Asian Journal of Andrology (2022) 24, 653–659
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ORIGINAL ARTICLE

Operational Andrology

Long-term follow-up results of testicular torsion in children

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A retrospective cohort study was conducted at the Children's Hospital of Chongqing Medical University from November 2004 to December 2020 to investigate the long-term follow-up results after testicular torsion (TT) in children. Boys with TT were divided into the salvage orchiopexy group and the orchiectomy group, and the baseline characteristics, ultrasonographic indications, intraoperative findings, testicular volumes, and adverse events during follow-up were compared. A total of 145 cases were included in this study. Approximately 56.6% of patients who underwent salvage orchiopexy had testicular atrophy (TA), and the median testicular volume loss of the testes was 57.4%. Age less than 6 years, delayed surgery, and intraoperative poor blood supply were associated with TA in pediatric TT after orchiopexy. Most atrophied testes appeared within 3–6 months after surgery. Compared with the corresponding age-matched healthy controls, the contralateral testicular volumes were larger in the orchiopexy ($P = 0.001$ without TA, and $P = 0.042$ with TA) and orchiectomy groups ($P = 0.033$). The adverse events were comparable in patients with orchiectomy or orchiopexy. In summary, follow-up before 3 months after surgery may not offer sufficient clinical value, while that 3 months after surgery should be regarded as the first follow-up time for testicular monitoring. The contralateral testes of patients with TT showed compensatory hypertrophy. We suggest performing orchiectomy when torsed testes are surgically assessed as Arda grade III or inviable.

Asian Journal of Andrology (2022) **24**, 653–659; doi: 10.4103/aja2021127; published online: 04 March 2022

Keywords: long-term; orchiectomy; pediatrics; salvage orchiopexy; testicular torsion

INTRODUCTION

Testicular torsion (TT) is defined as when the spermatic cord or the tunica vaginalis twists along the longitudinal axis, causing testicular blood flow obstruction and subsequent damage.[1] TT has an incidence of approximately 3.8–5.9 per 100 000 people in the pediatric population and is a common but time-dependent urological emergency that requires prompt surgery.[2,3] The two main determinants of testicular salvage after torsion are the duration from symptom onset to surgery and the degree of cord twisting.[4,5] Delayed diagnosis and management of TT lead to a higher rate of testicular atrophy (TA) or even total loss of the ipsilateral testis and eventually impairment of fertility.[6,7]

The terminal value of follow-up after TT is the evaluation of fertility status and endocrine function. According to the current available literature, the rate of TA ranges from 12% to 68% of detorsed testes that undergo salvage orchiopexy, even when intraoperatively assessed as viable.[8,9] Although most patients with TT have preserved endocrine function, the exocrine function is considerably more variable and controversial.[10–13] Arap *et al.*[11] concluded that most patients with TT had preserved sperm quality, and following orchiectomy, these patients presented with better motility and morphology compared with those who underwent orchiopexy. Anderson *et al.*[10] compared the sperm density of patients with TT who underwent orchiectomy and salvage orchiopexy and concluded that the semen parameters were similar between patients who underwent orchiopexy and fertile normal sperm donors, while sperm density after orchiectomy was obviously decreased. In contrast, several studies have reported seriously impaired semen quality after orchiopexy. Indeed, Thomas *et al.*[13] reported that only 17% of patients who underwent orchiopexy had normal semen parameters and none of the nine patients who underwent orchiectomy had normal semen analysis results. Additionally, the duration from symptom onset to surgery might greatly affect the semen parameters; in patients who underwent orchiopexy, approximately 44% showed normal semen analysis results within 12 h, but this decreased to 20% after 12 h.[12]

However, almost all of these studies were relatively old, concerned the adult population, and were largely limited by small case series. Long-term follow-up results regarding testicular volume loss (TVL), atrophy, clinical indications, and seminal and endocrine parameters in the pediatric population with TT are rare, and further investigation is necessary to fill the knowledge gap. Therefore, to guide clinical

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Received: 15 October 2021; Accepted: 30 December 2021

decision-making and provide appropriate guidelines for the pediatric population, we investigated the long-term follow-up results of testicular volume, exocrine, and endocrine functions in a large sample of children with TT.

PARTICIPANTS AND METHODS

Participants

This study was approved by the institutional review board of Children's Hospital of Chongqing Medical University (Chongqing, China; approval No. 2021-384), and written informed consent was obtained from the legal guardians of the participants during hospitalization. This retrospective cohort study was conducted based on the in-hospital medical records, the outpatient records of patients with TT, and an additional arranged follow-up at the Children's Hospital of Chongqing Medical University from November 2004 to December 2020. In the arranged follow-up, the patients were contacted by telephone and were interviewed according to a standardized questionnaire (**Supplementary Figure 1**). Furthermore, another follow-up, including ultrasound monitoring of the testes, clinical physical examinations in Children's Hospital of Chongqing Medical University, and semen and endocrine analysis for patients >18 years in The First Affiliated Hospital of Chongqing Medical University (Chongqing, China), was suggested.

