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Critical review of the justification of limitations in physical therapy and activities of daily living in cardiac surgery patients

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Abstract

Introduction. The study aim was to analyse the justification of limitations in physical therapy and activities of daily living in patients after cardiac surgery via sternotomy.

Methods. A narrative review design was followed. This study is the result of analysing and comparing the data obtained through investigating sternal closure stability after sternotomy, the load on the sternum during physical therapy, activities of daily living and coughing, as well as the effectiveness of sternum external fixation.

Results. Sternum closure stability after sternotomy and the force of the load on the sternum during cough are greater than when performing upper extremity movements and most of the activities of daily living. The benefits of using sternum external fixation are not marked. Mathematically, most of the presented statistical benefits of sternum external fixation were achieved owing to the large number of individuals in the samples. Therefore, it is important to analyse such statistical indicators as odds ratio, attributable risk, the number needed to treat in terms of such a 'harmful factor' as lack of sternum external fixation. The use of sternum external fixation should be biomechanically grounded.

Conclusions. Conventional restrictions and recommendations for patients after cardiac surgery via sternotomy lack theoretical justification and research to confirm their necessity.

Key words: therapeutic exercises, restrictions, sternal precautions, sternum external fixation

Introduction

Physical therapy of cardiac surgery and cardiac patients remains an important healthcare sphere owing to the prevalence of cardiac pathology, its complications and comorbidity [1–3]. Physical therapists routinely prescribe physical and respiratory exercises to patients after cardiac surgery via median sternotomy [4–6]. These are mostly exercises to strengthen the upper extremities, including those to promote movement amplitude [7]. However, physical therapy varies among hospitals [8–11]. Therefore, the issues of safe movement amplitude, unilateral and bilateral upper extremity movements, as well as the use of additional load cannot be considered thoroughly studied.

An even more complicated concern is the activation of critically ill patients, which requires the use of additional mobilization means to transfer body weight to upper extremities in order to promote patient's balance, mobility, and independence. Sometimes such patients may be overweight, which necessitates making a choice between ensuring their mobility, ability to walk (the main physical activity) and eliminating any load on the sternum.

According to a number of studies, one of the ways to prevent complications after sternotomy is to apply sternum external fixation (SEF) [12, 13]. However, it is necessary to study the biomechanical action of SEF after sternotomy and to compare the efficacy of its use in different studies [14].

The activities of daily living (ADL) decline after cardiac surgeries [15] and are regained over time [16]. Instructing patients in sternal precautions in ADL is quite rational and necessary. However, the extent of limitations in such instructions seems questionable [17], since their excessiveness can deteriorate patient's quality of life after surgery.

Currently, conventional restrictive guidelines [17] are criticized for reducing self-efficacy, promoting anxiety and depression, misinterpretation of instructions, even to immobilization. At the same time, postoperative anxiety and depression are considered as risk factors for mortality and morbidity [18, 19].

The purpose of the study was to analyse the justification of limitations in physical therapy and ADL in patients after cardiac surgery via sternotomy.

Subjects and methods

This study is the result of analysing and comparing the data obtained through investigating sternal closure stability after sternotomy, the load on the sternum during physical therapy, ADL, and coughing, as well as the effectiveness of SEF.

Search strategy

Research data were collected on the basis of Google Scholar until May 2020. The keywords were: 'cardiac surgical procedures,' 'cardiac surgery,' 'sternotomy,' 'sternal complications,' 'sternal precautions,' 'sternum external fixation,' 'external support devices,' 'activities of daily living'. The keywords and synonyms were entered in various combinations.

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Ethical approval

The conducted research is not related to either human or animal use.

Results

Patients after median sternotomy regularly receive precautions about shoulder movements and upper extremity activity [7, 20]. Although upper extremity movements and activities are believed to lead to dehiscence, the exact benefits of sternal precautions may be questionable, especially from a biomechanical perspective [20, 21].

To start with, let us consider the results of the research on the stability of sternal closure after sternotomy.

A mechanical analysis confirmed that sternal dehiscence could occur under physiological loads and that improved sternal stability might be readily achieved through mechanical reinforcement near the xiphoid [22]. Besides, it is noted that a 2.0-mm displacement in the lateral direction is caused by the least force (220 N on the average); in the anterior-posterior directions – 263 N; and in the rostral-caudal directions – by the largest force (325 N). The lower end of the sternum is more disposed to displacements, caused by wires cutting through the bone. Simulated Valsalva force causes the biggest displacements in the lateral direction – more than 2 mm.

