Turkish Journal of Endocrinology and Metabolism, (2005) 3 : 73-79 **REVIEW**

Thyrotoxic Hypokalaemic Periodic Paralysis (TPP) in Turkey: Report of a Case and Review of the Literature

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Thyrotoxic hypokalaemic periodic paralysis (TPP) is characterized by acute and reversible episodes of muscle weakness during thyrotoxicosis and associated with low potassium levels. Increased sodium-potassium ATPase activity in TPP leads to sudden influx of potassium into muscle cells and results in hypokalaemia. It is seen most commonly in Southeast Asian men. TPP is a rare condition in our country. Although only three patients were reported from Turkey in the English literature, there are Turkish cases reported in the national literature. Here we report a case of TPP due to toxic nodular goiter and review the literature.

Keywords: Thyrotoxicosis, hypokalaemia, paralysis, toxic nodular goiter

Introduction

Hypokalaemic periodic paralysis (HPP) is a major entity in the differential diagnosis of patients with hypokalaemia and extreme muscular weakness (1). While the familial type of the disease is more common in Western countries, the type related with thyrotoxicosis is more common in Asian populations (1, 2). Thyrotoxic hypokalaemic periodic paralysis (TPP) is characterized with episodic muscle weakness during thyrotoxicosis attacks (3). Thyrotoxicosis developing due to any etiology can precipitate TPP attacks (4). Although the most cause of hyperthyroidism is Graves' disease, there are case reports related to toxic nodular goiter and other etiologies of thyrotoxicosis (5).

In this article, a case of TPP due to toxic nodular goiter (TNG) is reported, and the review of the literature including the clinical and laboratory features the Turkish cases is done.

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Case Report

A 49 years old male patient applied to the emergency department with the complaint of acute onset muscle weakness. The muscle weakness had started in the proximal parts of the lower extremities bilaterally 8 hours ago and had become significant gradually. In the history, there was heavy exercise and carbohydrate- rich meal intake during the last three days. The patient had complaints of excessive sweating and tremor for a year. However he didn't apply to a physician. There was no history of drug use, vomiting, diarrhea or familial paralysis.

Physical examination findings were as follows: blood pressure: 140/90 mmHg, pulse rate: 92/min, respiratory rate: 20/min, temperature: 37ºC. The patient seemed restless. The skin was sweaty. There was fine tremor. The muscle strength was lowered 3/5 bilaterally in the lower extremities and 4/5 bilaterally in the upper extremities. There was no pathological reflex or additional neurological finding. Thyroid was soft, grade 2B palpable and had an asymmetric appearance. There were palpable nodules with diameters up to 4 cm in both thyroid lobes. Biochemical examination findings were as follows: random plasma glucose 124 mg/dl, serum creatinine: 0.9 mg/dl (normal: 0.8-1.4

mg/dl), sodium (Na): 144 mmol/L (normal: 136-146 mmol/L), potassium (K): 1.59 mmol/L (normal: 3.5-5.5 mmol/L), chloride:111 mmol/L (normal: 98-110 mmol/L), total calcium (Ca): 8.6 mg/dl (normal: 8.6-10.2 mg/dl), phosphorus: 1 mg/dl (normal: 2.7-4.5 mg/dl), albumin: 4.6 g/dl (normal: 3.5-5.2 g/dl), myoglobulin: 413 ng/ml (normal: 0-70 ng/ml), creatine phosphokinase: 278 U/L (normal: 26-167 U/L). The urine potassium/ creatinine ratio was calculated as 0.4. Arterial blood gas analysis revealed pH: 7.48, pO_2: 99 mmHg, PCO_2: 36 mmHg, HCO_3: 27 mmol/L. He had atrial flatter with block, ventricular extra systoles, flattening in the T wave, depression up to 2 mm in the ST segment and U waves in the initial electrocardiogram (ECG). Thyroid function test showed a thyrotropin (TSH) level of 0.044 μIU/ml (normal: 0.4-5), free 3,5,3'-triiodothyronine (FT3) of 7.8 pg/dl (normal: 1.8-4.2) and free thyroxine (FT4) of 4.1 ng/dl (normal: 0.8-1.9). The results were negative for serum antithyroid peroxidase antibody, antithyroglobulin antibody and thyroid receptor antibody.

