

Complications and intercenter variability of three-column osteotomies for spinal deformity surgery: a retrospective review of 423 patients

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Object. Three-column resection osteotomies (3COs) are commonly performed for sagittal deformity but have high rates of reported complications. Authors of this study aimed to examine the incidence of and intercenter variability in major intraoperative complications (IOCs), major postoperative complications (POCs) up to 6 weeks postsurgery, and overall complications (that is, both IOCs and POCs). They also aimed to investigate the incidence of and intercenter variability in blood loss during 3CO procedures.

Methods. The incidence of IOCs, POCs, and overall complications associated with 3COs were retrospectively determined for the study population and for each of 8 participating surgical centers. The incidence of major blood loss (MBL) over 4 L and the percentage of total blood volume lost were also determined for the study population and each surgical center. Complication rates and blood loss were compared between patients with one and those with two osteotomies, as well as between patients with one thoracic osteotomy (ThO) and those with one lumbar or sacral osteotomy (LSO). Risk factors for developing complications were determined.

Results. Retrospective review of prospectively acquired data for 423 consecutive patients who had undergone 3CO at 8 surgical centers was performed. The incidence of major IOCs, POCs, and overall complications was 7%, 39%, and 42%, respectively, for the study population overall. The most common IOC was spinal cord deficit (2.6%) and the most common POC was unplanned return to the operating room (19.4%). Patients with two osteotomies had more POCs (56% vs 38%, $p = 0.04$) than the patients with one osteotomy. Those with ThO had more IOCs (16% vs 6%, $p = 0.03$), POCs (58% vs 34%, $p < 0.01$), and overall complications (67% vs 37%, $p < 0.01$) than the patients with LSO. There was significant variation in the incidence of IOCs, POCs, and overall complications among the 8 sites ($p < 0.01$). The incidence of MBL was 24% for the study population, which varied significantly between sites ($p < 0.01$). Patients with MBL had a higher risk of IOCs, POCs, and overall complications (OR 2.15, 1.76, and 2.01, respectively). The average percentage of total blood volume lost was 55% for the study population, which also varied among sites ($p < 0.01$).

Conclusions. Given the complexity of 3COs for spinal deformity, it is important for spine surgeons to understand the risk factors and complication rates associated with these procedures. In this study, the overall incidence of major complications following 3CO procedures was 42%. Risks for developing complications included an older age (> 60 years), two osteotomies, ThO, and MBL. (<http://thejns.org/doi/abs/10.3171/2014.2.FOCUS1422>)

KEY WORDS • three-column osteotomy • pedicle subtraction osteotomy • spinal deformity
vertebral column resection • major complication • intercenter variability •

Abbreviations used in this paper: 3CO = three-column resection osteotomy; ASD = adult spinal deformity; BMI = body mass index; IOC = intraoperative complication; ISSG = International Spine Study Group; LSO = lumbosacral osteotomy; MBL = major blood loss; OT = operative time; POC = postoperative complication; PSO = pedicle subtraction osteotomy; ThO = thoracic osteotomy; VCR = vertebral column resection.

SURGERY for adult spinal deformity (ASD) is a challenging undertaking with significant complexity and technical demand. The surgical treatment of fixed sagittal and/or coronal plane deformities typically involves multilevel arthrodesis with one or more osteotomies for the restoration of global spinopelvic alignment. Three-column resection osteotomies (3COs) are power-

ful techniques allowing for simultaneous multiplanar deformity correction from a single posterior surgical approach.²¹ These techniques involve Grade 3–5 resections and encompass pedicle subtraction osteotomies (PSOs), vertebral column resections (VCRs), and kyphectomies. When purely posteriorly based, 3COs involve resection of pedicles and a portion of or the entire vertebral body, as well as the possibility of intervertebral disc removal. Despite variations in techniques, 3COs are effective procedures that allow for the correction of spinal deformity and the restoration of global alignment.^{2,4,9,10,26,27}

While 3CO procedures are powerful tools in the surgeon's armamentarium for the treatment of spinal deformity, the complexity of these procedures can result in major complications. Analysis of the Scoliosis Research Society morbidity and mortality database showed that patients who underwent osteotomies had higher rates of complications than those who underwent other surgical approaches, and more aggressive osteotomies were associated with higher complication rates.^{20,25} The complication rate for patients undergoing 3CO surgery has been reported to be up to 59%.^{2,13,16,17,27} Risk factors for developing major complications have been identified as advanced age, sagittal deformity, preoperative kyphosis, long fusion constructs, 3 or more medical comorbidities, excessive blood loss, and revision surgery.^{2,6–8,11,13} While the incidence and risk factors for complications after 3CO have been defined, these definitions have come from primarily single-center studies with small patient populations.^{2,8,13} In the present multicenter analysis we examined the complications of 3CO procedures for a larger patient population from 8 surgical centers and focused on the variability among the sites, an analysis that has not been previously done.