Similar results were presented in a survey by Cheng et al. [23], where the mean values of sternum cut comprised 0.012 mm/N for No. 5 stainless steel wire.

At the same time, better stability was discovered [22] in male cadavers, which indicates a possibility of different limitations in physical therapy and ADL in males and females, or in physically active people (having stronger bone tissue) and those with weak bone tissue of the sternum. In general, this difference correlates with the tendency for males to have bigger weight, which hypothetically implies the same safety of closure, taking into account body weight, which will be transferred to upper extremities after surgery during mobilization. The exception to this trend is people with weak bone tissue and overweight.

One of the studies [24] has put forward a hypothesis similar to the one of ours. The indicator of tolerated force exerted on sternal dehiscence can be the load that occurs during cough, since during wound healing the patient coughs a lot to clear the lungs of sputum.

It should be noted that cough is a complex, energetic, and rapid process [25].

An analysis of the force imposed on the sternum when coughing revealed that with a normal cough this force constituted 555.3 N (56 kg), whereas the force of maximal cough reached 1666 N (168 kg) [26]. Similar studies [27–29] showed that, in accordance with Laplace's law, forces imposed on the sternum ranged from 160 N to 400 N during breathing and from 550 N to 1650 N during coughing.

A comparison of Valsalva forces during cough and weightlifting activities revealed the advantage of the former, even compared with lifting 40 pounds (nearly 18 kg) [12]. Therefore, the stability of the sternum closure after cardiac surgery is significantly greater than is implied by the recommendation not to lift more than 4–6 pounds.

Concerning the influence of unilateral or bilateral upper extremity movements, with or without additional loading, these characteristics are known to affect equally the extent of sternal dehiscence in patients with chronic sternal instability after cardiac surgery. It is also recognized that in this group of patients unilateral movements are associated with a higher pain level [30].

On the other hand, studying the acceleration of the skin overlying the sternum among healthy people confirmed that heavier objects caused more sternal skin stress when they were lifted from countertop to shelf, whereas transfer techniques (sit-to-stand and supine-to-sit) as taught by therapists caused less sternal skin stress than those chosen by the patient (that allow pushing up on the hands). However, the authors note that although sternal precautions may be based on the studied indicators, the large variation in the indicators does not allow to prohibit certain activities completely [31].

The records also show that pushing up while applying a frontal support (table or walker) induced the same level of chest expansion as that during sit-to-stand transition while keeping the arms relaxed [32]. At the same time, activation of the pectoralis major muscle during arm weight bearing is minimal, which suggests that minor force occurs across the sternum [33].

According to another study, the sternum is exposed to compressive mechanical load during flexion, abduction, and lifting of upper extremities; therefore, the sternal skin strain (SSS) values were negative. SSS results were not statistically significantly different at a 90° and 180° flexion (about –10.8%), and were statistically significantly lower at a 180° than at a 90° abduction. The highest results were revealed for extension and for pushing up from the chair, though SSS values were both positive and negative. Either no or little relationship between rhomboid strength and SSS was established. An increase of weight for lifting overhead with the dominant arm led to SSS dynamics, however in the negative direction (from –3.6% to –6.8%) [21].

Ultrasound findings demonstrate a small magnitude of motion at the sternal edges after median sternotomy and conventional stainless steel wire closure when completing upper extremity and trunk tasks by cardiac surgery patients during 3 postoperative months. However, coughing caused a significant increase in the separation of the sternal edges in the lateral direction compared with rest and other tasks during the entire follow-up period. Interestingly, only 7% of the participants presented radiological sternal union 3 months after cardiac surgery [16].

By using a digital dynamometer, it was found that performing 6 of the 19 tasks of upper extremity ADL (lifting, pushing, or pulling) generated a peak force of less than 10 pounds, whereas this force exceeded 20 pounds for 5 tasks performed with a preferred speed. Therefore, peak force decreased from 8% to 61% in most of the tasks performed at a slow speed (except 1) [34]. Most tasks with instrumental ADL require peak force of less than 10 pounds. The reduction of the speed of task performance lowers the peak force [35]. When using a walker, the self-selected arm force was greater than 10 pounds (11.7–19.0 pounds) for all functional mobility tasks [33].

