

Table S1. Detailed information of studies evaluating the effects of BoNT A (Group A) and BoNT A combined with physical rehabilitation (Group B) for treating APAs in PD.

Study ID	No. of patients (gender)	PA duration	Type of Toxin	Muscles injected	Study outcomes and follow-up (if reported)	Main Results	QA-LE
Study design	Age at evaluation	Diagnostic criteria of PA, Severity of PA, if reported	Injection method	N of injection cycles, if reported			
PD duration							
Group A. Studies evaluating the only effect of BoNT A for APAs in PD							
Yahalom et al, 2023 [82]	1 (M)	More than 3 y (requiring surgery for myelopathy)	Abobotulinum (Dysport)	Bilateral Medial Scalene (50 U)	Neurologic examination	Absence of improvement (objective or subjective) of antecollis after BoNT	Poor - 4
AC	-	-	Method: n.r.				
Case series	76 y - 3 y	n.r - Marked antecollis, bilateral increased tonus of the trapezius pars descendens and of the scalene muscles, without weakness of the cervical extensor muscles		Bilateral Levator Scapulae (25 U)			
Seliverstov et al. 2020 [89]	2 pts	Pt 1: 1 y, Antecollis with mild laterocollis	Onabotulinum (Botox)	Pt 1: Longus Colli: 50 U - Anterior Scalene: 10	Duration of the Improvement	Pt 1 4-week follow-up: - Reduction of neck pain in anterior region and enhanced	Fair - 4
AC	Pt 1 (F) - 66 y - 11 y		EMG-guided,				

Case series	Pt 2 (M) - 63 y - 8 y	Pt 2: 5 m -Variability of the posture as well as significant regression in a supine position - Limiting dressing, mobility, and maintenance of social interactions	patient supine	U on each side - Levator Scapulae: 15 U/side Pt 2: - Longus colli 40 U/side	Satisfaction rate Side effects	capability to sustain a more upright posture of the head- Satisfaction rate 40% - Side effect: mild dysphagia for 1 week Pt 2 4-week follow-up: - Improved neck mobility and communication abilities - Satisfaction rate of 30% - Side effects: difficulties in maintaining an upright neck posture; moderate dysphagia for 1.5 months
Van de Warrenburg et al, 2007 [83]	n=9 PD (3F,6M) - 69.1 ± 5.8 y	2.7 ± 1.4 y - Forward flexion and anterior shift of the neck with prominent cervical paraspinal and levator scapulae muscles, without residual neck extension weakness	Abobotulin um (Dysport): n=7 pt Method: EMG prior to injection	Uni/bilatera l Levator scapulae: 50-250 U Uni/bilatera l Sternocleid omastoid 50-100 U Uni/bilatera l Splenius capitis 200 U	Pain Neurologic examination	The majority of patients did not experience benefits from these injection . Pain reduction (1 pt) Improvement of the AC (2 pts)

Matsumoto et al., 2018 [90]	1 (M)	5 y	Onabotulinum (Botox): n=1 patient	Ipsilateral paraspinal (right) muscles from L2 to L4 spinous processes level	Pain Postural improvement by body X-ray and Surface EMG	Pain relieved Improvement of posture at body X-ray Increased contralateral tonic contraction of lumbar paraspinal muscles; decreased in tonic contraction of ipsilateral lumbar paraspinal muscles by surface EMG analysis.	Fair - 4
CC+PS Case report	6 y	LTF (right side) - Severe right abdominal pain requiring access to emergency room	Method: palpation of hypertrophic muscle Two cycles, one month apart	First session 20 U Second session 30 U			
Todo et al., 2018 [84]	6 (4F, 2M)	2.3 ± 0.8 - Thoracic spine flexion.	Onabotulinum (Botox) Method: US guidance, two injections at the intersection of the anterior axillary line and the line level with the umbilicus	Bilateral External Abdominal Oblique muscle (range): 75 to 90 U into each side. 100-120 U into each side as maintenance dose (every 3-4 months, 3 patients)	Short term evaluation at 2 weeks and long term (1 year or more): - CC degree before vs. after BoNT - EMG findings - VAS	Significant mean angle of CC improvement from median of 38° (interquartile: 23.5°) to 18° (interquartile: 21°). 4/6 pts reported subjective relief. VAS of 2 pts with abdominal contraction from 84 and 98 to 4 and 77	Poor - 4
CC Case series	72.5 ± 8.5 - 10.6 ± 5.3 y	Severe symptoms: Abdominal contractions (2 pts), dysbasia (1 pts), difficulty in facing upward (3 pts)				Long-term: two cases with persistent benefit, one reduced	