The present study provides a comprehensive multicenter analysis of the incidence of, intercenter variability in, and types of major complications associated with 3CO procedures. The purpose of our investigation was to examine the incidence of major intraoperative complications (IOCs), major postoperative complications (POCs) measured until 6 weeks after surgery, and major overall complications (both IOCs and POCs), and to investigate how factors such as number of osteotomies and location of osteotomy in the spine affect the development of complications in patients undergoing 3COs. We further sought to examine intraoperative blood loss and the correlation between blood loss and the development of complications associated with 3CO procedures.

Methods

Study Design and Inclusion Criteria

This is a multicenter retrospective review of prospectively acquired data for consecutive patients who underwent 3CO for the treatment of ASD at 8 sites in the period from 1999 to 2012. All participating sites are part of the International Spine Study Group (ISSG). Prior to study initiation, institutional review board approval was obtained. Inclusion criteria consisted of an age over 18 years; a PSO, VCR, or kyphectomy performed for a

documented sagittal and/or coronal plane deformity; and complete pre- and postoperative full-length standing radiographs. Patients must have undergone surgical treatment that involved a 3CO within the lumbar spine and/or thoracic spine. Exclusion criteria were inadequate documentation of complications or radiographs, as well as any underlying preoperative neurological or neuromuscular condition.

Data Collection and Analysis

A retrospective chart review of the electronic medical records was performed. Collected data included patient demographics, surgical data (surgical procedure/approach, operative time [OT], estimated blood loss), and hospital data (duration of hospital stay). Intraoperative and postoperative complications until 6 weeks postsurgery were recorded. Data were collected at each site and forwarded to the principal investigator site for data entry and quality control.

The present study focused on the major complications described by Carreon et al.⁶ and used by Schwab et al.²⁴ in an analysis of complications of ASD surgery. Major IOCs included cardiac arrest, spinal cord deficit, death, nerve root injury, visual deficit or blindness, vessel or organ injury, pneumothorax, and unplanned staged surgery. Major POCs were defined as complications that developed within 6 weeks of surgery and included bowel or bladder dysfunction, death, deep venous thrombosis, cauda equina syndrome, deep infection, motor deficit or paralysis, myocardial infarction, pneumonia, pulmonary embolism, reintubation, sepsis, stroke, acute respiratory distress syndrome, pancreatitis, tracheotomy, unplanned return to the operating room, arrhythmia, major injury to a blood vessel requiring repair, and hemopneumothorax. Overall complications were defined as any major IOC or POC.

This study also examined blood loss during 3CO procedures, including the incidence of intraoperative major blood loss (MBL), as well as the percentage of blood lost during surgery. The definition of MBL is highly variable in the literature; thus, we arbitrarily defined MBL as more than 4 L of blood lost in 24 hours. Furthermore, percentage of blood loss was calculated for each patient by dividing the amount of intraoperative blood lost (ml) by the patient's estimated total blood volume. Estimated total blood volume was calculated as the patient's weight in kilograms multiplied by 70 ml/kg, which is the mean value for indexed blood volume in normal-weight adults.¹⁵

The incidence and types of major IOCs, POCs, and overall complications were determined for the entire study population and for each of the 8 surgical centers. The incidence of MBL, as well as the average percentage of blood loss, was also determined for the study population and for each surgical center. Intercenter variability was assessed as the variation in complications and blood loss across the 8 surgical centers. We also compared the complication rates and blood loss in patients who had undergone a double 3CO versus a single 3CO. Among the patients who underwent a single osteotomy, the complication rates and blood loss in those with a thoracic osteotomy (ThO) were compared with those in patients with a lumbosacral osteotomy (LSO). Risk factors for devel-

Complications and intercenter variability of 3CO for spinal deformity

oping complications and major intraoperative blood loss were determined.