The comparison of the sternal closure stability, the forces produced by coughing, and the load on the sternum during upper extremity activities enables to conclude that conventional limitations in upper extremity and ADL activities are excessive.

Similar comparisons are presented by Balachandran et al. [36]: coughing increases intrathoracic pressures (up to 300 mm Hg) and thus imposes excessive strain to the median sternotomy. Anecdotal reports, however, suggest that the risk of developing sternal instability increases with the failure to comply with the limitations of upper extremity and trunk activity.

Table 1. The main results of studying the effectiveness of sternum external fixation

Studies	Groups	Superficial wound infection (%)	Deep sternal complications (%)	Sternal wound dehiscence (%)
Gorlitzer et al. [13]	Vest group – no vest group	0.6 vs. 1.3	0 vs. 1	0 vs. 0.4
Celik et al. [12]	No SEF: COPD – no COPD	1.2 vs. 0.2	4.9 vs. 0.4	1.8 vs. 0.6
	COPD: vest group – no vest group	0 vs. 2.5	0 vs. 6.6 ($p = 0.009$)	1 vs. 2.5
Naismith and Street [52]	Cardibra – regular bra (female patients with bra cup size ≥ C)	0 vs. 0	0 vs. 0	0 vs. 0
Gorlitzer et al. [45]	Thorax vest – chest elastic bandage	0.61 vs. 1.11 ($p = 0.42$)	0 vs. 1.99 ($p = 0.0001$)	0 vs. 0.77 ($p = 0.046$)
Gorlitzer et al. [46]	Thorax vest – chest elastic bandage	1.55 vs. 1.09 ($p = 0.388$)	1.04 vs. 2.27 ($p = 0.017$)	

SEF – sternum external fixation, COPD – chronic obstructive pulmonary disease

Sleeping on side is one of the conventional limitations after median sternotomy. However, an analysis of the relationship between lateral position change and sternal complications did not confirm the statistical significance and critical importance of such a relationship [37]. At the same time, lying on side can be used quite often (up to 50%) in physical therapy [9].

The application of SEF is one of the conventional recommendations for the postoperative period.

However, the difference in superficial wound infection (SWI), deep sternal complications (DSC), and sternal wound dehiscence (SWD) among the intervention groups analysed in the survey comprises on average 1% (Table 1), which seems clinically insignificant, despite the presented statistically significant differences in some indicators. Such an advantage cannot be objectively assessed as SEF effect, as there are a number of factors that influence the risk of complications [38–44], the absence of SEF not being among them.

At the same time, if we compare the results of the studies, we can find some common factors and inconsistencies emphasizing the possibility of other factors' impact on the occurrence of complications.

According to a study by Celik et al. [12], the number of SWI, DSC, and SWD among patients without chronic obstructive pulmonary disease (COPD) and SEF was very insignificant. The number of SWI and DSC was smaller than in a similar group described by Gorlitzer et al. [13]. At the same time, in the study by Celik et al. [12], the complication rate among the patients without COPD and SEF was very close to and sometimes even lower than the one in the groups with SEF (vest and bandage) presented in other studies [13, 45, 46]. Celik et al. [12] also draw attention to the increase in the number of complications among patients with COPD and without SEF in a prospective analysis as compared with the patients in a retrospective analysis: SWI – from 1.2% to 2.5% (i.e. twice higher), DSC – from 4.9% to 6.6% (by 35%), SWD – from 1.8% to 2.5% (by 39%).

The study by Gorlitzer et al. [13] revealed that DSC percentage in the no vest group was lower than in the group where chest elastic bandage was used [45, 46], and was similar to the result of the thorax vest group in one of the studies [46]. An analogous situation was with SWI indicators: SWI percentage in the no vest group [13] was close to the one in the chest elastic bandage group [45, 46], and was slightly lower than the results of the thorax vest group in one of the studies [46].

Besides, most SWI, DSC, and SWD events occurred during the hospital stay, which questions the benefit of a 6-week use of SEF.

The presence of advertising in the studies by Gorlitzer et al. and duplicates of their works with almost the same authors [13, 47] make the results even more doubtful.