There were hypoechoic nodules in size of 44x29x47 mm in the right thyroid lobe and 41x26x46 mm and 20x20x20 mm in the left thyroid lobe in the ultrasonographic examination of the thyroid. Technetium 99 m thyroid scintigraphy revealed that there were hyperactive thyroid nodules in the left and right thyroid lobes with no background activity. The patient was diagnosed as having toxic nodular goiter and thyrotoxic hypokalaemic periodic paralysis. The patient's ECG showed sinus rhythm before any treatment was initiated. The neurological findings and hypokalaemia recovered completely at the end of 4 hours of observation. The patient received potassium infusion (a total of 40 mmol in 4 hours) and propranolol. Oral hydration was continued in order to prevent rhabdomyolysis, which may develop secondary to severe hypokalaemia. The patient was prescribed propylthiouracil 800 mg/day as antithyroid treatment. When he becomes euthyroid after 4 months of antithyroid medication he was recommended to have surgical therapy. However he refused to have surgery. No new attack was observed during the follow up of the patient.

Discussion

The first nonspecific periodic paralysis was reported in 1882, and its relationship with hyperthyroidism was reported in 1902 (6). Although family history is absent in the TPP, relationship with various human leukocyte antigen (HLA) types in various populations is reported, in contrast with the familial type of periodic paralysis (5-9).

The mean age at onset of the disease is between 3rd and 5th decades in TPP (10). There is a mild hyperthyroidism in most of the cases (11-13). The clinical findings of hyperthyroidism can be subtle in these cases (11). Therefore, thyroid examination and thyroid function tests should be performed in all patients with hypokalaemic paralysis (1). In addition to the clinical findings of hyperthyroidism, nodular goiter detected during the thyroid examination was the leading factor for diagnosis in our case. Although hyperthyroidism is more frequent in women, TPP is more common in men (10, 14). The most frequent thyroid pathology seen in TPP is the Graves' disease (5). However, there are reported cases related with solitary toxic adenoma, pituitary adenoma producing TSH, thyroxin abuse and toxic nodular goiter, as in our case (4, 5).

Three cases in the English literature reported from Turkey are a man presenting with an episode of TPP following oral diclophenac sodium usage (15)**,** a TPP attack observed in the course of Graves' disease after radioiodine treatment (16) and an another TPP episode due to Graves' disease (17). When the Turkish literature was also reviewed, data of 24 patients including our case were obtained (15-28). All of the cases from Turkey were males. While the youngest was 22 years old and the oldest 54 years old, the mean age of the cases was 35.33 years. Of the 23 cases whose thyroid function tests were available, 20 (87%) had overt hyperthyroidism, 2 (8.7%) had subclinical hyperthyroidism (15-28). In one of the cases (4.3%), although there was hyperthyroidism in his medical history, he was euthyroid at the time of diagnosis (26). Although it is classically suggested that TPP attacks are controlled by achieving euthyroid state, TPP attacks during euthyroid period were reported, like this case (29-31). However, TPP is very rare during the

euthyroid period and we suggest that a very careful differential diagnosis is necessary in case of hypokalaemic paralysis episode in the euthyroid period. Additionally, recurrence of TPP attacks can be observed with recurrence of hyperthyroidism (8). In patients, where levothyroxine replacement is required after the treatment of hyperthyroidism, attacks may be observed due to over dose of levothyroxine (8, 32). In addition, radioiodine treatment can lead increased thyroid hormone levels after a few days of administration and may precipitate TPP attacks (16).

Although the thyroid function tests in majority (87%) of the cases reported from Turkey demonstrated overt hyperthyroidism, the classical symptoms of hyperthyroidism were absent in 50% of the cases (15-28). Goh et al. have also reported that only two patients had symptoms of hyperthyroidism, while all of the 7 patients had overt hyperthyroidism shown by laboratory tests (33). The mild course of hyperthyroidism in patients with TPP can explain why most of the patients are asymptomatic regarding classical hyperthyroidism findings (7, 34, 35).