Statistical Analysis

All data were analyzed using SPSS software (SPSS Inc.). Statistical tests included independent-sample t-tests to calculate differences in continuous variables, ANOVA to determine site variability in continuous variables, and chi-square analysis to investigate site variability in categorical variables. Statistical significance was determined at $p < 0.05$.

Results

Demographics of the Study Population

Four hundred twenty-three of 835 patients with prospectively collected data met the inclusion criteria for this retrospective review. The population consisted of 302 females (71%) and 121 males (29%), with a mean age of 56 years and a mean body mass index (BMI) of 28.3 kg/m². Primary procedures were performed in 66.2% of the patients, whereas 33.8% had revision procedures. The mean operative time for the entire study population was 456.9 minutes (Table 1).

Incidence of Complications and Site Variability

After 3CO surgery, 7% of patients experienced a major IOC, 39% experienced a major POC, and 42% experienced an overall complication. The incidence of each type of major IOC (Table 2) and POC (Table 3) was determined. The most common IOC was spinal cord deficit (2.6%), and the most common POC was unplanned return to the operating room (19.4%). Another significant POC was bowel or bladder dysfunction (6.9%), defined as significant complications of the gastrointestinal or urinary system following surgery, 4.5% of which were characterized as neurological complications.

The overall rate of intraoperative and postoperative neurological complications was 18.6%. The incidence of intraoperative neurological complications was 3.5% and included 11 patients with spinal cord deficit and 6 patients with nerve root injury. The incidence of postoperative neurological complications was 16.7%, which included 20 patients with neurological bowel or bladder dysfunction, 2 patients with cauda equina syndrome, and 51 patients with motor deficit or paralysis. There was one death that occurred postoperatively within 6 weeks of surgery.

There were no significant differences between demographic variables for patients who did not have a complica-

TABLE 1: Summary of demographics in 423 patients who underwent 3CO

Characteristic	No.
F/M	302/121
mean age in yrs ± SD	55.85 ± 12.842
BMI in kg/m ² ± SD	28.27 ± 7.65
% of primary vs revision procedures	66.2/33.8
mean op time in mins ± SD	456.9 ± 131.1

TABLE 2: Incidence and types of major IOCs in 423 patients who underwent 3CO

Complication	Incidence
cardiac arrest	0.2%
spinal cord deficit	2.6%
death	0.0%
nerve root injury	1.4%
optic deficit/blindness	0.0%
vessel/organ injury	1.7%
pneumothorax	1.2%
unplanned staged surgery	1.4%

tion and those who had an IOC, POC, or overall complication. Furthermore, there were no significant differences in the incidence of IOC, POC, or overall complications between male and female patients or between patients with a BMI ≥ 25 kg/m² versus < 25 kg/m². Patients 60 years and older had a significantly higher rate of POC (49% vs 32%, $p = 0.001$) and overall complications (50% vs 37%, $p = 0.007$) than patients younger than 60. Interestingly, patients over 60 years had a significantly lower rate of IOC than those younger than 60 (4% vs 9%, $p = 0.03$).

There was significant variation in the incidence of POCs (chi-square = 41.30, $df = 7$, $p < 0.001$) and overall complications (chi-square = 51.64, $df = 7$, $p < 0.001$) across the 8 sites (Table 4). However, there was no sig-

TABLE 3: Incidence and types of major POCs in 423 patients who underwent 3CO*

Complication	Incidence
bowel/bladder dysfunction	6.9%
death	0.2%
DVT	3.1%
cauda equina syndrome	0.5%
deep infection	7.6%
motor deficit or paralysis	12.1%
myocardial infarction	0.5%
visual deficit/blindness	0.5%
pneumonia	2.8%
PE	2.8%
reintubation	1.2%
sepsis	0.7%
stroke	0.5%
ARDS	4.7%
pancreatitis	0.0%
unplanned return to OR	19.4%
tracheotomy	0.2%
arrhythmia	1.2%
major injury to vessel requiring repair	0.3%
hemopneumothorax	0.7%

* ARDS = acute respiratory distress syndrome; DVT = deep venous thrombosis; OR = operating room; PE = pulmonary embolism.

nificant variation in the incidence of IOCs across the 8 sites. The frequency of complications ranged from 0% to 14% for IOCs, 17% to 60% for POCs, and 18% to 67% for overall complications.