Wijemanne et al., 2014 [94]	1 (F) - 66 y - 7 y	2 y (and history of left Transverse Rectus Abdominis Myocutaneous flap procedure for breast reconstruction) - Palpable abdominal contractions in standing position. Pt was unable to lie flat on her back and had to lean upright against a wall. - Painful abdominal contractions with a 45-degree forward spine flexion in the OFF	Onabotulinum (Botox) Method: EMG-guided Two cycles, at a distance of 8 weeks Then, every 3-4 months	First injection: 200 U for each Rectus Abdominis Second injection: 200 U in left External Abdominal Oblique 200 U in right Rectus Abdominis	Anterior trunk flexion degree over 18 months	CC maintained a 15-20° improvement in the 'ON' state with a UPDRS score of 8, compared to 30° in the 'OFF' state, showing good response over 18 months	NA - 4
Colosimo et al., 2009 [86]	2 (n.r.) - n.r	n.r - Reducible forward flexion of the thoracolumbar spine > 45° - Severe CC	Onabotulinum (Botox) Method: CT guidance	300 U for each Iliopsoas (deep lumbar portion): 200 U for each Rectus Abdominis	Clinical evaluation	No objectively or subjective improvement of CC at 1 day, 1 week, and 2 weeks after BoNT injection	Poor - 4
Fietzek et al., 2009 [85]	10 (M/F n.r.) n=5 (age 70 ± 4.5	Iliopsoas group (1.9 ± 0.2), Rectus abdominis	Incobotulinum (Xeomin)	50 U per site Bilateral Iliopsoas (4-	After 3 weeks:	No improvement	Poor - 4

Goal attainment controlled study	y) injected in the Iliopsoas n= 5 (age 75.4 ± 1.6 y) injected in the rectus abdominis)	group (3.0 ± 1.4) - n.r. - Treatment goals included achieving a more upright gait (N=6), pain relief (N=3), enabling the grasping of previously unreachable items (N=3), facilitating social activities (N=2), and reducing stigmatization (N=3)	Method: US guidance	6 sites) muscle injected directly below the inguinal ligament with two to three sites (mean dosage 210 ± 50 U)	- Timed Up&Go 10 m - Goal attainment	
Von Coelln et al., 2008 [91]	3 (M) - 75y, 73y, 70y	3y, 1y, 1.5y - Abnormal trunk posture with marked thoracolumbar spine flexion when standing and walking, which lessens in the supine position	Abobotulinum (Dysport)	Unilateral, ipsilateral Psoas Major (n=2 PD with trunk deviation forward and toward the right side); Bilateral Psoas Major involvement (n=1 PD with pure forward flexion), treated via a ventral approach	Evaluation at 2, 4, and 16 weeks after each treatment: - Detailed interview - Physical examination - Body height (spontaneous and in maximal effort to stand)	All pts complained of mild to moderate weakness of hip flexion at the highest dose of BoNT. Limited or no efficacy in all patients