Data on the participants' date of birth, time of symptom onset and surgery, age at follow-up, laterality of the affected testis, ultrasonographic indications before surgery, intraoperative findings, and follow-up information were extracted and recorded. The inclusion criteria were boys >6 months, with surgically confirmed TT, who underwent salvage orchiopexy or orchiectomy, and who had sufficient follow-up information for at least 1 month. The exclusion criteria were TT with undescended testes, prenatal or neonatal torsion, negative explorations, unwilling to participate, or incomplete follow-up information.

Study design, definitions, variables, and outcomes

All patients with surgically confirmed torsed testes underwent salvage orchiopexy or orchiectomy. We investigated the differences in the baseline characteristics, duration of symptoms, intraoperative findings, and follow-up results of these two groups. Additionally, we matched a control group according to age and laterality at a ratio of 1:3 from healthy referral pediatrics to compare the testicular volume.

The age at surgery and duration from symptom onset to surgery were calculated from the date of birth, and the time of symptom onset and surgery, respectively. Ultrasonographic indications before surgery included echogenicity of testicular parenchyma on ultrasonography and testicular blood flow on color Doppler ultrasound (GE vivid E9, New York, NY, USA). Poverty counties were defined based on the previously reported average income of the local population (listed at http://www.cpad.gov.cn/art/2012/3/19/art_50_23706.html [last accessed on 2020 Feb 14]). The nine main districts in Chongqing were considered neighboring the main city. According to the European Association of Urology Guidelines on Pediatric Urology 2020 (available at https://uroweb.org/guideline/paediatric-urology [last accessed on 2021 Mar 21]), delayed surgery was defined as duration of more than 12 h from symptom onset to surgery.

Intraoperative findings included the direction of rotation, the degree of cord twisting, blood supply, the grade of Arda, fixation of the ipsilateral and contralateral testes, and bell clapper deformity during exploration. The grade of Arda was defined according to the bleeding status of the cut surface of testicular tissue during surgery by Arda and Ozyaylali[14] as follows: grade I, immediate or sufficient bleeding after incision; grade II, no immediate bleeding, but starting after no more than 10 min; and grade III, no bleeding until 10 min. Follow-up information included subsequent scrotal symptoms, atrophy, testicular volume, TVL, semen and endocrine analysis, and pregnancy rate. All data were extracted or transferred from reliable medical records.

As the definition of TA is inconsistent in the available literature, there is currently no standard definition for TA. TVL was defined as the percentage difference in the affected testis compared with the contralateral normal testis, based on measurement by ultrasound.[8] All TA definitions were taken into consideration, and we defined TA as TVL >50% during the follow-up, and severe TA as TVL >80% or no sustained blood supply.[8,9,15] Testicular length (L), width (W), and height (H) were measured by ultrasound of high frequency at our hospital. The testicular volume was calculated according to the formula of $L \times W \times H \times 0.71$ cm^3.[16] An age- and laterality-matched normal control group with a ratio of 1:3 was also chosen from the healthy referral population who visited our physical examination center, and oral informed consent was obtained from parents when visiting. As the legal age for marriage is 22 years old in China, the pregnancy rate only among patients older than 22 years in the follow-up was calculated.

The adverse events after surgery were recorded, including subsequent orchiectomy, contralateral TT, and scrotal pain, swelling, or discomfort, in patients who underwent orchiopexy or orchiectomy. The cumulative atrophy-free survival curve was used to detect the atrophy rate and trend by time after salvage orchiopexy. The testicular volumes were compared between the ipsilateral and contralateral sides of the patients who underwent salvage orchiopexy without obvious TA during follow-up, and were compared to healthy controls. Furthermore, the contralateral testicular volumes of patients with atrophied affected testes and those who underwent orchiectomy were compared with age- and laterality-matched healthy controls. We also summarized the latest TVL percentages of the detorsed testes during follow-up, and examined the TVL changes with time by analyzing patients with at least two visits for ultrasonographic monitoring more than 1 month after surgery. By doing so, we hope to provide robust evidence on the time strategies for monitoring after surgery TT.