Incidence of Intraoperative MBL and Site Variability

The incidence of intraoperative MBL over 4 L was 24% for the entire study population (Table 5). There were no significant differences in the incidence of MBL between male and female patients or between patients with a BMI ≥ 25 kg/m² versus < 25 kg/m². Patients with ages ≥ 60 years had a significantly higher frequency of MBL than those with an age < 60 (31% vs 19%, $p = 0.03$). Patients who experienced MBL had a longer OT (536.36 vs 431.31 minutes, $p < 0.01$) and a higher risk of developing IOCs, POCs, and overall complications than those who did not experience MBL (OR = 2.15, 1.76, and 2.01, respectively). However, when controlling for age, sex, BMI, OT, site size, location of osteotomy in the spine, number of osteotomies, and primary versus revision surgeries, patients with MBL only had a significantly greater risk of developing IOCs (OR = 4.67). There was significant variation in the incidence of MBL over 4 L (chi-square = 46.94, $df = 7$, $p < 0.01$), ranging from 0% to 66% across the 8 surgical centers.

Average intraoperative blood loss was 38.7 ± 35.8 ml/kg for the study population, corresponding to an average 55% loss of estimated total blood volume (Table 5). There was significant variation in the average percentage of total blood volume lost among the 8 sites. The average percentage of blood loss ranged from 8% to 100% across the 8 sites ($p < 0.01$; Table 4).

Number of Osteotomies

The incidence of complications and blood loss was compared between patients who underwent a single 3CO (391 patients) versus a double 3CO (32 patients; Table 6). Single 3CO procedures were more common at all sites. Patients with a double 3CO had significantly more major POCs (56% vs 38%, $p = 0.04$) than patients with a single 3CO. The two groups did not differ significantly in IOCs, overall complications, OTs, or unplanned returns to the operating room. Additionally, the two groups did not differ in MBL (23% vs 34%, $p = 0.20$) and average percent-

TABLE 5: Blood loss in 423 patients who underwent 3CO

Parameter	Value
incidence of MBL (%)	24
average blood loss (ml/kg) \pm SD	38.7 ± 35.8
average percentage of blood loss	55

age of estimated total blood volume lost (55% vs 55%, $p = 0.95$).

Location of Osteotomy in the Spine

For all patients with a single 3CO, the incidence of complications was compared between patients with a ThO (72 patients) and those with an LSO (319 patients; Table 7). Patients with ThO had significantly more IOCs (16% vs 6%, $p = 0.030$), POCs (58% vs 34%, $p < 0.01$), overall complications (67% vs 37%, $p < 0.01$), and unplanned returns to the operating room (39% vs 14%, $p < 0.01$) than the patients with LSO. However, there were no significant differences between MBL (19% vs 25%, $p = 0.23$) and the average percentage of estimated total blood volume lost (50% vs 57%, $p = 0.38$) between patients who had a ThO versus those who had an LSO.

There was significant variation between sites that performed ThO and LSO procedures (chi-square = 71.77, $df = 7$, $p < 0.01$). At every site, LSOs were more common than ThOs (Table 4). The majority of ThOs were performed at two of the 8 sites, which were high-volume sites.

Discussion

Given an aging population in the United States and greater expectations for a high quality of life, spinal deformity is a health care problem of increasing importance. Decomensation in the coronal and sagittal planes leads to disability and reduced self-image.^{14,23} Fixed and rigid sagittal deformity may result in sagittal imbalance with secondary compensatory mechanisms within the pelvis. Pelvic parameters are highly correlated with the disability of patients and provide a guide for patient assessment and surgical planning.^{12,14,22,23} Three-column osteotomies are powerful surgical techniques used for deformity cor-