					above the inguinal ligament, along the muscle's longitudina l axis Initial dose: 500 U/side Retreatmen t every 4-6 months with a total of 16 injections, dosage increased by 500 U to a maximum of 1500 U per side			
Azher et al., 2005 [35]	6 (4M, 2F)	3.8 ± 2.1 y - A significant	Onabotulin um (Botox)	Rectus Abdominis (4 pts, range 150-400 U)	Clinical effect and its duration	Good response in 3 pts (8 weeks, 14 weeks, 24 weeks)	Poor - 4	
CC	67.2 ± 6 y -	(>45°) flexion of the	Method: n.r.	Paraspinal muscles (2 pts, 200 U)		Not reports of 3 pts		
Case series	12 ± 7.2 y	thoracolumbar spine that intensifies during walking and substantially decreases or vanishes in the recumbent position		Paraspinal muscles (2 pts, unknown dosage)				
Ledda et al 2023 [92]	13 (8 M, 5 F)	4.1 ± 5 - PS: >10 degrees	Onabotulin um (Botox)	1 st injection: 50 U longissimus	Short -term (4 months) and	Short-term (13 pts): No improvement	(13 4	
PS	68.8 ± 9 -	of LTF, manifests	Method: US guidance	thoracis and 50 U		of angle of LTF and VAS		

Longitudinal observation study and case-control	12.7 ± 6.2 Control pts (untreated): 7 PD pts with PS (4 M, 3 F) - 69.7 ± 3.2 - 7.7 ± 5.8	when sitting or standing . LTF: involuntary lateral trunk bending, 5 to 10 degrees- Baseline standing flexion angle: 11.2 ± 4.6 degrees; back pain VAS score: 6 ± 3 Controls baseline angle of flexion 15.1 ± 4.3	EMG: a) Seated without upper limb or trunk support. b) With trunk held upright and straight by an operator c) during patient's self-realignment of the trunk. 4 BoNT cycles, administered every 4 months	iliocostalis lumborum ipsilateral to LTF From 2 nd injection: personalized treatment based on US and EMG (longissimus thoracis and/or iliocostalis lumborum muscles with pathological muscular hyperactivity, from 15 to 50 units for each injected muscle)	Long-term (12 months): - Posture assessment (NeuroPosture APP) - VAS score	Long-term (7 pts): Mild improvement of angle of LTF (from 10.4 ± 2.8 to 9.2 ± 6.4 degrees) Angle of LTF in controls at long-term (18 months): 20.2 ± 7.4 degrees Significant differences in LTF degree changes over time between treated and untreated control groups (p = 0.026)
Artusi et al., 2019 [88] PS Prospective, pilot study	13 (10M, 3F) - 70.5 ± 8.5 y - Age at PD onset 60.0 ± 12.0 y	2.7 ± 2.3 y - LTF ≥ 10° improved by passive mobilization and supine positioning.	Onabotulinum (Botox) MRI to assess atrophy of paraspinal and non-paraspinal axial muscles Method: US and EMG-guided. EMG was	Muscle selection: hyperactivity on EMG when standing (if not available, based on lying findings); absence of severe muscle atrophy on MRI.	Postural improvement observed two months after BoNT injection. Degrees of LTF changes measured using a wall goniometer and "ImageJ," with a 5°	The rate of Good responders was ~2c 84.6% (n= 11/13) LTF angle improved by 40%, from 15.7 ± 8.4 to 9.4 ± 11.8 degrees. Pain reduction was 52.2% in total VAS score, from 6.9 ± 2.2 to 3.3 ± 1.6

					conducted in lying down prone on an examination table with arms along the trunk, and then in standing position	Paraspinal muscles at L2-L4 (longissimus thoracis, iliocostalis lumborum, and spinalis dorsi) (range: 50 - 75 U)	cut-off defining significant improvement.	No procedural or post-procedural adverse events (AEs)
						Non paraspinal muscles (abdominal oblique and Iliopsoas) (range 25 to 50 U)		
Dupeyron et al., 2015 [95]	1 (F) - 69 y	A tonic side complete resolution	LTF one with in	Incobotulinum (Xeomin) EMG before injection	First injection: 50 U in two sites (T10 and L3 level), of left iliocostalis (Ipsilateral) muscle	Clinical improvement with pictures	Six weeks after first injection pain improved, but not PS.	NA - 4
PS	- 10 y	supine position and increased deviation during standing			Second injection, three months after: 50 U in two sites of ipsilateral quadratus		Improvement of PS after second injection, lasting for one year	