Surgical procedures and follow-up

TT was diagnosed by clinical examination and ultrasonographic indications. Following diagnosis, an urgent surgical exploration was arranged. First, after general anesthesia, the skin and tunica vaginalis of the affected side were incised to directly detect the torsion of the testis. Second, the torsed testis was detorsed without tension, and 1% lignocaine was infiltrated within the spermatic cord. A small incision was made in the tunica albuginea to check the blood supply, and a piece of gauze moistened with warm saline was used to cover the testicular tissue for 10–30 min. Third, the torsed testis was reexamined for potential salvageability. Then, the legal guardians were consulted during surgery to decide whether to perform contralateral testicular fixation, and, most importantly, whether to perform orchiectomy or just orchiopexy if the blood supply was poor (Arda grade III). The operation was completed and the patients were kept under strict observation. All of these intraoperative findings were noted in the operation records. In some cases, a subsequent orchiectomy was arranged for patients who underwent orchiopexy with inviable testes during hospitalization if obvious liquefaction necrosis or abscess was detected.

Upon discharge, 1-month, 3-month, and 6-month, and 1-year routine follow-ups at the outpatient clinic were suggested for the patients with TT. After approval by Children's Hospital of Chongqing Medical University institutional review board, another follow-up was arranged.

Patients were contacted by telephone and were interviewed according to a standardized questionnaire. During this time, patients were invited back for ultrasound monitoring of the testes, clinical physical examination, and possible semen and endocrine analysis for patients >18 years.

Statistical methods

Categorical variables are presented as ratios (%) and continuous variables are presented as median (interquartile range) or mean ± standard deviation (s.d.). Outcomes with normal distributions were analyzed using the Shapiro–Wilk test. Comparisons were conducted by χ^2 test for dichotomous outcomes and unordered multiple outcomes by Mann–Whitney U test for non-normally distributed continuous outcomes. Variables that were determined to be significant in the univariate analysis were included in the logistic regression analysis for TA (TVL > 50%). Multivariate analysis of variance was performed to evaluate the association between TVL and predictors. All statistical analyses were performed using IBM SPSS Statistics for windows, version 25.0 (IBM Corp., Armonk, NY, USA). $P < 0.05$ was considered statistically significant.

RESULTS

A total of 324 boys with TT were treated in Department of Urology in Children's Hospital of Chongqing Medical University during this 16-year clinical experience, among whom, 145 met the inclusion criteria (106 boys underwent salvage orchiopexy and 39 underwent orchiectomy). The median age of the boys who underwent orchiopexy and orchiectomy was 142.5 months and 137.0 months, respectively (**Table 1**). Compared with orchiopexy, the boys who underwent orchiectomy had a longer duration from symptom onset to surgery ($P < 0.001$), a higher rate of heterogeneous echogenicity of testicular parenchymal on ultrasonography ($P = 0.011$), less blood flow on color Doppler ultrasound ($P = 0.032$), a higher degree of cord twisting ($P = 0.032$), and poorer blood supply assessed intraoperatively ($P < 0.001$), as shown in **Table 1**. These results are in accordance with those of previously published literature reports.[8,9] Furthermore, 98.1% (104/106) of orchiopexies had ipsilateral fixation of the affected testes, and 51.9% had contralateral exploration and fixation during the same operation. Additionally, 24.5% of torsed

Table 1: Baseline characteristics, ultrasonographic indications, and intraoperative findings of children with testicular torsion who underwent salvage orchiopexy or orchiectomy

Item	*Orchiopexy (n=106)*	*Orchiectomy (n=39)*	*P*
Age at surgery (month), median (IQR)	142.5 (74.5–161.0)	137.0 (75.0–164.0)	0.841
Age (month), mean±s.d.	119.2±5.4	118.7±9.3	NA
Laterality, *n* (%)			0.925
Left	85 (80.2)	31 (79.5)	
Right	21 (19.8)	8 (20.5)	
Duration from symptoms onset to surgery (h), median (IQR)	25.0 (7.8–72.0)	72.0 (48.0–150.0)	<0.001*
Echogenicity of testicular parenchymal on ultrasonography, *n* (%)			0.011*
Homogenous	29 (27.4)	3 (7.7)	
Heterogeneous	77 (72.6)	36 (92.3)	
Testicular blood flow on color Doppler ultrasound, *n* (%)			0.032*
Decreased	25 (23.6)	3 (7.7)	
Absent	81 (76.4)	36 (92.3)	
Direction of rotation, *n* (%)			0.958
Clockwise	62 (58.5)	23 (59.0)	
Anticlockwise	44 (41.5)	16 (41.0)	
Degree of cord twisting, *n* (%)			0.032*,#
0–180°	19 (17.9)	3 (7.7)	
181°–360°	43 (40.6)	12 (30.8)	
361°–540°	26 (24.5)	4 (10.3)	
541°–720°	17 (16.0)	17 (43.6)	
>720°	1 (0.9)	3 (7.7)	
Blood supply, *n* (%)			<0.001*
Rich	15 (14.2)	0 (0)	
Poor	57 (53.8)	3 (7.7)	
Little	34 (32.1)	36 (92.3)	
Grade of Arda, *n* (%)			
I	12 (11.3)	0 (0)	NA
II	67 (63.2)	0 (0)	NA
III	27 (25.5)	39 (100.0)	NA
Fixation of testis, *n* (%)			
Ipsilateral (affected) side	104 (98.1)	NA	NA
Contralateral (normal) side	55 (51.9)	27 (69.2)	0.062
Bell clapper deformity among exploration, *n*/total (%)			
Ipsilateral (affected) side	26/106 (24.5)	2/39 (5.1)	0.009
Contralateral (normal) side	9/55 (16.4)	3/27 (11.1)	0.764
Bilateral	6/55 (10.9)	2/27 (7.4)	0.915