Assessing the ultrasonographic data of 13 patients with TPP, King et al have found toxic nodular goiter in one patient, Graves' disease and diffuse goiter in 11 patients and multinodular goiter accompanying Graves' disease in one patient. No specific sonographic finding for TPP was reported in this study (36). The most frequent thyroid pathology in Turkish patients was Graves' disease, in accordance with the literature (15-28). Additionally, TPP cases due to toxic nodular goiter and thyroiditis have also been reported (23, 26, 28). While in 4 (16.7%) of the Turkish cases the pathology of the thyroid was TNG, in 10 (41.7%) of them accompanying thyroid nodule was reported (15-28). Thus, it can be suggested that the sonographic findings in patients with TPP depends on the underlying thyroid disease (36). Most patients with TPP have acute paralysis as a chief complaint. Hyperthyroidism in these cases is usually mild (33). Therefore, most of the TPP patients apply to other departments. Eleven (45.8%) of the cases reported from Turkey were evaluated by neurologists, 9 (37.5%) by endocrinologists, one (4.2%) by specialist of emergency medicine, one (4.2%) by rheumatologist, one (4.2%) by general surgeon and one (4.2%) was evaluated by physical medicine and rehabilitation (PMR) specialist (15-28).

As a result of enhanced Na/K-ATPase pump activity in TPP, potassium suddenly directs to the muscle cells (34). Therefore, urinary potassium excretion and trans-tubular potassium gradient is low in TTP (1). In fact, Na/K-ATPase activity is increased in all of the patients with hyperthyroidism. However, the pump activity is more elevated in patients with TPP (37). In addition, hyperinsulinemia in patients with TPP enhances the Na/K-ATPase activity (38). High insulin levels and transient glucose intolerance during the TPP attacks are reported (39, 40). A paralytic attack could be established by glucose and insulin infusion in six out of seven patients with TPP in 90 minutes (41). These findings suggest that hyperinsulinemia may have a role in the pathogenesis. Additionally, the hyperadrenergic status due to thyrotoxicosis can be blamed, since the beta-blockers are effective in the treatment of TPP (42, 43). The nature of muscular weakness in TPP is myopathic (10, 44). In electromyography studies, the myopathic pattern observed during the TPP attacks recovers after remission (44). When the muscular biopsies performed during the attacks are examined by light microscopy, pathologic findings are observed in 76.5% of the cases. When the materials are examined by electron microcopy, abnormal findings were present in all of the cases (45). In another study it was demonstrated that the Ca-ATPase activity in the skeletal muscle and calcium uptake in the sarcoplasmic reticulum are decreased during the TPP attack (46).

As seen in our case, acute severe hypokalaemia may lead to rhabdomyolysis. The free myoglobulin and iron liberated from the destructed skeletal muscles may enhance the renal potassium loss their toxic effects on the tubules (47). Lin et al had evaluated 20 patients with TPP. The mean creatine phosphokinase (CPK) level was 319 IU/L (normal: 26-167 IU/L) in this study (11). Manoukian et al had measured CPK levels in 18 of 24 TPP episodes and found it higher than normal values in 12 patients. Four of these patients had CPK levels higher than 1000 IU/L. All of these four patients had CPK sub fraction analysis. All of the patients had an increase in the MM band (5). It is suggested

that hypokalaemic rhabdomyolysis occurs as a result of impaired myocyte energy mechanisms (48). Potassium deficiency impairs the glycogen synthesis in the muscle (49). The reactive hyperemia mechanism to compensate the increased oxygen need in the exercising muscles is impaired in hypokalaemic subjects (50). Therefore, the aerobic energy consumption can not be realized. Finally, energy deficit occurs in the muscle via both mechanisms and myocyte death occurs (48).

Commonly, TPP cases are evaluated in the emergency department and the patients are administered potassium replacement in the acute phase. Therefore, 24 hours urine can not be collected for electrolyte measurements and usually the measurements are performed in the spot urine. The polyuria existing together with hypokalaemia and rhabdomyolysis in TPP patients can lead to problems in evaluation of the urinary potassium excretion (9). Therefore, calculation of urine potassium/creatinine ratio or transtubular potassium concentration gradient (TTKG) are more reliable than measurement of urinary potassium excretion alone (9, 51). The urine potassium/creatinine ratio is expected to be smaller than 2, and the TTKG is expected to be smaller than 3 in patients with TTP (9, 52, 53). However, the urine osmolality can be lower than plasma osmolality in these subjects (9). This condition prevents the evaluation of TTKG (52). Urine potassium/creatinine ratio appears as a simple and feasible method (9). In our case, urine potassium/creatinine ratio was calculated as 0.4, which is in compliance with TPP.