				lumborum muscle				
Bonanni et al., 2007 [93]	9 (5M,4F)	2.4 ± 0.9 y	Abobotulinum (Dysport): 500 U	Injection of 125 U into four sites of paraspinal muscles, 2 to 2.5 cm lateral to the spinous processes at levels L2-L5, on the ipsilateral to the bend	Evaluation at 2 and 4 weeks, and at 3 months: - TDDS - VAS - Goniometric measurement of the LTF displacement	At 1 month, n=6 pts showed an improvement of lateral bending from 50% to 85.7% and reduction of pain	Fair - 4	
PS	BoNT treatment	LFT ≥ 15° that increase during walking and disappear in the recumbent position.	Method: EMG-guided (to evaluate continuous EMG activity of lumbar paraspinal muscles on the same side as the bend, occurring only when the patient is standing or walking. Baseline VAS 68.3 ± 11.3 Baseline TDSS 7 ± 2.8 Baseline bending degrees 30.6 ± 6.9	continuous EMG activity of lumbar paraspinal muscles ipsilateral to the bending side, appearing only when standing or walking, disappearing in lateral recumbent position - Following the blinded evaluation, BoNT injections were repeated quarterly over a two-year period	-	Pts treated with BoNT showed an average improvement of 4 points on the TDDS score and a 31.4 mm average reduction in pain, with improvements ranging from 24.1% to 76.4% on the VAS scale from baseline		

Group B. Studies of BoNT combined with physical rehabilitation for APAs in PD

Tassorelli et al., 2014 [87]	26 patients	Group A: 3.1 ± 1.9 y Group B: 3.0 ± 1.5.	Incobotulinum (Xeomin)	Maximum 6 sites per patient, with a maximum dose of 50 UI of BoNT per site, with a total dose per patient ranging between 50 to 200 UI.	Evaluation at the end of rehab, and 3 and 6 months after. - VAS of back pain - UPDRS score - FIM score - Degree of anterior trunk flexion - trunk ROM on the 4 plans - Kinematic analysis - Lateral inclination and anterior flexion while standing	Groups A and B improved significantly in static postural alignment and ROM at the end of the treatment period (BoNT/saline + rehabilitation)..	Good – 1b
PS+CC RCT	n=13 group A (8F, 5M) n=13 group B placebo (6F, 7M) - Group A 73.9 ± 4.3 y Group B 74.2 ± 5.1 y - Group A 10.2 ± 8.2 y, Group B 10.4 ± 10.1 y	PS: mild to moderate LTF (Cobb's angle >10°), CC: static anterior trunk flexion - VAS group A = 6.7 ± 1.5 VAS group B = 5.4 ± 2.5	Method: EMG-guided (injection if involuntary tonic activity longer than 500 ms) - Rehab: 5 days/week for 4 weeks	Bilateral Iliopsoas, ipsilateral or contralateral Multifidus, Rectus Abdominis, inferior thoracic and lumbar paravertebral muscles		Group A exhibited a significantly more reduction in pain scores compared to Group B, and also a longer-lasting efficacy on several clinical and kinematic variables.	
Santamato et al., 2010 [96]	1 M n.r.	n.r.- Significant deviation of the trunk to the right	Abobotulinum (Dysport)	Bilateral paraspinous muscles (2–2.5 cm lateral to the spinous processes, T10-L2)	LTF angle TDDS VAS	15 days after: improvement of PS from 35° to 15°, improvement of 5 points in TDDS, and a reduction of VAS score from 7 to 3	NA - 4
PS Case report			Method: EMG recordings + multidisciplinary rehabilitation program	600 U distributed across 6		After 3 months, the improvement	

		injection	appeared to be
Rehab:	5	sites (100 U	maintained
days/week,		per site)	
After	3		
months			
reduced to			
3days/week			