*$P \leq 0.05$. #A comparison between boys with a degree of cord twisting ≤360° versus cord twisting >360°. NA: not available; s.d.: standard deviation; IQR: interquartile range

testes had bell clapper deformity, which was present in only 16.4% of contralateral explored testes and 10.9% of bilateral explored testes. In patients who underwent orchiectomy, 69.2% chose simultaneous exploration and fixation of the contralateral normal testes, and 11.1% had bell clapper deformity (**Table 1**).

The median follow-up time of patients with orchiopexy was 4.5 months, whereas the median follow-up time of patients with orchiectomy was significantly longer at 14.0 months ($P = 0.028$; **Table 2**). Five boys who underwent orchiopexy had subsequent orchiectomy of the affected testes for severe testicular liquidation, and 10 patients complained of occasional testicular pain or discomfort during the telephone interview. One patient experienced ipsilateral testicular enlargement 77 months after orchiopexy, which was pathologically confirmed as mature teratoma by re-exploration. Four patients who underwent orchiectomy complained of occasional testicular pain or discomfort during the telephone interview. One boy who underwent orchiectomy without contralateral exploration and fixation experienced subsequent contralateral TT and underwent urgent orchiopexy within 4 h; he was clinically monitored and showed good results from a sonograph. Of the patients who were older than the legal marriage age, two of the nine patients who underwent orchiopexy and two of the seven who underwent orchiectomy already had children.

Sixty patients (56.6%) had TA after salvage orchiopexy during follow-up, among whom 44 cases (41.5%) proved to be severe TA. Twenty-seven patients were surgically assessed as Arda grade III and inviable and underwent orchiopexy, 3 had subsequent orchiectomy, 17 had severe TA, 4 had TA, 2 had normal testicular volume compared with the contralateral testis, and one had paternity. The cumulative atrophy-free survival curves of the patients with preserved detorsed testes are shown in **Figure 1**. From the curves, approximately 23.4% of testes atrophied before 3 months and 35.7% atrophied before 5 months. Additionally, we summarized the TVL of the affected testes at the onset of TA or at the last follow-up (**Figure 2a**), as well as the change trends of the TVL of patients with at least two ultrasonographic visits to monitor the testes after surgery (**Figure 2b**). Most atrophied testes appeared within 3–6 months after surgery. The TVL tended to be stable from 3 months after surgery (not across the transverse green dotted line in **Figure 2b**, which indicates TA), while the results remained changeable 1 month or 2 months after surgery (across the green dotted line, from normal to atrophied).

The median TVL of the patients who underwent orchiopexy was 57.4% (range: 0–99.4%); 11 detorsed testes had a slightly increased testicular volume percentage compared to the contralateral normal testis, with a median of 6.2% (range: 0.5%–30.9%). Both the ipsilateral and contralateral testicular volume of the boys who underwent salvage orchiopexy without TA were larger than those of age-matched healthy controls; this enlargement was significant in the contralateral side ($P = 0.001$; **Table 2**) but not between the affected and normal sides. The contralateral testes of boys who underwent orchiectomy and orchiopexy with TA had compensatory hypertrophy, and the testicular volumes were statistically larger than those of age- and laterality-matched healthy controls ($P = 0.033$ and $P = 0.042$, respectively; **Table 2** and **Figure 3**).

Semen and endocrine analyses were performed on five patients older than 18 years of age; of these patients, two underwent orchiectomy, and three underwent orchiopexy. All endocrine levels (testosterone, progesterone, estradiol, follicle-stimulating hormone, and luteinizing hormone) were within the normal range (data not shown). One patient with severe TA who underwent orchiopexy had abnormal semen analysis (**Supplementary Table 1**).