The clinical findings in TPP are observed in attacks and are of short duration. Generally, they improve in 3-36 hours after the initiation of the treatment with intravenous potassium (8). TPP episodes usually follow stress, exercise and/or carbohydrate-rich meal intake (5, 14, 17). Some reports suggest that paralytic attacks in TTP tend to occur during the night (5, 16). The proximal muscles of lower extremities are more affected than other muscles (5). It is suggested that stress and exercise via adrenalin, and carbohydrate consumption via insulin, enhance the Na/K-ATPase pump activity and lead to potassium influx (54). In 16 (66.6%) of the Turkish cases, there was exercise and/or carbohydrate-rich meal intake before the attack (15-28). Similarly in our case, there was story of heavy exercise and carbohydrate-rich diet intake in the last three days before the attack. In addition, exposure to cold in one case (4.2%) and radioiodine treatment in another one (4.2%) was considered as trigger factor in Turkish cases (16, 25). In one case (4.2%) a paralytic episode following administration of diclophenac sodium was reported (15). While 8 (33.3%) of the cases were diagnosed during the first attack, other 7 (29.2%) had more than ten attacks until they were diagnosed. No relationship could be established between the serum potassium and phosphorus levels and number of attacks in the patients ($p > 0.05$). The TPP attacks were reported to end in 72 hours in all of the patients. There was no relationship between the serum levels of potassium and phosphorus and times to recovery ($p > 0.05$). However, younger Turkish patients had longer times to recovery and the negatively correlation between age and recovery time was statistical significant ($r = -0.495$, $p = 0.023$).

There were findings due to hypokalaemia in our patient's ECG. Additionally, atrial flatter with block was observed in the presenting ECG of the patient. Sinus rhythm was observed during the follow-up, without any treatment. In addition to typical ECG findings secondary to hypokalaemia, various arrhythmias can be observed in the ECG of patients with TPP (12). In the retrospective study performed by Hsu et al on a total of 54 patients with hypokalaemic paralysis, of which 31 had TPP, U waves, shortening in the QT segment, depression of the ST segment and flattening in the T wave were present in a majority of the patients. While these findings were present in similar rates in various etiological groups, increased pulse rate, high QRS voltage and first-degree atrioventricular block were observed more frequently in the TPP group (13).

Hypophosphatemia can be established in some of the cases with TPP, just as in our case. Furthermore, within the patients with hypokalaemic paralysis, hypophosphatemia is found more often in patients with TPP (11, 13). Exaggerated insulin response or hyperadrenergic status affected by genetic factors may be the reason of hypophosphatemia in TPP (5). Beta receptor blockage achieved by propranolol is useful in improving both the hypokalaemia and hypophosphatemia

(42). Of 12 Turkish cases whose phosphorus levels were reported, together with our case, hypophosphatemia was present in three (25%) (17, 18, 20, 26, 27).

Treatment of TPP differs from other conditions that present with hypokalaemia. Although the pathogenesis is not known completely, intensive intravenous potassium treatment in the acute phase is under discussion, since intracellular potassium shift is suggested as the primary cause (1). There is no known relationship between the amount of potassium administered via intravenous route and the time to recovery of the attack (5). Lin et al have observed rebound hyperkalaemia in 1/3 of a series of cases with hypokalaemic paralysis (1). On the other hand, Manoukian et al reported that rebound hyperkalaemia occurred in 42% of 24 episodes in 19 patients studied. These 19 patients in 24 episodes had a mean 89 mmol potassium chloride replacement (5). Additionally, there are hypokalaemic periodic paralysis cases in the literature that have recovered without intravenous potassium chloride (KCL) administration spontaneously, or with beta blocker treatment alone (1, 43). Rebound hyperkalaemia was not reported in any of the Turkish cases. While one of the cases (4.2%) did not receive potassium replacement, another 23 cases (95.8%) had received potassium replacement via intravenous or oral route (15-28). Potassium replacement treatment may be administered together with close follow-up of cardiac functions and serum potassium levels in the presence of extremely low serum potassium levels, as in our case (13). Beta blocker agents are effective in terminating the attack and avoiding the recurrences in the thyrotoxic form of periodic paralysis (42, 43, 55). The base for the treatment is terminating the hyperthyroidism and it avoids new attacks (10). In majority of the Turkish cases where information could be obtained regarding the treatment, it was observed that beta blockers and antithyroid drugs were used (17, 18, 26, 27).