Interesting is the approach to measuring the total number of complications when comparing the groups with and without SEF, although the causes of SWI, DSC, and SWD are slightly different [48]. This emphasizes, to some extent, the authors' desire to find the benefits of SEF.

Besides, a fairly long follow-up period (up to 1.5–6 months) increases the number of factors that could affect infecting and dehiscence, as there was no continuous follow-up of the patients. Such factors include wound care, peculiarities of physical activity, and physical exercises (including sexual activity).

Among the surveys analysing the benefits of using SEF, special attention is drawn to a survey by Tewarie et al. [49]. This study compared the impact of an SEF corset and a standard elastic thorax bandage on the prevention of sternal instability and mediastinitis in high-risk patients (in particular, a large number of patients had COPD, diabetes, body mass index > 30). The prevalence of wound infection and sternal dehiscence was lower in the corset group. The authors note that the hospital stay in the intervention group was shorter. The ventilation time, however, was also relatively longer in the control group (bandage) [49], which is a risk factor for wound infection [22, 38].

The use of SEF, similar to that presented by Tewarie et al. [49], as compared with applying a conventional bandage, also showed better results among females [50]. According to this survey, sternal wound infection occurred in 7% of patients in the intervention group vs. 17.6% in the control group (bandage) [50].

It should be noted that in both these studies [49, 50], the percentage of wound infection in control groups is significantly higher than in other surveys [38, 39, 51, 52]. On the other hand, both studies [49, 50] mentioned the name of the external fixation, which, along with the marketing description in the articles, raises a question whether it was research or advertisement.

A systematic review [53], however, did not take into account the fact of advertising in most studies.

The detailed study of preoperative, intraoperative, and postoperative strategies reducing deep sternal wound infection did not consider SEF as a strategy or factor for sternal stability at all [38, 54].

Another survey included antibiotic prophylaxis with a first-generation cephalosporin for at least 24 hours, application of local gentamicin before chest closure, sternal closure with figure-of-eight steel wires, and SEF as deep sternal wound infection prevention measures [55].

Concerning wound infection, the excerpt below recommending a patient to wear a vest after cardiac surgery via median sternotomy states the following: 'If any part of the wound is a little open or suppurates/drains yellowish/transparent liquid or a drop of blood, do not panic, it is normal' [56]. The document recommends conventional and individual treatment of the wound presenting the abovementioned signs without consulting a doctor. Such strategy may affect the incidence of wound infection.

Since the use of SEF in the reviewed studies (Table 1) was analysed in terms of complications and infections, there is a need for a short analysis of their prevalence and causes in cardiac surgery patients.

Wound infection is a serious complication, which can lead to prolonged hospital stays, high treatment costs, and mortality [51]. Problems with wound healing after cardiac surgery via median sternotomy persist in a small but consistent percentage of patients [22, 38, 57]. There is evidence of 0.4–4% of patients having sternal wound infections after cardiac surgery via sternotomy [39, 44, 51].

Considerable studies reported that sternal wound infections developed after 0.97% of 7949 operative procedures involving median sternotomy [58], and coronary artery bypass grafts were performed with a total sternal wound infection rate of 0.47% (44 cases) and a deep sternal wound infection rate of 0.22% [57]. Besides, concomitant infection at other sites with the same organism as that cultured from the sternum was present in 42% of patients [58], which, once again, emphasizes the role of infection and the effectiveness of antibiotic therapy rather than SEF in reducing wound infections.

Most of the literature on sternal closure deals with patient-related factors that contribute to complications [22]. At the same time, predisposing factors for sternal wound infection are multiple, with varied frequencies in different studies [57]. This conclusion may imply a reduced effectiveness of using SEF, since the average differences when comparing the groups were insignificant (Table 1).

Moreover, inadequate mechanical stabilization of the sternum performed by surgeons is undoubtedly an important variable, although difficult to identify and quantitate [23].

Discussion

The comparison of the data obtained through investigating sternal closure stability after sternotomy, as well as the load on the sternum during ADL and coughing confirms the doubts presented in the literature concerning the effectiveness of restrictive recommendations, routinely given to the patients.