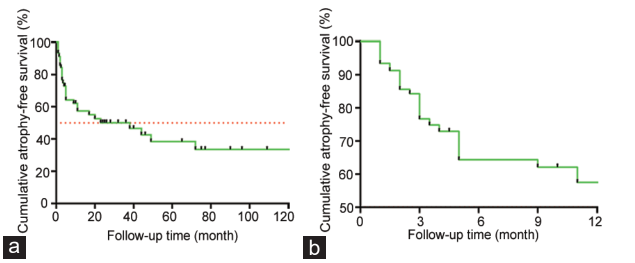

Figure 1: Cumulative atrophy-free survival curve of pediatric patients with testicular torsion who underwent salvage orchiopexy during the follow-up period: (**a**) within 10 years of follow-up and (**b**) within 12 months. Red dotted line indicates cumulative atrophy-free survival rate of 50%.

Table 2: Follow-up information of children with testicular torsion who underwent salvage orchiopexy or orchiectomy

Item	*Orchiopexy (n=106)*	*Orchiectomy (n=39)*	*P*
Follow-up time (month), median (IQR)	4.5 (2.0–24.3)	14.0 (4.0–52.0)	0.028*
Subsequent orchiectomy, *n* (%)	5 (4.7)	NA	NA
Subsequent testicular tumor, *n* (%)	1 (0.9)	0 (0.0)	NA
Subsequent contralateral torsion, *n* (%)	0 (0)	1 (2.6)	NA
Testicular volume of boys underwent salvage orchiopexy without TA (ml), median (IQR)			
Age matched healthy referral	7.055 (3.033–10.567)	NA	Reference
Ipsilateral (affected) side	8.747 (5.498–13.151)	NA	0.058
Contralateral (normal) side	10.738 (6.8–13.637)	NA	0.001*
Contralateral testicular volume of boys underwent orchiectomy and orchiopexy with TA (ml), median (IQR)			
Age-matched healthy referral	1.754 (0.819–6.278)	4.781 (0.906–9.849)	Reference
Orchiectomy	NA	8.515 (1.999–14.880)	0.033*
Orchiopexy with TA	2.464 (1.078–10.180)	NA	0.042*
TVL of affected testis (%), median (IQR)	57.4 (13.3–83.9)	NA	NA
Testicular atrophy, *n* (%)	60 (56.6)	NA	NA
Severe testicular atrophy, *n* (%)	44 (41.5)	NA	NA
Testicular pain or discomfort, *n* (%)	10 (9.4)	4 (10.3)	1.000
Paternity rate among patients older than 22 years to date, *n*/total (%)	2/9 (22.2)	2/7 (28.6)	NA

*$P<0.05$. IQR: interquartile range; NA: not available; TA: testicular atrophy; TVL: testicular volume loss

The univariate analysis between factors and TA (TVL >50%) and TVL are shown in **Supplementary Table 2** (five subsequent orchiectomies and one testicular tumor were excluded). Logistic analysis showed that age less than 6 years ($P = 0.024$), delayed surgery ($P = 0.001$), and intraoperative poor blood supply ($P = 0.029$) were associated with TA in pediatric TT after salvage orchiopexy (**Table 3**). Multivariable analysis showed that 50.8% ($R^2 = 0.508$) of the total variation in TVL could be explained by this regression model, and that heterogeneous echogenicity of the testicular parenchyma on ultrasonography was an independent risk factor for TVL (**Supplementary Table 3**).

DISCUSSION

This study had a relatively large sample size regarding long-term follow-up results of testicular volume, atrophy, atrophy-free survival, and exocrine and endocrine analyses in pediatric patients with TT. The longest follow-up in this study was 198 months after salvage orchiopexy. The overall TA rate after orchiopexy was 56.6% compared with the previously reported TA rate range of 12.0%–68.0%,[8,9] while the severe TA rate was 41.5%, neither of which were sufficiently low for testicular salvageability. Furthermore, of the 27 patients who underwent reluctant orchiopexy who were surgically assessed as Arda grade III and inviable, 88.9% had their testes resected subsequently or atrophied during follow-up, and only 7.4% (2/27) had normal testicular volume and activity. The semen analysis of two patients who underwent orchiectomy proved to be normal, indicating that early orchiectomy of torsed infarcted testis may preserve fertility. Therefore, to prevent damage to the contralateral normal testes, we suggest performing orchiectomy if the torsed testes are surgically confirmed as Arda grade III and remain viable after infiltrating 1.0% lignocaine into the spermatic cord, followed by the application of warm saline gauze covering the tissue for 10–30 min. As legal guardians do not know the possible clinical results and the underlying mechanisms of the damage to the contralateral normal testes, explanation and authorization should be exchanged in clinical experience.