In summary, all of the Turkish cases were male. While the underlying thyroid pathology was frequently Graves' disease in the Turkish patients, thyroiditis and TNG as our case are also reported. In most of the Turkish patients the TPP attack was precipitated by exercise and/or carbohydrate-rich nutrition. In addition, exposure to cold, radioiodine treatment and oral diclophenac sodium administration were considered as a precipitant factor. No relationship could be established between potassium levels and number of attacks or time to recovery in the Turkish cases. However, younger age was associated with the longer time to recovery. Although TPP is rare in our country, it should be taken into account in cases presenting with hypokalaemia and muscle weakness. The attacks end in a short time with beta blocker administration in the acute phase and potassium replacement where necessary; and recurrence of attacks can be prevented with the treatment of hyperthyroidism.

References

1. Lin SH, Lin YF, Halperin ML. Hypokalaemia and paralysis. *Qjm* **94**(3): 133-9, 2001.
2. Phakdeekitcharoen B, Ruangraksa C, Radinahamed P. Hypokalaemia and paralysis in the Thai population. *Nephrol Dial Transplant* **19**(8): 2013-8, 2004.
3. Brandenburg VM, Knackstedt C, Gobbele R, et al. [Thyrotoxic hypokalemic paralysis.]. *Nervenarzt* **75**(10): 1007-11, 2004.
4. Peiris AN. Thyrotoxic periodic paralysis. *South Med J* **95**(11): 1233-4, 2002.
5. Manoukian MA, Foote JA, Crapo LM. Clinical and metabolic features of thyrotoxic periodic paralysis in 24 episodes. *Arch Intern Med* **159**(6): 601-6, 1999.
6. Paul B, Hirudayaraj P, Baig MW. Thyrotoxic periodic paralysis: an unusual presentation of weakness. *Emerg Med J* **20**(5): E7, 2003.
7. Salifu MO, Otah K, Carroll HJ, et al. Thyrotoxic hypokalaemic paralysis in a Black man. *Qjm* **94**(11): 659-60, 2001.
8. Sinharay R. Hypokalaemic thyrotoxic periodic paralysis in the UK. *Qjm* **96**(8): 611-3, 2003.
9. Lin SH, Chiu JS, Hsu CW, Chau T. A simple and rapid approach to hypokalemic paralysis. *Am J Emerg Med* **21**(6): 487-91, 2003.
10. Magsino CH, Jr., Ryan AJ, Jr. Thyrotoxic periodic paralysis. *South Med J* **93**(10): 996-1003, 2000.
11. Lin YF, Wu CC, Pei D, Chu SJ, Lin SH. Diagnosing thyrotoxic periodic paralysis in the ED. *Am J Emerg Med* 21(4): 339-42, 2003.
12. Boccalandro C, Lopez L, Boccalandro F, Lavis V. Electrocardiographic changes in thyrotoxic periodic paralysis. *Am J Cardiol* **91**(6): 775-7, 2003.
13. Hsu YJ, Lin YF, Chau T, Liou JT, Kuo SW, Lin SH. Electrocardiographic manifestations in patients with thyrotoxic periodic paralysis. *Am J Med Sci* **326**(3): 128-32, 2003.

14. Tassone H, Moulin A, Henderson SO. The pitfalls of potassium replacement in thyrotoxic periodic paralysis: a case report and review of the literature. *J Emerg Med* **26**(2): 157-61, 2004.

15. Aldemir M, Guloglu, C, Balakan, O, Süner, A, Kaya, Z. Thyrotoxic periodic paralysis: A case report and review of the literature. *Eur J Gen Med* **1**(2): 48-51, 2004.