The results of our survey are compliant with the opinion of Cahalin et al. [59] on the need to change the conventional sternal precaution approach for patient-specific sternal precautions focusing on function. Cahalin et al. [59] noted that currently, sternal precautions had several limitations, including that they: have no universally accepted definition; are often based on anecdotal/expert opinion or at best supported by indirect evidence; are mostly applied uniformly for all patients without regard to individual differences; may be overly restrictive and therefore impede ideal recovery.

It is worthwhile to mention the recommendations on sexual life. One of the surveys [56], for instance, recommends to avoid positions that exert strong pressure on the sternum or that require all weight on the upper extremities within the first 6–8 weeks after cardiac surgery. The latter limitation (all weight) increases the extent of criticizing the abovementioned information on the use of SEF, limitations in loading upper extremities, in the use of special transfer techniques (sit-to-stand and supine-to-sit) to prevent complications. Instead, it emphasizes sterility measures, quality of the sternum closure performed by surgeons, sternum condition (the presence of osteoporosis), and other factors increasing the risk of complications after midline sternotomy.

Other studies focused on conventional post-sternotomy limitations showed results similar to ours.

Brocki et al. [60] did not present any evidence to support weight limitation regarding activity if upper arms are kept close to the body and the activity does not cause any pain. In addition to keeping the elbows close to the body during loaded activities and moving not to induce pain as an overload indicator, it is recommended to limit upper extremity stretching, for 10 days only, which is very similar to the healing time of the skin rather than the sternum. It is recommended to put legs down as a counterweight when getting out of bed, and cross the arms ('self-hugging' posture) when coughing. A supportive bra or vest is advised if breast cup is of size D or more, if body mass index is 35 or more, and in cases of frequent cough.

Other studies [7] also consider pain as a criterion for limiting the amplitude of upper extremity activities and exercises.

Studies prove that experts' opinions form the main ground for sternal precautions, since there is no evidence to support specific sternal precaution limit values [31]. The evidence base for sternal precaution protocols has been questioned owing to a paucity of research, unknown effect on patient outcomes, and possible discrepancies in the pattern of use among institutions [20]. However, according to the recent work by Balachandran et al. [16], despite all the existing evidence, patients after cardiac surgery are still recommended to use sternal precautions restricting upper extremity and body movements in order to reduce such complications as dehiscence, instability, infection, and pain.

Research emphasizes significant differences in sternal precautions and physical activity after cardiac surgery [7, 20, 61], drawing attention to the absence of any attempts to reduce the risk of serious sternal complications by forming integrated sternal precautions [61].

Such facts make us suggest that the lack of sternal precaution consistency is not a factor influencing the occurrence of sternal complications; otherwise, this problem would be thoroughly studied. Imposing reasonable load limitation, instead of an excessive one, may be a possible solution of this problem.

It is important to realize that the use of sternal precautions varies significantly among physical therapists [20], let alone cardiologists and cardiac surgeons.

Sternal precautions most commonly applied by physical therapists include wound support, restrictions on lifting and transfers, restrictions on mobility aid use. The main factors determining the practice are 'workplace practices/protocols' and 'clinical experience' [20].

An analysis of physical therapy practice in Australia and New Zealand [62, 63], Canada [11], Greece [9], the United Kingdom [10], and Sweden [8, 64] confirms a great variability of physical therapy treatment and sternal precautions, particularly in bilateral and full active range of motion of upper extremities, lifting restrictions, weight bearing with upper extremities for mobility, use of gait aid, and the length of restrictions. However, these studies did not include the use of SEF into the list of sternal precautions.

The purpose of some studies analysing SEF effectiveness is highly questionable (research or advertising). One could affirm that there is not enough research since the same authors are involved in several studies. There are duplicate publications varying only in the order of the listed authors.

There are also inconsistencies in the recommendations for the use of SEF. For example, males after cardiac surgery are noted [56] to use a vest that facilitates movements and protects when coughing, whereas females are recommended just to use a bra (sports type, wire-free). This prompts the following question: Why is a sports bra that does not compress the sternum or restrict movements and breathing sufficient for females, but not sufficient for males?

At the same time, there is a need for distinct biomechanical explanations of SEF benefits, with regard to the forces pressing the sternum. The explanations presented in the studies seem insufficient.