There is currently no standard definition for TA. Previous studies considered approximately 10%–20% or >2 ml difference in size compared with the contralateral sides as "hypotrophy" and >30% or >4 ml as "atrophy", although these terms have been used interchangeably in infertility and varicocele contexts.[17,18] We consider that percentages of TVL would be more accurate and appropriate to describe TA, given that the testicular volume will change with age, and this is consistent with the findings of recent studies.[8,9]

The first TA evidence appeared on Doppler ultrasound at least 3–4 months after orchiopexy for cryptorchidism.[19] We also examined the TVL changes with time after surgery. According to our analysis, most atrophied testes appeared within 3–6 months after surgery, although some atrophied testes appeared just 1 month or 2 months after torsion (**Figure 2a**). However, the testicular volume of the affected testes remained changeable 1 month or 2 months after surgery (from normal to atrophied), indicating that the affected testes after torsion remained unstable. In contrast, the TVL tended to be relatively stable from 3 months after surgery (**Figure 2b**). This new finding provides robust evidence for the follow-up time strategy after TT, in that 3 months after surgery should be regarded as the first follow-up time to monitor the testes. Follow-up before this time is not cost-effective and does not offer sufficient clinical value. While follow-up should be a long-term and flexible procedure, routine follow-up at 6 months, 12 months, or other time intervals should be judged by clinicians on a case-by-case basis, and urgent checks should be performed in response to sudden testicular pain or swelling. We believe that this suggestion also may be applied to other testicular diseases, such as cryptorchidism and hydrocele, although further evidence is necessary.

The contralateral testes of boys who underwent orchiectomy and orchiopexy with TA were found to have compensatory hypertrophy. The boys who underwent orchiectomy had a significantly longer follow-up time than those who underwent orchiopexy. Although semen and

Table 3: Logistic regression analysis of factors associated with testicular volume loss >50% (testicular atrophy) in pediatric testicular torsion after salvage orchiopexy

Factor	*Parameter estimate*	*s.e.m.*	*P*	*95% CI*
Age <6 years	0.076	1.142	0.024*	0.008–0.715
Delayed surgery	8.131	0.616	0.001*	2.431–27.196
Intraoperative poor blood supply	3.897	0.623	0.029*	1.149–13.215
Away from the main city zone	1.149	0.587	0.814	0.363–3.629
Grade of Arda	1.458	0.793	0.634	0.308–6.897
Echogenicity of testicular parenchymal on ultrasonography	2.948	0.637	0.090	0.846–10.278

*$P<0.05$. CI: confidence interval; s.e.m.: standard error of mean

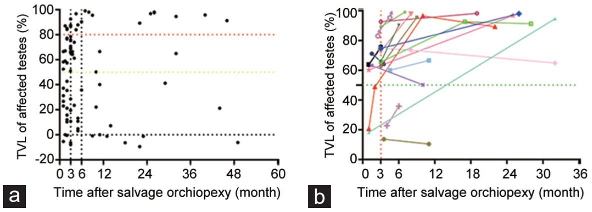

Figure 2: (**a**) TVL of boys with testicular torsion who underwent salvage orchiopexy in the latest follow-up. (**b**) TVL changes of boys with at least two ultrasonographic monitoring visits during follow-up. Black dotted line indicates no testicular volume loss or increase, yellow and green dotted line indicate testicular volume loss of 50% (testicular atrophy), red dotted line indicates testicular volume loss of 80% (severe testicular atrophy). TVL: testicular volume loss.

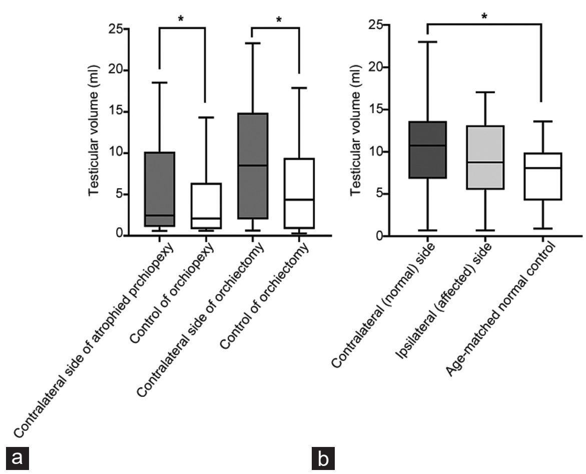

Figure 3: (**a**) Comparison of the contralateral testicular volume of boys who underwent salvage orchiopexy with atrophic testes during follow-up and age-matched healthy controls, and comparison of the contralateral testicular volume of boys who underwent orchiectomy and normal controls. (**b**) Box plot of the comparison of the ipsilateral and contralateral testicular volume of boys who underwent salvage orchiopexy without obvious testicular atrophy during follow-up. $^{*}P < 0.05$.

endocrine analyses were insufficient to draw a reliable conclusion, we do not consider that the endocrine level will be affected after TT; a healthy testis still provides fertility potential, and TA may act as a risk factor for fertility loss. Further evidence and understanding of the underlying mechanism are necessary to confirm our findings.