TABLE 4: Surgical center variability

Site	No. of Patients (%)					Average Blood Loss	No. of Patients (%)			
	Total	IOC	POC	Overall Complications	MBL		ThO	LSO	Single 3CO	Double 3CO
1	87	12 (14)	52 (60)	58 (67)	17 (20)	51%	40 (46)	47 (54)	82 (94)	5 (6)
2	7	1 (14)	3 (43)	4 (57)	0 (0)	25%	0 (0)	7 (100)	7 (100)	0 (0)
3	23	2 (9)	7 (30)	8 (35)	6 (26)	66%	1 (4)	22 (96)	23 (100)	0 (0)
4	128	10 (8)	59 (46)	62 (48)	28 (22)	73%	21 (16)	107 (83)	111 (87)	17 (13)
5	105	4 (4)	18 (17)	19 (18)	13 (12)	8%	3 (3)	102 (97)	98 (93)	7 (7)
6	23	2 (9)	9 (39)	11 (48)	9 (39)	44%	2 (9)	21 (91)	22 (96)	1 (4)
7	32	0 (0)	12 (38)	12 (38)	21 (66)	100%	1 (6)	30 (94)	30 (94)	2 (6)
8	18	0 (0)	5 (28)	5 (28)	7 (39)	78%	1 (6)	17 (94)	18 (100)	0 (0)

Complications and intercenter variability of 3CO for spinal deformity

TABLE 6: Incidence of complications in patients with single and double 3COs

Complication	Single 3CO	Double 3CO	p Value
IOC	8%	3%	0.19
POC	38%	56%	0.04
overall complications	41%	56%	0.11
unplanned return to OR	18%	31%	0.08
MBL	23%	34%	0.20
average % blood loss	55%	55%	0.95

rection and restoration of global balance; however, they can be associated with major complications, especially in the elderly population.

Complications associated with 3COs have been investigated in small, single-center retrospective studies, with a reported incidence ranging from 25% to 59%.^{2,8,13,16–18,27} Daubs et al. evaluated patients undergoing spinal deformity surgery and found a major complication rate of 20%.⁸ Auerbach et al. found that major complications occurred in 35% of patients, and 53.9% of the complications resolved within 4 weeks.² Kim et al. found that the incidence of complications after PSO and VCR osteotomies was 40.3%.¹³ In the present study, the incidence of major complications until 6 weeks post-3CO was 42%. The definition of major complications and the duration of follow-up varied among the different studies listed here, probably contributing to the variations in the incidence of major complications.

Significant complications in spinal deformity surgery have been listed as wound infections and pulmonary complications, including pneumonia and pulmonary embolism.^{3,11} In a review of 98 patients undergoing lumbar decompression and arthrodesis procedures, Carreon et al. found a 10% incidence of wound infections.⁶ A literature review by Baron and Albert showed pneumonia to range from 1% to 3.6% and pulmonary embolism to range from 0.3% to 14% in ASD procedures.³ In the present study, the incidence of deep wound infection was 7.6%, and the incidence of pneumonia and pulmonary embolisms were each 2.8%.

The overall incidence of any intraoperative and postoperative neurological complications was 18.6% in the present study. In a retrospective multicenter review of 147 pediatric patients, Lenke et al. found a 27% rate of intraoperative neurological complications.¹⁶ Suk et al. found a

TABLE 7: Incidence of complications in patients with ThO and LSO

Complication	ThO	LSO	p Value
IOC	16%	6%	0.03
POC	58%	34%	<0.01
overall complications	67%	37%	<0.01
unplanned return to OR	39%	14%	<0.01
MBL	19%	25%	0.23
average % blood loss	50%	57%	0.38

17.1% rate of neurological complications within 2 years postsurgery.²⁷ Buchowski et al. retrospectively evaluated 108 patients who had undergone lumbar PSO and found the incidence of neurological complications, defined as the loss of bowel or bladder control only, to be 11.1%.⁵ The rate of neurological complications is higher in the present study, probably because of our more comprehensive definition of neurological complications. Variation in the follow-up could also lead to differences in the rates of neurological complications between the studies.

Evaluating for risk factors associated with major complications is an essential part of the decision-making process for spine surgeons. We identified multiple risk factors associated with developing major complications after 3CO procedures. Patients over 60 years of age had a significantly higher rate of complications. This finding is consistent with data in the study by Daubs et al., in which the authors reported that patients over 60 years old were 7 times more likely to develop a major complication following a PSO.⁸

The incidence of IOCs (0%–14%), POCs (17%–60%), overall complications (18%–67%), and MBL (0%–66%) varied across the 8 sites. The ThO and LSO procedures also varied across the 8 sites (ThO: 0%–49%, LSO: 54%–100%). Thus, surgeon experience and the particular 3CO technique may play a role in the development of major complications following such procedures and should be further investigated.