16. Akar S, Comlekci A, Birlik M, et al. Thyrotoxic periodic paralysis in a Turkish male; the recurrence of the attack after radioiodine treatment. *Endocr J* **52**(1): 149-51, 2005.

17. Erem C. Thyrotoxic hypokalemic periodic paralysis in a Turkish male with graves' disease: a rare case report and review of the literature. *Endocrine* **27**(1): 63-5, 2005.

18. Aktaran S, Akarsu E, Kartal M. Graves hastalığında hipokalemik ve hipofosfatemik periyodik paralizi. In: 27 Ulusal Endokrinoloji ve Metabolik Hastalıklar Kongresi; 2004; İstanbul, Türkiye; 2004.

19. Aluçlu U, Hamdanoğulları D. Tirotoksik periyodik paralizi: Olgu sunumu. *Dicle Tıp Dergisi* **31**(1): 62-4, 2004.

20. Ataoğlu S. Tirotoksik hipokalemik periyodik paralizi bir olgu sunumu. Türkiye Fiziksel Tıp ve Rehabilitasyon Dergisi **47**(6), 2001.

21. Dokmetas H, Yuksel, I, Yonem, O. Hypokalemic thyrotoxic periodic paralysis. *Turkish Journal of Endocrinology and Metabolism* **3:** 127-9, 2001.

22. Gencer A. Tirotoksik periyodik paralizi. In: 18Ulusal Nörofizyoloji EEG-EMG Kongresi; 2001; Antalya, Türkiye; 2001.

23. Gökçe C, Bayram F, Şakrak Ö, Atmaca H, Ünlühızarcı K, Keleştimur F. Toksik nodüler guatr ile birlikte bulunan tirotoksik periyodik paralizi: Olgu sunumu. In: 27 Ulusal Endokrinoloji ve Metabolik Hastalıklar Kongresi; 2004; İstanbul, Türkiye; 2004.

24. Guloglu C, Aldemir, M, Sogut, O, Al, B. Tirotoksik periyodik paralizi. *Sendrom* **16**(8): 92-5, 2004.

25. Kaya A, Akpinar, Z, Karakose, S. Thyrotoxic periodic paralysis: The report of four cases. *Turkish Journal of Endocrinology and Metabolism* **3:** 123-6, 2001.

26. Koç F, Bozdemir H, Över F, Sarıca Y. Tirotoksik hipokalemik periyodik paralizili; 7 olgunun analizi ve literatürün gözden geçirilmesi. *Gülhane Tıp Dergisi* **46**(1): 59-65, 2004.

27. Kızkın S, Özışık HI, Çalışkan Ö, Özcan C. Hipokalemik tirotoksik periyodik paralizili bir olgu sunumu. *İnönü Üniversitesi Tıp Fakültesi Dergisi* **9**(4): 269-71, 2002.

28. Tataroğlu C, Baran L. Tirotoksik hipokalemik periyodik paralizi: Bir olgu sunumu. *Anadolu Tıp Dergisi* **3:** 230-3, 2000.

29. Rone JK, Brietzke SA. Euthyroid thyrotoxic periodic paralysis. *Mil Med* **156**(8): 434-6, 1991.

30. Gandara DR, Fariss BL. Persistence of periodic paralysis following treatment of thyrotoxicosis: case report. *Mil Med* **144**(5): 337-8, 1979.

31. Coates JT, Mirick MJ, Rubino FJ. Thyrotoxic periodic paralysis with relapse during the euthyroid state. *Wis Med J* **86**(8): 20-2, 1987.

32. Layzer RB, Goldfield E. Periodic paralysis caused by abuse of thyroid hormone. *Neurology* **24**(10): 949-52, 1974.

33. Goh SH. Thyrotoxic periodic paralysis: reports of seven patients presenting with weakness in an Asian emergency department. *Emerg Med J* **19**(1): 78-9, 2002.

34. Dixon AN, Jones R. Thyrotoxic periodic paralysis in a white woman. *Postgrad Med J* **78**(925): 687-8, 2002.

35. Deitch S, Davis D. Hypokalemic thyrotoxic periodic paralysis. *Am J Emerg Med* **19**(1): 85-6, 2001.

36. King AD, Chow FC, Ahuja AT, Richards PS. Thyrotoxic periodic paralysis: sonographic appearances of the thyroid. *J Clin Ultrasound* **30**(9): 544-7, 2002.