The effect of a torsed testis on subsequent male spermatogenesis is not as simple as TT-detorsion, although the exact influence on the contralateral testis and the underlying mechanism remain unclear. Both removing the torsed infarcted testes and leaving it on the scrotum after sufficient detorsion and fixation may have negative effects on testicular functions. Moreover, whether the remaining contralateral testes have sufficient capacity to maintain spermatogenesis and testosterone production is still contradictory.[20]

Even so, the cross-injury theory has been accepted by many researchers.[21–23] Theories of the causes of contralateral damage are mainly derived from animal studies, which are difficult to translate into human modalities. The existing hypotheses are three-fold. First, ipsilateral ischemia-reperfusion injury would cause contralateral reflectory sympathetically-mediated vasoconstriction, resulting in testicular ischemia,[22] and, even worse, the ischemia-reperfusion injury is much more severe than ischemia alone.[24] Second, the torsion of the affected spermatic cord breaks down the blood-testis barrier, which would initiate autoimmunization against the spermatogonia by anti-sperm antibodies, and that will reduce sperm motility and concentration.[21] Third, in a study on preexisting congenital testicular dysgenesis, Hagen *et al*.[25] found that 88% of the contralateral testes of 34 patients with TT were abnormal following biopsy.

Our study has some noteworthy limitations. First, the retrospective design of this study may have inevitable recall bias and selection bias. Second, the rate of loss to follow-up was relatively high, and the patients did not receive consecutive and regular follow-ups. Some patients received more than four follow-ups, whereas others had only one recorded follow-up. Thus, the TA-free survival curve was not completely accurate; indeed, some testes atrophied long before the time at which the atrophy was detected. Third, ultrasonographic measurements of the testes were not conducted by a single physician, and this was a subjective procedure. Fourth, and most regretfully, the semen and blood samples were insufficient to make a robust conclusion regarding spermatogenic functions and endocrine production after TT.

CONCLUSION

Approximately 56.6% of patients who underwent salvage orchiopexy had TA, and with age less than 6 years, delayed surgery, and intraoperative poor blood supply were associated with TA. Of the patients who were surgically assessed as Arda grade III and inviable, and who underwent orchiopexy, approximately 88.9% patients underwent subsequent orchiectomy or experienced TA. The TVL tended to be stable from 3 months after surgery, but follow-up before this time may not offer sufficient clinical value. The contralateral testes of patients who underwent orchiectomy or orchiopexy had compensatory hypertrophy compared with those of healthy children. The adverse events were comparable in patients who underwent orchiectomy and orchiopexy.

In summary, we suggest performing orchiectomy when torsed testes are surgically assessed as Arda grade III and inviable. Moreover, 3 months after surgery should be regarded as the first follow-up time for testicular monitoring.

AUTHOR CONTRIBUTIONS

CJY and SDW conceived and designed the study. CJY, JZ, and JL extracted the clinical data. CJY, YFH, and TXZ led the analysis and interpretation of data, drafted the manuscript, and revised the content based on feedback. LJ and SW assisted with the acquisition of data and interpretation. LJ, TL, DWH, and GHW assisted with the conception and design and the critical revision of drafts. SDW provided funding support. All authors read and approved the final manuscript.

COMPETING INTERESTS

All authors declare no competing interests.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (No. 81873828), Chongqing Municipal Health Commission (High-Level Medical Reserved Personnel Training Project of Chongqing), the Innovation Program for Chongqing's Overseas Returnees (cx2019030), and the Senior Medical Talents Program of Chongqing for Young and Middle-Aged.

Supplementary Information is linked to the online version of the paper on the *Asian Journal of Andrology* website.

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Supplementary Table 1: Age, operation information, and semen analysis of the five patients who were available and willing to undergo semen analysis

Items	*Case #1*	*Case #2*	*Case #3*	*Case #4*	*Case #5*
Age, years	19	24	20	23	20
Laterality	Left	Left	Left	Right	Right
Operation strategy	Orchiectomy	Orchiectomy	Orchiopexy[&]	Orchiopexy	Orchiopexy[&]
Prognosis of affected testis during follow-up	-	-	Severe atrophy	Severe atrophy	Normal
Semen analysis					
Semen volume, ml	2.9	5.9	1.5	4.3	1.7
Liquefaction status	Abnormal	Normal	Normal	Normal	Normal
Acid base, pH	7.4	7.4	7.4	7.4	7.4
Sperm count, 10^6	59.83	140.61	28.17*	62.71	107.03
Sperm concentration, 10^6/ml	20.63	13.83	18.78	14.58*	62.96
Forward motile sperm, 10^6	35.07	100.73	2.13*	36.71	60.47
Nonforward motile sperm, 10^6	3.09	10.49	0.43	7.65	17.54
Motionless sperm, 10^6	21.66	29.39	25.61	18.35	29.02
Sperm viability, %	63.79	79.1	9.09*	70.73	71.88