Abbreviations: APAs, Axial Postural Abnormalities; BoNT, Botulinum toxin; CC, Camptocormia; CT, Computed tomography; EMG, Electromyography; US, ultrasound; M, Male; F, Female; FIM, Functional Independence Measure; LE, Levels of Evidence; LTF, Lateral trunk flexion; ms, milli-seconds; PD, Parkinson's disease; PS, Pisa syndrome; AC, Antecollis; Pt, patient; ROM, range of motion; SD, Standard deviation; U, units; QA, Quality of Assessment; RCT, Randomized Controlled Trial; TDDS, Trunk Dystonia Disability Scale; UPDRS, Unified Parkinson's Disease Rating Scale; US, Ultrasound; VAS: Visual Analogue Scale; y, years; NA, not available; n.r., not reported.

Supplementary S1

This section provides detailed information on the search strategy for all databases. Pubmed

(Pisa syndrome OR lateral trunk flexion OR Camptocormia OR Anterior trunk flexion OR Forward trunk flexion OR Retrocollis OR Anterocollis OR Stooped posture OR Spinal curvatures OR Antecollis OR Cervical Dystonia OR torticollis) AND (Parkinsonian disorders OR Parkinson Disease OR Multiple System Atrophy OR Progressive Supranuclear Palsy OR Dementia OR Lewy body OR Corticobasal syndrome OR Axial manifestation OR Postural syndrome)) AND ("Surgical Procedures, Operative"[Mesh]) OR ("Orthopedic Equipment"[Mesh] OR corset) OR ("Chemicals and Drugs Category"[Mesh] OR drug) OR (treatment OR "Therapeutics"[Mesh] OR Therapy OR rehabilitation) AND (outcome OR evaluation OR effect OR result OR efficacy OR assessment) AND (severity OR posture OR walking OR postural OR balance OR equilibrium OR gait OR deambulation)

Web of Science All databases

("Parkinsonian disorders" OR "Parkinson Disease" OR "Multiple System Atrophy" OR "Progressive Supranuclear Palsy" OR "Dementia" OR "Lewy body" OR "Corticobasal syndrome" OR "Axial manifestation" OR "Postural syndrome") AND ("Pisa syndrome" OR "lateral trunk flexion" OR Camptocormia OR "Anterior trunk flexion" OR "Forward trunk flexion" OR Retrocollis OR Anterocollis OR "Stooped posture" OR "Spinal curvatures" OR Antecollis OR "Cervical Dystonia" OR torticollis) AND (outcome OR evaluation OR effect OR result OR efficacy OR assessment OR evaluate OR assess) AND (severity OR posture OR walking OR postural OR balance OR equilibrium OR gait OR deambulation) AND (surg* OR drug OR therap* OR rehabilit* OR stimulation OR exercise OR manipulation OR ortho* OR corset OR walker OR crunches OR lidocaine OR pallidotomy)

SCOPUS

("Parkinsonian disorders" OR "Parkinson Disease" OR "Multiple System Atrophy" OR "Progressive Supranuclear Palsy" OR "Dementia" OR "Lewy body" OR "Corticobasal syndrome" OR "Axial manifestation" OR "Postural syndrome") AND ("Pisa syndrome" OR "lateral trunk flexion" OR Camptocormia OR "Anterior trunk flexion" OR "Forward trunk flexion" OR Retrocollis OR Anterocollis OR "Stooped posture" OR "Spinal curvatures" OR Antecollis OR

"Cervical Dystonia" OR torticollis) AND (outcome OR evaluation OR effect OR result OR efficacy OR assessment OR evaluate OR assess) AND (severity OR posture OR walking OR postural OR balance OR equilibrium OR gait OR deambulation) AND (surg* OR drug OR therap* OR rehabilit* OR stimulation OR exercise OR manipulation OR ortho* OR corset OR walker OR crunches OR lidocaine OR pallidotomy)