Double osteotomy procedures were associated with greater POCs. Only 32 patients had a double osteotomy procedure; thus, it makes sense that they had a higher incidence of major POCs. Contrary to what would be expected, however, double osteotomy procedures were not associated with longer OTs, higher incidence of IOCs, higher incidence of overall complications, higher rate of MBL, or higher percentage of blood loss than single osteotomy procedures. The small number of double osteotomy procedures may have contributed to these findings.

We also found that for single osteotomies, the incidence of IOCs, POCs, overall complications, and returns to the operating room was higher for patients undergoing ThOs than for those undergoing LSOs. There were no significant differences in MBL or average percentage of blood loss for patients who underwent ThO versus LSO.

Major blood loss was identified as a risk factor for developing complications. The complexity of osteotomy procedures results in a risk of significant blood loss, ultimately affecting patient outcomes.¹⁶ Major blood loss is a symptom of the physiological burden that the body has endured and has to overcome in the postoperative period. In the present study, patients lost an average of 55% of their total blood volume during surgery. Blood loss of more than 50% of the total blood volume during spine surgery has been defined as significant blood loss.¹⁹

Major intraoperative blood loss is commonly associated with spinal deformity surgery. In a multicenter review of 953 consecutive patients undergoing surgical correction of ASD, Schwab et al. identified excessive blood loss above 3 L as the most common complication.²⁴ Throughout the literature, there is no consistent definition of blood loss as a complication. In the present study, we

defined major intraoperative blood loss as 4 L to have a more conservative representation of MBL. In our study, the 24% of patients who experienced MBL > 4 L also had a higher risk for developing IOC, POC, and overall complications and had a longer OT than patients without MBL. Furthermore, patients older than 60 years of age had a higher incidence of MBL than younger patients.

The variability in MBL (0%–66%) and the percentage of estimated total blood volume lost (8%–100%) among surgical centers implies that blood loss can be reduced and recording procedures can be improved. This variability could be attributed to surgeon experience or to the fact that some sites operate with two fellowship-trained spine surgeons instead of one. Recently, Ames et al. found that the use of two surgeons decreases OT, estimated blood loss, and incidence of major complications during PSO surgeries.¹ In the present study, only one site operated with two spine surgeons.

The strengths of this study include its large number of patients and multicenter design. An extensive amount of demographic, radiographic, clinical, and complication data were recorded and analyzed. Furthermore, our results are consistent with previous reports on the complications of 3CO procedures.¹⁶ The primary limitation of this study is its retrospective design. To mitigate this limitation, we evaluated patients consecutively and across eight surgical centers. Future studies on this topic should include a prospective enrollment of consecutive patients undergoing 3CO. Another limitation of this study is that the postoperative complications were only evaluated until 6 weeks after surgery. Future studies should have longer follow-ups to determine if complications resolve or are permanent. Yet another limitation was that the use of antifibrinolytics, which could have affected blood loss and complications associated with blood loss, were not recorded. Neither did we identify the reasons for returning to the operating room following surgery, although these unplanned visits were considered to be related to the spine surgery. Further analysis should reveal the specific cause of unplanned returns to the operating room. Finally, the variability in complication rates in the present study could be attributed to differences in the reliability of reporting from the various sites. Future research should establish a more standardized reporting method to mitigate the variability in data recording across sites. Further studies should also examine factors such as 3CO technique, use of antifibrinolytics, surgeon experience, and the use of multiple surgeons during the procedure.

Conclusions

Understanding the complications and risk factors associated with 3CO is essential in deciding whether to perform sagittal deformity surgery. In this study, 7% of patients experienced a major IOC, 39% had a major POC, and 42% experienced either a major IOC or a major POC. However, the incidence of major complications varied among the 8 sites. The most common IOC was spinal cord injury, and the most common POC within 6 weeks of surgery was an unplanned return to the operating room. There was significant variation in the com-

plication rates for the different sites, depending on the number and anatomical location of the 3CO performed. Risks for developing complications included an age over 60 years, MBL, double osteotomies, and osteotomies in the thoracic spine. In this study we aimed to provide a comprehensive review of major complications after 3CO surgery and to reveal the factors that contribute to these complications.

Disclosure

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