[&]This patient had a salvage orchiopexy with fixation of contralateral testis, *Below the normal range. "-" indicates data not available

Supplementary Table 2: Univariate analysis of factors associated with testicular volume loss in pediatric testicular torsion after salvage orchiopexy

Variables	*TVL >50% (n=60)*	*TVL ≤50% (n=40)*	*P*	*TVL (%), medium (IQR)*	*P*
Age category, *n* (%)			<0.001*		<0.001*
0-5	21 (35.0)	1 (2.5)		76.20 (64.28-89.25)	
6-18	39 (65.0)	39 (97.5)		36.50 (10.85-74.23)	
Laterality, *n* (%)			0.126		0.108
Left	51 (85.0)	29 (72.5)		60.10 (23.43-82.93)	
Right	9 (15.0)	11 (27.5)		22.15 (2.98-81.95)	
Delayed surgery, *n* (%)			<0.001*		<0.001*
0-12 h	9 (15.0)	27 (67.5)		13.90 (0.30-41.00)	
>12 h	51 (85.0)	13 (32.5)		66.80 (46.95-87.40)	
Echogenicity of testicular parenchymal on ultrasonography, *n* (%)			0.001*		<0.001*
Homogenous	9 (15.0)	18 (45.0)		22.10 (7.20-51.00)	
Heterogeneous	51 (85.0)	22 (55.0)		70.80 (43.60-88.40)	
Degree of torsion, *n* (%)			0.683		0.856
0°–360°	29 (48.3)	21 (52.5)		58.00 (14.55-85.65)	
>360°	31 (51.7)	19 (47.5)		57.40 (23.00-77.20)	
Direction of rotation, *n* (%)			1.0		0.775
Counterclockwise	24 (40.0)	16 (40.0)		54.60 (20.08-76.68)	
Clockwise	36 (60.0)	24 (60.0)		57.70 (14.30-86.90)	
Intraoperative blood supply, *n* (%)			0.001*		0.01*
Rich	10 (16.7)	19 (47.5)		21.80 (5.40-69.75)	
Poor	50 (83.3)	21 (52.5)		62.50 (27.30-86.90)	
Grade of Arda, *n* (%)			0.001*		0.049*
I-II	36 (60.0)	36 (90.0)		47.90 (11.50-81.18)	
III	24 (40.0)	4 (10.0)		66.50 (29.30-92.98)	
Medical insurance, *n* (%)			0.529		0.636
Yes	44 (73.3)	27 (67.5)		58.10 (11.73-79.78)	
No	16 (26.7)	13 (32.5)		48.50 (23.08-84.05)	
Poverty county residence, *n* (%)			0.664		0.394
Yes	11 (18.3)	6 (15.0)		64.55 (24.48-79.78)	
No	49 (81.7)	34 (85.0)		54.90 (13.60-83.45)	
Neighboring main city zone, *n* (%)			0.016*		0.271
Yes	29 (48.3)	29 (72.5)		52.40 (12.00-82.10)	
No	31 (51.7)	11 (27.5)		61.30 (23.45-84.05)	

*$P<0.05$. TVL: testicular volume loss; IQR: interquartile range

Supplementary Table 3: Multivariate analysis of variance of testicular volume loss in pediatric testicular torsion after salvage orchiopexy

Variables	*F*	*P*
Echogenicity of testicular parenchymal on ultrasonography	7.929	0.006*
Age <6 years	3.450	0.067
Delayed surgery	3.203	0.077
Intraoperative poor blood supply	2.264	0.136
Grade of Arda	0.039	0.843

*$P<0.05$. F indicates F-test of multivariate analysis. $R^2=0.508$

Patient questionnaire:

Patient Name: ______________________________

Contact number: ______________________________

Questions:

1. Did you have any scrotal pain or discomfort after surgery? Yes / No
2. Did you have any medical attention or consultant after surgery? Yes / No
3. For what reason?______________________________
4. Did you have contralateral testicular torsion? Yes / No
5. If yes, how you manage it, and the prognosis? ______________________________
6. Have you monitored your testes by ultrasound after surgery? Yes / No
7. Was these any testicular atrophy or hypotrophy of the affected testis after surgery, and how you defined or learned it? ______________________________
8. Have you ever visited an infertility clinic, and what was the result? ____________
9. Have you married? Yes / No
10. Do you have any children? Yes / No

Supplementary Figure 1: Standardized questionnaire for possible telephonic interview.