If one takes into account the analysed results of the studies focused on sternal closure stability after median sternotomy [22, 23], the forces caused by coughing, and the laws of physics, the importance and role of SEF seem to be absent. If respiratory movements are possible when using SEF, the increase of the chest circumference (CC) is possible as well. Accordingly, the displacement of the sternum edges in the lateral direction when coughing will be also possible. Any SEF is unlikely to respond significantly to a 2-mm CC increase, although a quite high pressure is required to cause a 2-mm separation of the sternum edges [22]. Therefore, all the pressure will be restrained by the surgical closure rather than SEF. Even a greater displacement will not be susceptible to SEF if respiratory movements are not severely restricted. For instance, a 2- and 5-mm increase of CC due to the separation of the sternum edges makes up only 0.25% and 0.6% of 80 cm of CC, and 0.2% and 0.5% of 100 cm of CC.

Moreover, exhalation during cough is fuller than usual; therefore, the SEF compressive effect on the sternum will decrease in proportion to the fullness of exhalation. Moreover, if the SEF device is not elastic, the compressive effect may disappear at all, as it was put on the sternum at the state of relative rest.

Besides, the sternum is covered with soft tissues, which adds to the reduction of SEF effectiveness in accordance with the laws of physics, since soft tissues are able to compress and shift quite easily.

Therefore, only if the corset circumference corresponds to the CC at full exhalation, and the force of constant pressing or that during CC increase reaches more than 500 N, can we insist on an SEF restricting effect. However, it is impossible to implement such a condition in practice.

Taking into account the forces pressing the sternum during cough [26–29], we can conclude that SEF has to press the chest with the same strength to prevent wires cutting through the sternum. For these reasons, it is necessary to tighten SEF on the sternum with a force exceeding 500 N, although this seems impossible to accomplish both with and without help. Another criterion is the ability to breathe, feel comfortable, or tolerate such compression for a very long time (up to 24 hours a day for 1.5–3 months, according to the recommendations).

Comparing the force pressing the sternum during cough and a possible size of sternum edge displacement in the lateral direction during cough (can be calculated by the force values [26–29] and correlation of the sternum wire cut size with this force [23]), we can come to a conclusion that SEF must be susceptible to CC increase of less than 5 mm, i.e. 0.5–0.6%. However, the theoretical validity of SEF effectiveness excludes the possibility to increase CC on inhalation or, for instance, to slip a few fingers between the sternum and the SEF device. This is not consistent with the importance and necessity to restore the respiratory system after cardiac surgery.

It is very important to control the accuracy of patients' use of SEF in full compliance with the received recommendations: the strength of pressing, correct putting on and fixation (especially in the overweight and among females), the length of use throughout the day. In this respect, it should be noted that some patients refuse SEF [13, 45, 46]. However, patients who do not refuse SEF but still do not follow usage recommendations properly, i.e. stay in the 'grey area,' are not mentioned in the studies on SEF effectiveness.

Taking into account the prevalence of sternal complications (Table 1), we can conclude that only grounded indications and biomechanical explanation can be the basis for SEF prescription to patients after cardiac surgery in order to reduce complications.

Mathematically, most of the presented statistical differences (Table 1) were achieved owing to the large number of individuals in the samples. Therefore, it is important to measure and analyse such statistical indicators as odds ratio, attributable risk, the number needed to treat, the number needed to harm in terms of such a 'harmful factor' as lack of SEF.

On the other hand, if the problem of sternal dehiscence can be solved so quickly, why do surgeons keep on improving techniques [22], even using the pectoralis muscle closure; why do they emphasize the importance of developing closure techniques aimed to minimize wire migration into the sternum [23]?

In view of the above, we should agree that a small change in care delivery may lead to a big improvement in the results of patients' recovery after cardiac surgery [17], and recommendations on activity precautions should be based on a patient supportive approach focusing on possibilities and not restrictions [60].

Conclusions

The results of assessing sternal closure stability after sternotomy, as well as the strength of the load on the sternum during cough or performing upper extremity activities and ADL give grounds to consider conventional restrictions and sternal precautions unreasonable. The use of SEF should be biomechanically grounded. Physical therapists should employ the results of research in the development of protocols and recommendations enhancing life quality of the patients after cardiac surgery rather than form restrictions that are difficult to follow.

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Conflict of interest

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