37. Chan A, Shinde R, Chow CC, Cockram CS, Swaminathan R. In vivo and in vitro sodium pump activity in subjects with thyrotoxic periodic paralysis. *Bmj* **303**(6810): 1096-9, 1991.

38. Chan A, Shinde R, Chow CC, Cockram CS, Swaminathan R. Hyperinsulinaemia and Na+, K(+)-ATPase activity in thyrotoxic periodic paralysis. *Clin Endocrinol (Oxf)* **41**(2): 213-6, 1994.

39. Shishiba Y, Shimizu T, Saito T, Shizume K. Elevated immunoreactive insulin concentration during spontaneous attacks in thyrotoxic periodic paralysis. *Metabolism* **21**(4): 285-90, 1972.

40. Hamada N, Ishii T, Hasegawa M, et al. Transient glucose intolerance during attacks of thyrotoxic periodic paralysis. *Horm Metab Res* **17**(6): 301-5, 1985.

41. Takeda R, Miyamori I, Yamamoto I, Ueda M, Uchida K. [Changes of pituitary and adrenal systems in thyrotoxic periodic paralysis of the limbs. A case with changes in plasma ACTH and cortisol levels at paralysis induction]. *Horumon To Rinsho* **24**(5): 429-31, 1976.

42. Lin SH, Lin YF. Propranolol rapidly reverses paralysis, hypokalemia, and hypophosphatemia in thyrotoxic periodic paralysis. *Am J Kidney Dis* **37**(3): 620-3, 2001.

43. Huang TY, Lin SH. Thyrotoxic hypokalemic periodic paralysis reversed by propranolol without rebound hyperkalemia. *Ann Emerg Med* **37**(4): 415-6, 2001.

44. Puvanendran K, Cheah JS, Wong PK. Electromyographic (EMG) study in thyrotoxic periodic paralysis. *Aust N Z J Med* **7**(5): 507-10, 1977.

45. Cheah JS, Tock EP, Kan SP. The light and electron microscopic changes in the skeletal muscles during paralysis in thyrotoxic periodic paralysis. *Am J Med Sci* **269**(3): 365-74, 1975.

46. Au KS, Yeung RT. Thyrotoxic periodic paralysis. Periodic variation in the muscle calcium pump activity. *Arch Neurol* **26**(6): 543-6, 1972.

47. Appel CC, Myles TD. Caffeine-induced hypokalemic paralysis in pregnancy. *Obstet Gynecol* **97**(5 Pt 2): 805-7, 2001.

48. Kao KC, Tsai YH, Lin MC, Huang CC, Tsao CY, Chen YC. Hypokalemic muscular paralysis causing acute respiratory failure due to rhabdomyolysis with renal tubular acidosis in a chronic glue sniffer. *J Toxicol Clin Toxicol* **38**(6): 679-81, 2000.

49. Streicher HZ, Gabow PA, Moss AH, Kono D, Kaehny WD. Syndromes of toluene sniffing in adults. *Ann Intern Med* **94**(6): 758-62, 1981.

50. Knochel JP, Schlein EM. On the mechanism of rhabdomyolysis in potassium depletion. *J Clin Invest* **51**(7): 1750-8, 1972.

51. Halperin ML, Kamel KS. Potassium. *Lancet* **352**(9122): 135-40, 1998.

52. Kamel KS, Quaggin S, Scheich A, Halperin ML. Disorders of potassium homeostasis: an approach based on pathophysiology. *Am J Kidney Dis* **24**(4): 597-613, 1994.

53. West ML, Marsden PA, Richardson RM, Zettle RM, Halperin ML. New clinical approach to evaluate disorders of potassium excretion. *Miner Electrolyte Met*ab **12**(4): 234-8, 1986.

54. Missiaen L, Robberecht W, van den Bosch L, et al. Abnormal intracellular ca(2+)homeostasis and disease. *Cell Calcium* **28**(1): 1-21, 2000.

55. Birkhahn RH, Gaeta TJ, Melniker L. Thyrotoxic periodic paralysis and intravenous propranolol in the emergency setting. *J Emerg Med* **18**(2): 199-202, 2000.