [24]. Furthermore, a meta-analysis showed that pooled overall mean BFS score of three studies is 16.78 [25]. In contrast, the BFS of our group was better. Additionally, compared with short-segment group, the BFS was lower in the long-segment patients, which was consistent with other reports [26].

Several studies have shown that soiling and fecal incontinence are the main problems of long-term follow-up after the operation [25, 27, 28]. In our study, a total of 73.6% (78/106) of the patients had no soiling or fecal incontinence during the follow-up, and the rest had a few problems that occurred with a frequency of less than 1/week. Constipation only occurred in 2 long-segment patients, which was less than the proportion previously reported in the literature [23]. We considered that constipation in the long-segment might be related to poor bowel function, which leads to insufficient...
intestinal peristalsis, resulting in stool retention. This is our speculation, and more research evidence is needed.

Previous study shows no difference in effect on the growth outcomes in HD patients following pull-through [29]. Among all the follow-up patients, 6 children were poor in growth and development, and 22 children were above the normal level, which may be basically consistent with the normal population distribution.

As our study is a retrospective study, only patients who underwent radical surgery in the neonatal period were analyzed, while the patients with long-segment and TCA who underwent one-stage surgery in the neonatal period were selected, and they were in good condition. In addition, more long-term follow-up data for patients are needed. We also recommend that TEPT be performed for HD in the neonatal period when using the expertise of experienced pathologists. We also recommend diagnosing and treating patients with HD in the neonatal period with experienced pathologists, as pathological diagnosis of newborns could be slightly difficult.

**Conclusion**

TEPT performed by our department offers an improved method for the treatment of neonatal HD patients. Our data suggest that TEPT is effective and safe. Longer-term follow-up and controlled studies are needed to confirm these results in the future.

**Author contributions** JH, YZ, and ZL designed the study. ZL and YZ wrote the main manuscript text. SY, WG, SL, and YL prepared Tables 1, 2, 3, 4, and 5. All authors reviewed the manuscript.

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**Declarations**

**Conflict of interest** The authors declare that they have no competing interests.

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